An investigation of interactivity and flow: student behaviour during online instruction

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Submitted in total fulfilment of the requirements of the degree of Doctor of Philosophy

December 2004

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Abstract

This thesis combines ideas from human-computer interaction, education and psychology to explore the interactions of students in an online learning environment. The motivation for the work was to understand better how to engage students in a highly enjoyable experience of online learning.

The thesis describes three experiments. The first experiment was an exploratory study investigating the influence of learner interactions in an online physics learning task. Students worked through an online learning experience that offered high and low levels of interactivity. The aim was to explore their interactions and choices in an environment in which they could elect to move from the highly interactive mode to the less interactive mode at any time. Web logs were used to track their interactions and question probes gathered data on their emotions, learning goals and strategies. The analysis revealed a number of different patterns of interaction. Statistical analysis showed that most, but not all, preferred to follow an interactive path through the material. Students who used the interactive materials showed improved learning gains in transfer-style questions compared to those in the less interactive mode. Several issues were identified as important to consider in a follow-up study: emotions, affect, challenge, and the degree of control that the learner perceives.

The second experiment explored these issues using flow theory as a theoretical underpinning. The aim was to explore how the flow concepts of control, challenge and skill described learner interactions. Fifty-nine undergraduate students were randomly assigned to two groups using a 2 x 2 factorial design, testing two levels of control against two levels of expertise. Again their interactivity was monitored, as well as their learning outcomes and measures of flow. The outcome of this experiment was the re-conceptualisation of flow as a process rather than a state; the development of a visualisation technique with which to monitor the flow process; and the identification of patterns of flow which related to the students’ learning. A comparison of two different flow measurement techniques indicated some inconsistencies between them.

The third experiment probed more deeply the flow experiences of students by using a qualitative research design. Its aim was to understand how flow manifested itself during a learning task. Eight students completed a modified online exercise and responded to interview questions that aimed to enrich our understanding of the flow process. Analysis of this final experiment showed that flow is a process associated with either the software simulation (artefact) with which students interacted, or the learning activity (task) with which students were engaged. Separating artefact from task was crucial to measuring flow and understanding students’ flow behaviour. This not only helped to explain why the earlier flow measurement techniques were inconsistent, but also sounded a warning that whilst a flow experience can be supportive of learning, it also has the potential to hinder learning if the student’s focus is distracted by the engaging nature of the artefact.

This research has suggested a link between flow and learning and produced a challenge for software designers and instructional designers to find ways to direct students' focus away from an engaging software simulation towards the learning task at hand.
Declaration

This is to certify that

(i) the thesis comprises only my original work towards the PhD except where indicated in the Preface,

(ii) due acknowledgement has been made in the text to all other material used,

(iii) the thesis is less than 100,000 words in length, exclusive of tables, maps, bibliographies and appendices.

Jon Malcolm Pearce
December 9, 2004

Preface

Part of the research described in Chapter 3 was carried out in collaboration with a colleague. The extent of this is explained fully in Section 3.2.

Acknowledgments

I have been fortunate to have wonderful support from numerous people through the duration of this study. My two supervisors, Steve Howard and Mary Ainley, have each given me unique and valuable advice and guidance through the various twists and turns of the last five years. I am enormously grateful for their encouraging and insightful support. My head of department, Liz Sonenberg, strategically found time for me to fit this research around my teaching and other commitments. My wife, Michelle Livett, so often made time to consult, discuss, debate and reflect with me; her wise advice has nurtured this thesis from its beginning. Numerous colleagues in the Department of Information Systems challenged my thinking through their support, discussions and by reading aspects of this work – Jennie Carroll, Frank Vetere and Connor Graham in particular. And finally my sons, Robin and Simon, who have endured my late night typing for this seemingly endless obsession. Thanks to all of you.
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Chapter 1

Introduction

“What should we call these “new” students of today? Some refer to them as the N-[for Net]-gen or D-[for Digital]-gen. But the most useful designation I have found for them is Digital Natives. Our students today are all “native speakers” of the digital language of computers, video games and the Internet.”

(Prensky, 2001a)
1.1 Engagement in an online world

We live in interesting times. The rapid spread of technological devices is highly visible in our world: computers, mobile phones, cameras, PDAs, the Internet. Educational institutions have been quick to take up the opportunities offered by technology through the use of online courses, Web resources, and computer-based instruction.

A closer examination, however, suggests this might be a case of ‘all that glitters…’. ‘Glitter’ is an apt word as much of the material presented by the Web is criticised for its extensive use of multimedia that is not matched by the substance of its content. The criticisms apply to educational material as much as any other. Even in the tertiary sector, early Web materials were often laced with colour and sound, but devoid of meaningful pedagogical content. Drill-and-practice exercises, true/false quizzes, simplistic multiple-choice questions were the norm because that was easy to do. These new technologies brought few, if any, paradigm shifts to tertiary education. The new media absorbed, and even encouraged, some of the poorest of our educational methods.

As the capabilities of Web-based technologies improved, a new term was added to the already poorly defined set of terms ‘multimedia’, ‘multi-modal’ and ‘hypermedia’ (Alty, 1991), namely ‘interactive multimedia’. This phrase has produced ongoing debates about the definition of ‘multimedia’, the meaning of ‘interactivity’, and whether they help learning or are simply ‘glitzy animations that dazzle the eyes’ (Mayer & Moreno, 2002). While these debates have continued our students have moved with the times, taking on board the functionality of the media and bringing to the classroom Web-based computing skills that did not exist a decade ago.

Hence, in contrast to research in the 1980’s showing students grappling with the concepts of hyperlinked navigation in a computer-based learning package, we now face students who have been brought up with the richness of the Web. Prensky (2001a) labels such students as ‘digital natives’, drawing an analogy with native speakers in order to describe the generation gap separating today’s students from their teachers (who are ‘digital immigrants’). These students come to us ‘pre-programmed’ with navigation skills; they are comfortable to click, explore and backtrack; they are happy to launch an applet, play for a while, and then move on; they are more than happy not to read any instructions or text on the screen. Digital natives crave interactivity (Prensky, 2001b).

It is with this background in mind that this research project began its exploratory study of students engaging in an interactive learning environment. The changes in technology over the past decade have been obvious; the changes to students not so obvious. My initial aim was to explore how students interact during online instruction given various choices of where they can go and what they can do.

1.1.1 A context and a domain

To explore students in an interactive environment required a cohort of students and a subject domain for them to explore. Tertiary students were conveniently available and constituted an ideal cohort: they were old enough to be well-experienced users of technology, yet young enough to have adopted the technology early in their lives. Physics was chosen as a subject domain for two reasons. First, my own background as
a physics educator gave me insights into the well-documented issues in physics education and approaches taken to address them. Second, physics is a discipline of deep conceptual learning that lends itself to the use of rich multimedia materials. This enabled me to construct an environment in which students could experience interactions that were far more sophisticated than simply navigation, content selection and pacing. The environment allowed students to explore a world in which the learning difficulties were well known, the interactions were significant and the conceptual challenges were considerable.

The research crosses the boundaries of three research domains: human-computer interaction (HCI), psychology and education. It draws together ideas of HCI in terms of a person’s interaction with elements presented on a computer screen, psychology in terms of the motivation, emotion and engagement experienced, and education in terms of how the interactive environment impacts on a person’s learning.

1.1.2 Flow: an engaging experience

Among the assumed benefits of an interactive multimedia environment are that it will provide interaction, engagement and motivation. The question of how to explore these facets of a learning environment quickly led to ‘flow theory’ (Csikszentmihalyi, 1975; 1990; 1997). Flow is an optimal experience described as enjoyable, challenging, engaging, totally immersing. Flow has been researched in many aspects of everyday life (Csikszentmihalyi & Csikszentmihalyi, 1988) and many of those research projects have commented on students experiencing flow whilst partaking in a learning activity.

The reasons that flow theory became a principal focus for this research relate to its embodiment of three important aspects of online learning. First, the flow experience describes many important aspects of a rich learning environment: clearly articulated goals, feedback, skills, challenge, control, and concentration. Second, flow theory provides an approach for handling the affective aspects of an experience such as the emotions of pleasure, frustration, anxiety, and boredom, which play significant roles in learning. Finally, flow describes an autotelic experience. That is, one that is enjoyable for its own sake. If a person enjoys activities in life that are flow experiences, then he or she is likely to want to come back and do them again – just for the fun of it. For students in a hectic world in which study often takes a poor back seat to employment, socialising and the continual bombardment of fast-paced media, the prospect of providing environments that might achieve flow while learning is highly attractive.

There is much research into flow, and research into learning, but there is almost none that explores the role that flow plays in a learning experience, seeking to understand student behaviour in such an interactive environment. This research project took on that challenge.

1.2 Research problem

This research was about interactivity and the ways in which a learner can engage with an online learning environment to effect learning. It was also about control. Control is an important aspect of interactivity, learning and flow; it forms a thread throughout this thesis as the focus moves from investigating interactivity and engagement through to a deeper understanding of how the design of a learning activity can capture students’ attention and engage them with a learning task.
The aim was to develop a better understanding of students’ behaviour when presented with highly interactive tasks embedded in an online learning environment. What was their pattern of interaction? What kept them engaged and interested? What had impact on their learning?

The choice of ‘flow theory’ as a theoretical model for this research has provided a solid foundation on which to base my exploration of students’ behaviour. It has also enabled me to contribute to our understanding of flow in a learning context – an area not well researched in the past.

The key research question:

\[ RQ: \text{ How can flow theory be used as an explanatory framework for investigating student engagement in an online interactive learning environment?} \]

was decomposed into three sub-questions\(^1\); each was addressed by one of the three experiments carried out in this research:

\[ RQ1: \text{ What are the influences on learner interactions in an online interactive learning task?} \]

\[ RQ2: \text{ Of those influences on learner interactions, how do the flow concepts of control, challenge and skill describe learner interaction?} \]

\[ RQ3: \text{ Why do the flow concepts of challenge and skill present such an apparently inconsistent picture?} \]

Each of the three experiments is overviewed below. They used appropriately different methodologies and approaches for the collection and analysis of both quantitative and qualitative data. The initial experiment was an exploratory one in that its goal was to formulate more precise questions to be answered in the later studies (Neuman, 2000). The nature of how students interact while working with online interactive materials is still poorly understood. Hence methodologies to explore the nature of students’ interaction were developed in this first experiment, which were later refined for use in the second experiment. These methodologies included the development of a visualisation technique to display how students navigated Web pages and how they interacted with Web content. The second experiment was quantitative in nature employing statistical methods to establish links between various parameters. A second visualisation technique was developed to help identify students’ patterns of flow experiences as they worked through online materials. From this experiment, issues were identified that required a more in-depth study to obtain rich qualitative data that would help describe the nature of the flow that students experienced. The third study was also descriptive but moved from the broad quantitative nature of the previous experiment to a smaller, focused set of interviews producing an extensive set of varied and rich data. This interpretive approach was in contrast to the positivist approach of the previous two experiments. This decision came from the analysis of the second experiment which suggested that the objective data gathered relating to the students’ interactions and emotions was not telling a complete story of their flow experiences. Hence the third experiment, using a small group of participants, was designed to enable a richer story to be told.

\(^1\) For clarity, I have numbered research questions by the number of each study (1, 2 or 3) followed (later) by the number of the question within that study. Later, the research findings are numbered in a similar manner.
Physics knowledge tests were used in the second and third experiments to measure learning. These were taken from standard achievement tests extensively researched and validated in the physics education community (Hestenes & Halloun, 1995; Hestenes, Wells, & Swackhamer, 1992; Thornton & Sokoloff, 1998). These tests are reliable and valid for assessing specific physics knowledge. However, they were not designed to assess incidental learning gained by the students as they worked their way through the exercise. Incidental learning is a highly desirable and likely consequence of engagement in such an exploratory environment. Since it was not measured in this research, the conclusions drawn concerning learning gains only apply to the explicit knowledge that was intended to be learnt through the design of the learning materials.

As is standard with research of this nature, an ethics application was submitted to the Departmental Human Ethics Advisory Group and approval granted for each experiment. Each participant was provided with a Student Consent Form and Plain Language Statement (Appendix A-1) that conformed to the university’s ethics requirements.

### 1.2.1 Experiment One

**RQ1:** *What are the influences on learner interactions in an online interactive learning task?*

The first experiment explored students’ motivations and goals during an online interactive task in which they had control over their degree of interactivity. I was interested in understanding the role of interactive tasks in online learning. The context of online learning presents its own particular constraints different from many other online activities. In this context students were expected to pursue a specific activity, rather than being allowed to digress and prowl the Web. The learning was highly focused. To learn, students needed to have motivation, yet often this had to be provided extrinsically by the task, rather than intrinsically by the student. Mastery of the software was not an end in itself, but a gateway through which students explored more complex ideas. Their aim was to learn, yet there are many different styles and preferences for learning and many different goals that students might have had as they went about it.

In order to derive a better understanding of some of these issues the first experiment was designed to examine aspects of an online learning environment in a fairly broad manner, leaving a more focused approach to the experiments that followed. Although the nature of this ‘experiment’ was more akin to an exploratory study, some variables not being controlled, I have referred to it as an experiment for simplicity and consistency throughout this thesis. I chose a quantitative methodology in order to obtain data from a diverse range of students and to determine patterns of behaviour in both their interactive strategies and emotional responses. I designed a task with a high degree of interactivity as this provided an option to vary the amount of control an individual could have over the environment.

This experiment enabled me to explore how students’ motivation and goals changed throughout the task. Since the aim was to find out what choices students would make if they could decide for themselves how much they wanted to engage interactively, they were allowed to self-select the degree of interactivity of the task by choosing appropriate navigation paths. They were given the control to change this choice during the experiment, providing some initial insights into the roles played by ‘user-control’, referring to
control over the software being used, and ‘learner-control’, describing control over the student’s learning strategy.

Students’ physics skills were measured using a pre-test, and their emotion and goal responses were recorded using probes as they progressed through the session. Their learning achievements were measured using a post-test. The progress of each student’s learning session was monitored in detail.

The outcome of this first experiment revealed the value of monitoring the progress of students throughout an activity of this nature. Students approached the task with a variety of goals and interests that changed significantly during the task. Pre-test, post-tests and surveys were not adequate to give an understanding of how their emotions were changing in response to the task. The emotion probes gave some information, but more frequent feedback was required. The experiment provided me with a test-bed for further work in which I could track the path each student took through an online task and probe for various responses along the way.

Letting students self-select the degree of interactivity through this experiment gave students control over the way information was conveyed to them and, through this, gave them control over how they were able to interact with the concepts. This identified distinct groups of students who elected high or low interactivity, or a mix, but it did not give a clear picture of the influence that control was having on their behaviour. I needed to predetermine the level of control experienced by students rather than let them self-select. I also needed to gather data reflecting students’ overall feelings from the task: a measure of their engagement, perceived control and enjoyment.

These issues led to the design of the second experiment, which was designed specifically to explore flow. It required tighter management of the degree of control that students experienced and frequent measures of the indicators of flow throughout the learning task. The research in this and the final experiment used novel techniques to measure and represent the flow experiences of students.

1.2.2 Experiment Two

RQ2: Of those influences on learner interactions, how do the flow concepts of control, challenge and skill describe learner interaction?

To pursue the roles of interactivity and control in this learning context I required a theoretical underpinning on which to base further experiments. Flow theory, with its strong links to engagement, control and enjoyment, was an appropriate choice. Flow theory suggested an established methodology for monitoring students’ progress during a learning session as well a method to obtain an overall view of flow after the session.

Hence, this second experiment focused on exploring flow in an online learning context – a different context from much of the existing research on flow. The varying contexts of other flow research bring their own unique features. For example, studies in the area of online marketing need to contend with issues such as the diverse distractions of the Web and the users’ individual computing skills (Hoffman & Novak, 1996; Novak, Hoffman, & Yung, 2000). Studies exploring workplace training often focus on the acquisition of skills in the software being used within the context of common workplace constraints (H.
Chen & Nilan, 1998; Ghani & Deshpande, 1994). Those studying flow during game-play usually have highly motivated subjects who need to achieve no overall goals other than to master a game and have fun (Douglas & Hargadon, 2001; Johnson & Wiles, 2003). This study, in an online learning context, focused on the engagement of students in a complex learning task facilitated by a complex interactive simulation.

Experiment One had set the stage for studying flow in this context and suggested several further requirements: to make frequent flow measures, to predetermine the degree of control students experienced, and to gather richer survey information after the experience. In this second experiment I measured flow using two methods. The first method used an established flow measurement technique of recording students’ perceived challenges and skills (Ghani, Supnick, & Rooney, 1991; Konradt, Filip, & Hoffmann, 2003; Novak & Hoffman, 1997). These attributes were monitored throughout the task in order to explore the process students followed. Challenge and skill measures are often used as a way of determining the flow state of an individual and of providing a relatively non-invasive way of obtaining frequent measures. In this manner I was able to track the flow state of students more closely as they progressed through the session.

The second method used a student survey at the end of the learning session in order to obtain a retrospective measure of flow that could be contrasted with the earlier measures. My aim was to understand how a measure representing flow changing throughout the session compared with the students’ retrospective assessment of flow at the end of the session. Retrospective measures of flow are a common technique in flow research (H. Chen, Wigand, & Nilan, 1999; Ghani, 1995; Konradt & Sulz, 2001; Novak, Hoffman, & Duhachek, 2003; Webster, Trevino, & Ryan, 1993).

I also examined more closely the link between flow states and learning. I refined the learning environment and the tools in order to accommodate the issues described earlier. I developed a new set of learning activities that related to a strong body of research in learning outcomes for the particular subject domain of physics. The subjects for the experiments formed two groups: those with a Physics background and those with an Information Systems background.

The variable ‘control’ was manipulated by allocating students to one of two different levels of interactivity in an otherwise identical set of learning activities. The more interactive activities gave students a higher degree of control than the less interactive mode.

The experiment showed that challenge-skill measures of flow reported students moving through various flow states during the session – flow was clearly a concept better described by a process rather than a destination. I developed a visualisation of the process (‘flow-paths’) and used these to help identify groups of students with different learning behaviours. Whilst some of the learning performance of these groups could be related to their flow characteristics, many individuals showed flow behaviour that did not fit any expected pattern.

The student group with a physics background showed a marked difference in the flow states they recorded depending on the degree of interactivity of the environment. Those in the more interactive mode tended to report more instances of being in a state of high skill and low challenge, while those in the less interactive mode tended to report more instances of balanced challenge and skills, that is, flow. This was
a surprising result since it was initially thought that a more interactive environment would lead to more instances of flow. This result was later explained using the outcomes of the third experiment. As was the case with the first experiment, the recordings of interactivity data showed that students used many different exploratory strategies and exhibited very different degrees of interaction.

The similarities and contrasts between the flow processes observed through challenge-skill measurements and the flow measures recorded at the end of the exercise raised the question of why these methods appeared to give inconsistent pictures of flow. This question was addressed in the third experiment.

1.2.3 Experiment Three

RQ3: Why do the flow concepts of challenge and skill present such an apparently inconsistent picture?

The challenge-skill measure of flow has been shown to be effective in general Web browsing activities (Novak & Hoffman, 1997) but the task in Experiment Two involved a reasonably complex learning task. Flow has rarely been studied for such tasks. Whilst physical activities such as rock climbing might lend themselves to registering extreme scores on ratings of all flow elements, we cannot assume that a flow experience during learning would give similar results. Learning is less physical. It is often an imposed activity rather than a self-motivated one. The motivations that would prompt an individual to try to achieve learning are also often imposed (extrinsic) rather than self determined (intrinsic). Yet Csikszentmihalyi’s (1992) philosophy that we might find more meaning and enjoyment in our lives due to the autotelic drive of flow activities is a very powerful motive for developing a better understanding of how we might achieve this during online learning activities. Even if the flow experience is rarely as intense for the learner as it is for the rock climber, to capture the essence of it may help attract and retain learners in a learning task for a longer time and possibly with more effective learning outcomes. It is these thoughts that motivated this final experiment.

Whilst the flow-paths of Experiment Two showed interesting patterns of the changing balance between challenge and skills, I could not be sure what students were focusing on when they responded to each challenge-skill probe. Nor could I be sure how their thinking combined, or distinguished between, the learning task and interactive software components when they responded to the post-survey questions. This uncertainty questioned the validity of using challenge-skill measures in this manner to describe the flow experience of students. There was a need to probe more deeply and listen to students’ comments as they were invited to reflect on their experience in terms of the various aspects of a flow experience.

The outcomes of Experiment Two also raised the question ‘how does a learning task differ from other types of tasks studied in the flow literature?’ One major difference is that many of the elements of flow become multifaceted in the context of a learning task. For example, control is a prime factor influencing flow, yet in a learning context it can be seen to take on the meaning of either ‘user-control’ (the user’s control over the computing environment) or ‘learner-control’ (the learner’s control over the material to be learnt). Control should be affected by the differences between a student’s skill in performing a task and the perceived challenges of the task (Ghani, 1995) – an important concept in flow theory. Yet in a learning context both ‘challenge’ and ‘skill’ might refer to the student’s abilities with the computing environment or it might refer to the student’s domain knowledge relevant to the task at hand. Similarly
‘providing clear goals’, another important element of flow, could relate to what the students need to do at a particular time in relation to the current task, or it could refer to the higher order learning goals that they may have set for themselves in order to succeed.

Many of the elements of flow suffer from this dichotomy of two tasks vying for the student’s attention. I have used the terminology from HCI literature of ‘task’ and ‘artefact’ to refer to the learning task and the computing tasks, respectively. These aspects of flow have not been addressed in the flow literature except in the context of flow antecedents in computer-mediated environments generally (Finneran & Zhang, 2002; 2003).

This final experiment probed more deeply into students’ experience during a learning task in order to develop a better understanding of the challenge-skill measure, to understand how to maximise the potential for flow in a learning environment, and to gain a better understanding of the characteristics of flow that students perceive in such an environment.

I chose a qualitative methodology allowing me to gather rich data about the way the students perceived the activity. To ensure that the students had strong intrinsic motivation to learn, rather than simply a financial reward as the subject of an experiment, I modified the learning materials and, after the learning session, required them to ‘teach’ a third person some of the ideas that they had learnt. I carried out in-depth post-task interviews to probe the students’ experiences relating to some of the traditionally accepted elements of flow.

The analysis of this experiment clearly showed that there were contradictions between accepted flow theory and the perceptions that students had whilst involved in an online learning activity. A simple challenge-skill measure was not an adequate measure of flow as it failed to take into account that students were working at two levels: that of the task (learning objectives) and that of the artefact (simulation software).

Hence I propose a new view of flow that represents the flow process in a learning environment. This model represents the engagement that a student has with both the learning task and the interactive object (‘artefact’) used to explore the task. It presents the concept of the artefact being positioned between the student and the learning task in a manner that may enhance the students’ engagement with that task, or, undesirably, may distract from it. The model makes clear that the task of designers (of both the learning strategies and of the instructional material) is to consider carefully students’ skills in relation to aspects of the learning task and to develop a design strategy that moves the students beyond simple engagement with the artefact through to a deep engagement with the task.

1.2.4 Summary
The outcomes from this final study complete a highly fruitful series of investigations into flow and learning. From a starting point of looking at general features of students’ online learning experiences, it has embraced flow as a valuable methodology with which to probe more deeply. Established measurement techniques have been found wanting and an explanation for this given. The insights gained into how students behave in such environments will be of value to software designers and instructional designers alike.
1.3 Major contributions made by this thesis

The major contributions made by this thesis are briefly introduced below.

1.3.1 Flow as a process

This research has shown that, in a learning context, flow is better regarded as a process than a state. This process describes the ‘ebb and flow’ as a student engages and disengages with aspects of a learning activity. The students’ behaviour is influenced by the learning task, their abilities and interest in the task, as well as the software environment used to present the task.

A method for visualising this process, referred to as a ‘flow-path’, has been developed that shows how students’ perceptions of challenge and skills vary throughout a learning activity. Through the repeated measures of perceived challenges and skills during the activity, this visualisation maps students’ paths through the learning materials showing the nature of their engagement at each stage. This visualisation can be used to identify patterns that relate to their engagement with the materials and their learning from them. For an instructional designer, flow-paths highlight the importance of matching challenges to individuals’ skills in order to produce an effective learning environment.

1.3.2 Roles of task and artefact

A second contribution points to the need to distinguish between the two significant influences on a student’s flow experience: the learning task and the software artefact used to present the task. These have not previously been considered in the measurement of flow in a learning environment. Traditional techniques for measuring flow have been based on the students’ perceived challenges of a task and their perceived skills to meet those challenges. However, online learning tasks involving interactive multimedia components add complexity in that students’ focus may move from the learning task to the software artefact several times during a learning session. Hence it is important to determine whether the students’ focus is on the task or artefact when challenge-skill measures are made.

In a learning environment the learning task provides strategies and conceptual challenges to the students whilst the software artefact provides motivation and a means through which the students may engage with the concepts to be learnt. Both of these must be considered when measuring flow, as well as when designing environments that might encourage flow.

1.3.3 Flow in a learning environment

A third contribution of this research has been to identify that flow can either support learning or distract a student from learning. Positive benefits in terms of motivation and learning may result from an environment that supports students in experiencing flow whilst engaged with a conceptual learning task. However, the fact that a student experienced flow does not inform us whether the student achieved the learning outcomes expected from the activity. Flow can be an engaging environment in which to learn, but the nature of that learning will be determined by factors relating to the design of the learning materials.

Flow might even distract a student from learning. A student may engage only with the software artefact used to present the task, in which case there is little control over what, if anything, the student may learn.
This is a possible outcome if the software artefact is an attractive multimedia interaction in which the learning challenges presented are not well matched to the students’ knowledge skills. Flow by itself cannot guarantee effective learning, but it can motivate and engage a student in a task, which, if appropriate, will provide a positive learning experience.

1.4 Structure of the thesis

The structure of this thesis is represented in Figure 1-1. This introductory chapter has overviewed the research methods, research questions and contributions. Chapter 2 discusses the literature on interactivity and control, which is background to the first experiment described in Chapter 3. The literature relating to flow is then discussed in Chapter 4, which leads into two experiments that explore flow (Chapter 5 and Chapter 6). Chapter 7 discusses the outcomes of this research and the significance of the contributions made.
Chapter 2

Interactivity and control

“Indeed, the worldwide web and commercial software are replete with examples of glitzy animations that dazzle the eyes, but it is fair to ask whether or not they promote learner understanding that empowers the mind.”

(Mayer & Moreno, 2002)
2.1 Introduction: overview of literature reviews

To provide an appropriate introduction to the three experiments of this thesis, I have presented a background discussion of the literature in two parts. This reflects the path taken by the research. The principal research question of the thesis is:

RQ: How can flow theory be used as an explanatory framework for investigating student engagement in an online interactive learning environment?

The initial research, presented as Experiment One in Chapter 3, was exploratory, looking at various aspects of interactivity, student behaviour and learning. As background to that exploration, this current chapter reviews the literature relating to interactivity and control.

An outcome of Experiment One was a clear indication that, in order to understand student behaviour in online interactions, a different approach was needed. Rather than focussing simply on what interactions the students made with the software, more recognition needed to be given to the students’ emotional feelings and their reactions to the materials presented. A theoretical construct that was ideally suited to satisfying these requirements was ‘flow theory’. It provided a framework encompassing the engagement with a task, the affective response to it, as well as issues of control, challenge and skills. All of these were pertinent to the nature of the online learning tasks to be addressed by this thesis.

Hence, after presenting my first experiment in Chapter 3, I present a second review of literature in Chapter 4 in which I discuss the literature relating to flow, before describing the two experiments that explored flow.

2.2 Interactivity

2.2.1 Interactive learning environments

Reeves (1998) provides a broad description of interactive learning environments as follows:

A learning environment is “interactive” in the sense that a person can navigate through it, select relevant information, respond to questions using computer input devices such as a keyboard, mouse, touch screen, or voice command system, solve problems, complete challenging tasks, create knowledge representations, collaborate with others near or at a distance, or otherwise engage in meaningful learning activities.

An interactive learning environment is a dynamic environment in which the equilibrium changes between teacher and learner (Giardina, 1992). Typically, such environments employ a variety of media formats to provide an interactive experience that is a multisensory interweave of activities to support exploring and searching (Wilson, 1992).

The focus of the research reported in this thesis is on interactive learning environments that contain significantly challenging tasks for students to complete. This has been made possible by the advent of the World Wide Web and the rich variety of media and interactions now available though it. The Web has brought new possibilities as to what interactivity can mean in a learning context. It has allowed us to move beyond a vehicle for presenting hypertext paths through learning materials on videodiscs, rote-
learning-style materials, drill-and-practice testing, interspersed with colourful multimedia. The objects within a Web page can now be highly interactive allowing the user to interact with the objects as well as the surrounding environment.

A starting point for this discussion is to explore what makes a learning environment interactive.

### 2.2.2 The nature of interactivity

Interactivity is a term that is used extensively in a broad range of disciplines and topic areas. As will become apparent, the term is often misinterpreted, misunderstood and used with subtly different meanings (Klettnicks, Whitt, & Hall, 1999). It is thus important to have an understanding of how the term has been used in this thesis, since, by the end, I will draw conclusions about how interactive systems can encourage learning. In this section, I discuss some of the interpretations of the term as used by researchers working in areas that inform the use of interactive systems in educational contexts, particularly education, design and human-computer interaction (HCI). I will then describe the interpretation used in the rest of this thesis.

Defining interactivity is problematic. Sims (1999) points out the paradox of a term deemed so central to computer-based applications, yet so ill defined and difficult to implement. The term is often hotly debated at conferences and amongst academics and is frequently noted as being poorly defined (Klettnicks et al., 1999), having confused meaning (M. J. Hannafin, Hannafin, Hooper, Rieber, & Kini, 1996 p. 385) and in need of better definition (Borsook & Higginbotham-Wheat, 1991; Jaspers, 1991; Kirsh, 1997; Milheim, 1996). Even before the advent of the World Wide Web, after which the term has taken on even greater popularity, Weller (1988) commented that the term was ‘misused’ as simply a sales pitch for promoting computer-based instruction. Interpretations of ‘interactivity’ can range from the use of a computer with a significant role in a learning environment (Reeves, 1998), an on-screen artefact (Otero, Rogers, & Boulay, 2001), through to a description of behaviour in terms of cooperation, coordination, power and negotiation (Kirsh, 1997). Early studies into interactive video instruction concluded that learning improvement is proportional to the amount and type of interactivity provided (Schaffer & Hannafin, 1986). Such clear-cut outcomes are rarely observed today.

In this thesis ‘interactivity’ is being applied in the context of online learning. It refers to interactive Web sites, animations and simulations, and the discourse between student and computer. But, of course, the importance of interactivity to learning pre-dates the use of such technologies by many years. The first learning technology to be identified as interactive was ‘programmed instruction’ (Jonassen, 1985). Such technology provided feedback to students and enabled them to follow different branches depending on their responses. Although such ‘point and click’ styles of interacting are now common on the Web and can provide engaging experiences, they do not represent the style of interacting being discussed here.

The focus on interactivity has become more important in Web learning environments where static Web sites are often disparagingly referred to as ‘electronic textbooks’ that, whilst presenting valuable information, are criticised as offering nothing to engage the learner in meaningful learning tasks. The notion that a Web-based learning environment must employ interactivity to be engaging is becoming accepted among Web designers. A high degree of interactivity is not necessarily considered desirable.
amongst educators, depending on the nature of the learning task (Haseman, Polatoglu, & Ramamurthy, 2003) but a degree of engagement is essential to user goal completion (Laurel, 1986).

What do the terms interactive and interactivity mean? The words take on a range of meanings determined in part by the discipline in which they are being used and in part by the context of their use. The following sections will examine differences in meaning between use in educational and design contexts.

2.2.3 Engagement and learning

Constructivist learning

Interactivity has held a high profile in education circles for a long time (Berge, 1999). Phrases such as ‘learner centred’, ‘hands-on’, and ‘activity-based’ all fit well within a constructivist philosophy of learning and imply interactivity in one form or another. A constructivist view argues that learning is a complex dynamic process through which the learner constructs knowledge through active participation (Bruner, 1966; Piaget, 1971). The learner needs to be encouraged to relate new materials to prior learning (Jonassen, 1985; Mayer, 2001). This view of learning stresses the importance of placing the learner in a role with personal impact in a learning dialogue and stresses the importance of learner interaction.

Both constructivist and social-constructivist perspectives on learning propose that learning involves the learner constructing knowledge. This happens through active participation by the learner (Vygotsky, 1962). Learners need to process information actively in order to learn (Ausubel, 1960). The notion of ‘active’ versus ‘passive’ is crucial to this view of learning. ‘Learner activity’ describes the learner doing something that engages his or her mind in a task that challenges existing concepts, encourages linkages to existing concepts, or generates new ideas. Existing knowledge structures or schema are modified and expanded through active engagement with the learning content. The learners are challenged to articulate their own understanding of such concepts; this is often achieved through discussing their views with others, hence refining their own views and forming conceptual links with their existing knowledge base.

In contrast, a learner trying to learn in a passive manner might be merely reading text, listening to a presentation, watching a video, but not engaging in adequate activities to construct meaning. However, the ‘activity’ of the learner need not be physical. Mayer and Moreno have developed a cognitive theory of multimedia learning which can be used to describe how multimedia, such as animations and microworld games, can be used to promote understanding of scientific explanations (Mayer, 2001; Mayer & Moreno, 2002). Whilst the use of a microworld demands physical interactions, viewing an animation does not. Nevertheless, research by Mayer et al. shows that, by following guiding principles, the viewing of an animation can promote cognitive activity that results in constructivist learning (Mayer, Moreno, Boire, & Vagge, 1999). These principles relate to three main ideas: visual and verbal materials are processed in different processing systems (dual coding), the processing capacity of visual and verbal memory systems is limited, and that learners have the ability to mentally select relevant information in order to build coherent connections. Hence the interactivity of the learner can be stimulated by the design of a multimedia object, the text or verbal audio that accompanies it, or both.

The unspoken assumption regarding interactive multimedia is that, being an interactive medium, it should therefore encourage active learning. Certainly the interactive nature of multimedia has the potential to
encourage active learning of the sort Ausubel (1960) and Vygotsky (1962) refer to. However, we need to unpack the nature of this interactivity in order to understand how it might be used to support learning.

**Interactivity as dialogue**

A fundamental interpretation of interactivity is that of a two-way communication, or dialogue (Gilbert & Moore, 1998; Williams, Rice, & Rogers, 1988), involving feedback and adaptation (Weller, 1988) in a learning context. Such a dialogue often refers to a sequence of verbal exchanges between two people, but can equally well describe the exchanges that occur when a person clicks a mouse and a computer responds. Within a simulation, for example, a student exhibits some exchange of roles (for example, the student enters text and the system responds), and some discourse takes place (one action causes a response which prompts a subsequent action, and so on).

In the case of human-human dialogue, feedback and adaptation is usually guaranteed by the intelligence of the people involved and results in a highly interactive dialogue. When a computer is part of the dialogue, the quality of feedback and adaptation is determined by the skills of the designer to produce a program that can respond appropriately to the user’s inputs. This learner-computer interaction is used to describe complex activities by the learner rather than simple menu choices or mouse-clicks. Whilst adaptation refers to the way in which the technology can change to respond to the needs of the learner (Jonassen, 1985), many regard adaptation and feedback as having similar meaning ranging from ‘the program responding to a user’s choice (such as menu selection) to presenting material specifically structured according to the learner’s prior responses or options’ (Sims, 1999).

For a learner to make an action without feedback is completely unproductive (Laurillard, 1993). However, to be useful in an educational context, interactivity needs to go beyond feedback and adaptation. The aim of interactivity in a learning context is to facilitate learning. This requires the learner to interact with learning content and reflect on how the new knowledge integrates with their existing knowledge (Berge, 1999). This is referred to by Laurillard as the interface being ‘operationally transparent’ such that the student reflects on the content of their learning, the meaning of the interaction, and not on how to operate the program (Laurillard, 1993 p. 204). This reflection helps the learner construct new ideas by seeing how they fit in with established ideas. The prior knowledge of the learner is regarded by Ausubel as ‘the most important single factor influencing learning’ (Ausubel, 1968).

Laurillard (1993) describes feedback as being ‘intrinsic’ or ‘extrinsic’. A computer-based simulation, she argues, is a medium that is interactive in the sense that it gives ‘intrinsic’ feedback on students’ actions. This form of feedback comes naturally from the system itself and has been found to be useful to people learning procedural tasks (Chai, 2003). ‘Extrinsic’ feedback depends on external comment from a third party and while it has been shown to have a positive effect on satisfaction for some types of learning (Chai, 2003) it has also been shown to be distracting and have negative effects in other learning situations (Carroll & Kay, 1988). In most educational settings, provision of extrinsic feedback is the role commonly adopted by the teacher; it might take the form of praise or encouragement, or an indication of whether the student understands the work adequately or not. In computer-aided instruction, extrinsic feedback is most often an indication of a student’s correct or incorrect response.
Interactivity and control

A further element of interactivity is control (Sims, 1997; Williams et al., 1988). Like interactivity itself, this term is also used in ambiguous ways and its meaning has changed over time. Before advances in computer technology gave us highly interactive objects, control was often related to the ability of an individual to choose the sequencing, pacing and content of a communication act (Jonassen, 1985; Rhodes & Azbell, 1985; Williams et al., 1988). Even in more recent times, control has been regarded simply as ‘the extent to which the system (program control) or user (learner control) is making the instructional or navigational decisions’ (Sims, 1997) with no acknowledgement that more sophisticated degrees of control might exist.

The program-control to learner-control dichotomy is often regarded as a continuum (Depover, 1992; Sims, 1997). At one end of the continuum the learner has no control – the program is in control, decisions are seen as being the responsibility of an external design. At the other end, the learner has full control and all decisions are in the learner’s hands (Depover, 1992). This begs the question of how much control is desirable to maximize the benefits of interactivity. This issue arises because in a learning environment the aim is to encourage the students to interact with the learning task, not with the interface through which they view it. Might a learner of low ability, who is given no control by the above definition, perceive being more in control of the whole environment and hence feel more confident to interact with the learning task and achieve learning? This question relating to the meaning and role of learner control, and how the control moves from learner to computer, is discussed in Section 2.3.

What makes an activity encourage active learning?

For educational material to be interactive ‘something in the “world” must change observably as a result of their actions’ (Laurillard, 1993 p. 100). The student acts on the learning material and then observes what happens. Within a simulation the student acts on the system and the system responds with a consequence of that action (for example, the student enters text and the system responds with text). Discourse takes place in the sense that one action causes a response that prompts a subsequent action, and so a human-machine dialogue is initiated. Interaction in this form is a valuable component of the learning process but, as Laurillard (1993) suggests, this is not the complete learning process. An important omission from this description of the learning process is a strategy whereby students reflect on what they observe. Hence, the essence of interactivity, according to Laurillard, is an active learner receiving immediate feedback concerning the consequences of those actions. But equally as important is the learner perceiving or making the connection between action and consequence, between action and feedback.

Thus, from the educational perspective, interactivity has several requirements. It requires more than one agent, a degree of control (between the user and the system), a dialogue, intrinsic feedback and some ability for agents to exchange roles. Interactivity, when interpreted in this manner as an activity between people, is an extremely powerful vehicle for learning. The added value of having another human reacting to one’s thoughts and ideas helps both to challenge and reinforce developing concepts. How can this translate to a computer environment?

Harrasim, Hiltz, Teles and Turoff (1995), when discussing learning networks, rated active learning incorporating collaborative learning components as the second most important factor after motivation for
student success in a networked environment. The significance of such collaboration is not just its importance in the design of collaborative learning activities, but it also reminds us of the crucial role of a teacher in the learning process. When a teacher is present, interactivity utilises direct human feedback to stimulate the reflection by students on their learning. When a teacher is not present, technology must take over this role and sustain a meaningful dialogue. Not only that, but the reflection stimulated should be cognisant of the students’ background skills and preferences – it should take place in ‘digital native language’ – this is the challenge (Prensky, 2001b).

Interaction

The distance education community have defined the term ‘interaction’ to have a distinctly different meaning from interactivity. While interactivity is a feature of the medium, interaction is a learning outcome. It is defined by Wagner (1994) as two objects and two actions mutually influencing each other. An instructional interaction is defined as an event that takes place between the learner and the learner's environment and helps move learners towards their goal. Moore (1989) discusses three types of interaction in this context: learner-content, learner-instructor, and learner-learner. Learner-content interaction is an intellectual interaction with the content to bring about learning; learner-instructor interaction is interaction between learner and the expert; learner-learner interaction is where learners interact with each other alone or in groups.

Whilst these types encompass many different kinds of interactions, they do not cater well for a learner’s interaction with technology. Hillman, Willis and Gunawardena (1994) propose a fourth type: ‘learner-interface interaction’. This describes the dialogue between learner and machine. For example, a student enters parameters into a simulation and then attempts to interpret the resulting graphical output on the screen. In this case the interaction is between the learner and computer’s output display; the aim is for the learner to interpret the output and interact with the meaning behind it. The learner acts, perceives feedback, and interprets it. However, it is often this close contingency between action, feedback on action, and reflection, that is missing in human-computer interactions and hence makes for a poor learning experience.

Interactivity facilitates interaction, but cannot guarantee beneficial interaction with learning content. Whereas interactivity describes what the user is doing during a learning activity in front of the computer, that interactivity is with the computer interface. The user cannot interact with the content of the learning task if he or she is unable to interact with the interface (Hillman et al., 1994). The aim of the design of the interface and the learning task is to make the learner-content interaction possible.

It is no surprise then that ‘interactivity’ can take on a spectrum of meanings. One end of the spectrum focuses on the task itself, the degree to which the task can engage the student and promote learning. The other end focuses on the interaction between one student and another (or a teacher). Somewhere in between lies a learner engaging with a computer. Hence when one refers to ‘interactivity’ in a Web-based learning context, one could be referring to an interaction between an individual and a computer, or an interaction between individuals mediated in some way by a computer.
The above discussion has highlighted that, in spite of the confusion and varied interpretations of the term, at the heart of the interactive learning process in educational contexts lies dialogue between two or more parties. This dialogue implies a degree of control that each party must have and that can move between them as the dialogue progresses.

Exploring interactivity from a Web designer’s perspective further adds to our understanding of the term by reminding us that, although the interactivity takes places with the medium, the reaction of the user determines how interactive a particular dialogue is. Definitions of interactivity in the writings of designers reveal many of the computer-human aspects of interactivity, rather than computer-human-computer aspects. Szeto, et al. identify ‘the components of interactivity’ as being the software tools such as software development tools, Web environments, etc. (Szeto et al., 1997). But they point out that interactivity is not an experience in itself – it is simply the mediator between the user and the information. There is ready acknowledgement that interactivity is ubiquitous in our world and that computer-based interactivity has strong competition from everyday interactions. Hence, to compete in a commercial world, an interaction designer must consider producing a ‘totally immersive’ environment. This notion of ‘immersion’ is particularly apt to the games and marketing Web sites where the aim is to hold the attention of the user for purposes of pleasure or sales (Douglas & Hargadon, 2001; Green, 2000; Jones, 1998).

Designer Nathan Shedroff’s online thoughts titled ‘What is interactivity anyway?’ describe interactivity as a continuum from passive to interactive (Shedroff, n.d.). In contrast to Szeto et al. (1997), he regards the components of interactivity as being the processes that comprise it rather than the technologies that might support it. The six processes he identifies are: feedback, control, productivity, creativity/co-creativity, communications and adaptivity. He is clear that software components (Flash, Shockwave, Java, CD-ROMs, etc.) are not interactive whilst his examples of what is interactive relate to life experiences involving two-way interactions between people (conversation, storytelling, games) or highly productive or creative activities (building and decorating a house).

This reminder that a medium by itself is not interactive, but simply offers the potential of interactivity, resonates well with early criticisms of educational designer Jonassen (1985) who commented on the tendency to focus on the technology first, and then look for a use for it later. This tendency is not unique to education. Alty (1991) notes that the design of computer applications is often hindered by taking a techno-centred approach and asking what the user might be able to do with the technology, rather than what the user wants to do with it.

The notion that a medium simply offers the potential of interactivity also fits well with research discussed later that suggests interactivity is determined significantly by the user and how he or she chooses to react to it. Whilst an environment might offer the potential for interactivity, it is the user who determines whether that environment actually becomes interactive or not. The technology itself is not interactive (nor educationally useful), but its application can be. This notion will arise again in discussing the role of control further on.
Affect – the feelings of interactivity

An important aspect of interactivity is affect: the arousal of feelings or emotions that it brings to the user. Green (2000) incorporates these through the term ‘Immersive Media Experiences’ (IME). This is a broader term than ‘interactive programmes’ or ‘multimedia programmes’ because it includes the senses of touch and kinaesthetics and emphasises the intense nature of these experiences. He observes that ‘many interactive experiences are strangely “flat” and un-involving’. He describes Csikszentmihalyi’s concept of ‘flow’ (Csikszentmihalyi, 1975; 1996a) as ‘the state of being deeply involved in a process that offers challenges and allows a sense of achievement that results in a feeling of enjoyment’ (Green, 2000). Flow, he claims, is ‘conspicuously absent’ in many IMEs. Douglas and Hargadon (2001) place the concept of flow on a continuum between the extremes of ‘engagement’ and ‘immersion’ such that an increase in one diminishes our sense of the other. Flow hovers within this continuum drawing on the characteristics of both simultaneously. The missing element, flow, that Green observes in many IMEs is the engagement identified by Douglas. This use of the flow concept will be addressed in the review of literature presented in Chapter 4.

The concept of immersion is one addressed in a substantial report by Youngblut (1998) into efforts developing, evaluating or using virtual reality (VR) technology in education. Youngblut uses the term immersion to describe applications using head-mounted displays, or large visual displays. Unlike Douglas and Hargadon’s (2001) separation of engagement from immersion, Youngblut sees immersive environments as providing the user a rich and engaging experience usually embedded in a 3-D world. They are often ‘experiential’ in that, rather than leaving the user to merely walk through the virtual world, they require interaction on behalf of the user, often encouraged by guiding instructions. For the students described in Youngblut’s report, this produced environments that were highly supportive of constructivist learning that was often reflected in enhanced learning outcomes. In some of the studies these learning benefits appeared to relate more to the interactive nature of the environments, and the way in which they supported constructivist learning, rather than the immersive qualities themselves. However, a benefit that did appear to be related to immersion was increased affect in terms of greater enjoyment and motivation compared to the non-immersive environments (Youngblut, 1998 p. 98).

The importance of the affective side of interactivity is an observation also made by Laurel (1986) who refers to a sense of ‘first-personness’. She defines three variables: frequency – the rate at which the user interacts with the system; range – the number of choices that each interaction offers; and significance – the impact that the interaction has on the dialogue. After first describing first-personness as being most fully realised when each of these three variables is at the extremes of its continuum, Laurel later proposes that these variables alone are not adequate to define such immersion, but that a more rudimentary measure reflects whether the user feels herself participating in the ongoing action or not (Laurel, 1993, p. 20). This ‘missing element’ idea expresses a similar notion to Green’s ‘flat and uninvolving’ experience (Green, 2000) and is suggestive of Csikszentmihalyi’s ‘flow’. The significant suggestion here is that there is something beyond the sophistication of the technology in the successful application of interactivity. That missing component that is so often overlooked is affect.
This message provided from the designer’s viewpoint is the notion that a sense of playfulness, or ‘flow’, plays an important role in interactions that are designed to be engaging or immersive. If a learning environment’s aim is to motivate students through interactivity, then we should explore this affective side to increase the chance of success.

‘Interactivity’ in HCI and Human Factors

Researchers within the HCI and Human Factors disciplines tend to agree that interactivity refers loosely to the ‘degree of coupling’ between the user and the system, and where the control of dialogue resides is critical to categorising that degree of coupling. For instance, Kirsh (1997) characterises one highly communicative definition of interactivity as involving cooperation between parties, coordination of activities, negotiation over time, and a power relationship between parties. This definition differs considerably from Laurel’s three variables of interactivity: frequency, range and significance (Laurel, 1986). Despite the differences, both Kirsh and Laurel agree that coupling between user and system is important. Kirsh (1997) describes interactivity as ‘a complex, dynamic coupling between two or more intelligent parties.’ Laurel (1993) describes how her three variables ‘provide only part of the picture’ and that user engagement is a measure of how effectively these variables have been manipulated. She further argues that engagement can be achieved through ‘sensory immersion and the tight coupling of kinaesthetic input and visual response’.

Fabre, Howard and Smith (2000) argue that the temporal aspects of usability (for example, the frequency of user input, or the delay in a system’s response to user input) are important in determining the ‘feel’ that a system’s interactivity generates. Drawing on ecological psychology, Norman (1988) discusses ‘constraints’ as limiters on the options available to users during interaction. Likewise, Fabre, Howard et al. talk in terms of ‘contingency’ and Laurel in terms of ‘range’ (Laurel, 1993). Sheridan (1998), when reviewing earlier work in automation, describes the ‘degree of specificity required for the human for inputting requests to the machine’. Though not entirely interchangeable, these treatments are each attempting to capture the borders of possible user action in terms of time and space.

Laurel (1986) sees interactivity as having an ‘outcome’ or ‘dependent variable’, which she terms as ‘interactive significance’. Shadoff (1998) uses ‘productivity’ in a similar way. This is a key dimension of the coupling between user and system and describes the impact that each has on the ongoing interaction. Thus, in addition to varying control (residing with one agent or another), capturing the degree of coupling between the user and the system also requires consideration of temporal aspects, and the effects that these design variables have on the dialogue, in addition to range and degrees of freedom. Any research into interactivity needs to capture information about the ongoing patterns of interactivity as well as interactive instances themselves.

Alty (1991) emphasises the distinction between the presentation aspects of multimedia and the interface issues arguing that multimedia interfaces improve the communication bandwidth to the benefit of the user. This argument essentially puts interactivity and the user at centre stage. It suggests that we should develop a good understanding of the user’s patterns of use, wants and needs in order to create interactive objects that will support rather than hinder the user’s goals.
2.2.4 A definition of interactivity for this thesis

The above discussion shows the term ‘interactivity’ as describing a multidimensional concept that is not well defined. Its meaning has a muddied history. Whilst ‘definitions’ of interactivity frequently refer to dialogue, communications and exchange of information, in practice interactivity has often meant little more than content selection, sequencing and pacing. In more recent times this has evolved to include the more sophisticated interactions possible with more advanced computer software and hardware. Nevertheless, we currently still have many shades of meaning held by different interest groups, such as educators, designers, and HCI professionals.

For this thesis I will use a meaning of ‘interactivity’ based on Laurel’s dimensions of frequency, range (or degrees of freedom) and significance, but with the addition of a fourth dimension: ‘locus of control’ (Graham, Pearce, Howard, & Vetere, 2001). Whereas the ‘dialogue’ signifies a coupling between user and system, ‘control’ adds the notion of ‘who is controlling the dialogue?’. The addition of a control dimension is especially important in a learning context, as will be explained in the next section. Each of these four dimensions is explained briefly below.

The first dimension, frequency, refers to how often the student is required to interact with the system. ‘Interact’ in this sense could mean using common input devices (mouse, keyboard, voice) to enter data, drag a slider, move an object, play a movie, click a radio button, and so on. An environment with high frequency, that requires the user to make many such interactions, could be described as ‘highly interactive’. However, on its own, frequency says nothing about the nature of these interactions. The next two dimensions address the nature of the interactions.

Range (degrees of freedom) refers to the number of choices each interaction offers. Screen elements, such as radio buttons, ‘next page’ buttons, check boxes, each have only one degree of freedom in that they can be either on or off. A slider might have a small number of degrees of freedom, if it moves in a discrete number of steps, or it might have essentially infinite degrees of freedom if it changes a variable continuously. This notion can be extended beyond a screen element to the whole of a screen. A screen offering the student many choices of what to do (click a button, move a slider, enter text, etc.) can be regarded as having many degrees of freedom. By either measure, the potential for interactivity increases as the number of degrees of freedom goes up.

The third dimension, significance (or the impact of activity), relates to the consequence of the interaction to the dialogue. An interaction can be trivial in its impact – we say this has ‘low significance’. Alternatively, it can be highly significant in that it has a major impact on the dialogue. For example, flight simulator software might allow the user to turn on and off a cockpit light with little effect on the flight. However flicking a switch that turns the engine off could be expected to have major impact, a highly significant interaction!

The final dimension, locus of control, refers to who is in control of the initiation, maintenance and closure of the dialogue at a point in time. The question of ‘what is the balance of locus of control?’ is akin to asking ‘to what degree is the user telling the computer what to do and to what degree is the computer telling the user what to do?’. One could predict that an extreme in either direction might be detrimental in a learning context.
Note that the term *locus of control* has different meanings in the Human-Computer Interaction (HCI) and Psychology communities. The HCI community use the term to describe where control lies between user and system. Norman’s Approximate Theory of human decision-making in HCI describes how a user’s general goals drive two main stages: execution and evaluation (Norman, 1988). Execution can be reduced to formation of intention to act based on the user’s goals, formation of a sequence of actions, and finally the execution of these actions. Evaluation involves perception of the result of the action(s), interpretation of the result, followed by a final evaluation of this result. During the final stage the user evaluates the action in the context of his or her goals and this evaluation contributes to the formation of future intentions to act. Hence a dialogue is established in which control moves between user and computer, passing back and forth between the two.

The Psychology community use the same term to refer to the extent to which an individual perceives events or behaviour to be determined by themselves or by external influences. The locus of control is internal if individuals perceive their own behaviour as the determining one, and external if they perceive it as being attributable to chance, luck or controlled by others (Rotter, 1966). It is the difference in the perceptions of the world between things happening to you and things being done for you; events caused by the external actions of others or through your own agency.

In this thesis I use the HCI definition of this term.

The above definition of interactivity allows for varying *degrees* of interactivity from very low to very high. However, it does not tell us what constitutes a highly interactive system or a highly interactive experience for an individual; it does not suggest what settings of the four dimensions are optimal for such an experience. The role of the user is clearly an important one here. A computer-based learning system might offer a simple, non-linear access to a set of static pages of text. Such a system, offering users free choice as to the order in which they navigate the materials, might be considered of ‘low interactivity’ based on measures of *frequency* (one mouse-click, now and then), *range* (each navigation button has only one option – to be clicked, although there may be several buttons on each page), *significance* (each click simply presents a new page) and *control* (high, in this case, since the onus would be almost always with the user to determine the next action). However, such a system might be highly engaging for users who felt that they could navigate to any area of text, go forwards and backwards at whim, find what is required and learn in a self-directed manner. The user’s experience might be recorded as a highly interactive one. However, that interactivity is due to the *user* not the *system*. A different user might work through the materials in a linear manner with little interaction other than electronic page-turning.

The point of the above illustration is to introduce the importance of *control* to interactivity. In that example the locus of control resided with the users most of the time, a choice that could be used effectively by them to produce an interactive experience, or neglected by them to result in a non-interactive experience. The user had full control over the system, but the impact of the control was minimal (page-turning). I regard this system as being of low interactivity. If the system offered greater sophistication, reflected in higher levels of frequency, range and significance, then it would offer the potential of a more interactive experience, but this would depend on where the locus of control lay. For
maximum interactivity, the environment needs to encourage an optimal balance between the control available to the user and system. Clearly the characteristics of the user will be important here.

Control, in this sense, becomes an important aspect of an interactive system. In addition, control is an important aspect of learning with or without technology. The same issues are paramount: How much control should the learner have and how should the locus of control move between learner and system? These issues are addressed in the next section.

2.3 Control, interactivity and learning

The term ‘control’ takes on different meanings in the contexts of interactivity literature, learning literature and psychology literature. In this section, these will be differentiated and the role of control in this thesis given a firm basis.

The literature presents the use of interactivity in learning from many diverse viewpoints: defining it and its measurement (Kletnick et al., 1999; Yaccì, 2000); building taxonomies (Green, 2000; Jonassen, 1985); reviewing its application to computer-based (Najjar, 1996) and Web-based (Liaw & Huang, 2000) instruction; questioning its meaning and deconstructing it (Rose, 1999); judging its efficacy in an online context (Zirkel & Sumler, 1994) and even implored us to ‘exploit its power’ (Bosco & Higginbotham-Wheat, 1991). Some studies examining the use of interactive videodiscs in learning conclude that it is the increased level of interactivity which results in better learning achievement, retention of knowledge and better attitudes towards learning than traditional classroom lectures (Bosco, 1986; Fletcher, 1989; Stafford, 1990; Verano, 1987). Others warn that interactivity is not always needed or desirable in a learning context and may depend on the nature or complexity of the task (Haseman et al., 2003). Yet there have been few significant studies focusing on the learning provided by interactive media, apart from those early ones exploring interactive video instruction (Kettanurak, Ramamurthy, & Haseman, 2001).

One of the dangers of a new and highly engaging technology is the lure of its attractive features. This is observed in software that appears to value ‘bell and whistles’ above pedagogy. Jonassen (1985) recognised and addressed this issue in the very early days of computer-based learning by proposing a taxonomy of interaction specifically aimed at lesson designs. He was concerned that interactive videodiscs had become the ‘latest technological bandwagon’. In order to offset the ‘media in search of design’ syndrome, he proposed a simple taxonomy of interactive lesson designs to facilitate instruction design and media selection procedures. His definition of an interactive lesson is simply one in which the learner responds to information presented by the technology, which in turn adapts to the learner. It presents a continuum from the specific nature of the learner’s actions to the more general orientation and organisation of the instructional technology. His taxonomy has two dimensions: an adaptive one and an interactive one. The adaptive dimension describes internal adaptation based on the nature of the task presented to the learner, and external adaptation in which the system assesses characteristics of the learner’s performance and adapts the sequence, strategy or type of instruction presented. The interactive dimension describes the way in which the learner interacts with an instructional program. Jonassen (1985) notes the importance of giving learners adequate control over their own instruction. However, he cautions
that learners need meta-cognitive skills in order to control their instruction or they risk choosing the method of instruction from which they learn least, especially if the task becomes difficult and the content structure complex.

The notion of control appears in much of the research into interactivity and learning (Arts, Segers, & Gijseelaers, 2002; Berge, 1999; Borsook & Higginbotham-Wheat, 1991; El-Tigi & Branch, 1997; Gilbert & Moore, 1998; M. J. Hannafin & Land, 1997; Kettanurak et al., 2001; Lawless & Brown, 1997; Leung, 2003; Weller, 1988) and is of central importance (Shedroff, 1998; Sims, 1997). Learner control, together with feedback, has often been criticised as being missing from CD-ROM-based and web-based learning materials (Aldrich, Rogers, & Scaife, 1998; El-Tigi & Branch, 1997) resulting in the medium driving the design of learning materials in a way that Jonassen had been critical of ten years earlier (Jonassen, 1985).

In the context of the four dimensions of interactivity used in this thesis, control is the one of most interest since its puts the focus firmly on the user rather than on attributes of the technology. Hannon and Atkins (2002) illustrate this with their model for interactivity that comprises three components: meaning, participation and a sense of control. In their model, an interactive environment achieves meaning through meaningful experiences, adaptive responses and immersion; it is participatory in that the learner engages in a goal-orientated conversation; and a sense of control describes ‘the extent to which the learner has agency and influence in his/her digital environment’ (Hannon & Atkins, 2002 p. 7).

Control spans and links the domains of interactivity and of learning and, as such, presents a challenge to the designer to find an appropriate balance. In part, this is a choice of where the interaction sits on Berg’s (1999) continuum from teacher-centred to student-centred approaches. Interaction sitting at either extreme can lead to boredom, information overload and frustration, even for students who are actively engaged (Berge, 1999).

Whilst not the prime focus of this thesis, control is an underlying theme that is present in each experiment to differing degrees and hence is worthy of further discussion.

### 2.3.1 Learner control

The phrase ‘learner control’ was first used by Mager and McCann (1961) to describe the option for a student to sequence the objectives within a course of instruction. It refers to the opportunity for learners to control various aspects of their learning environment such as path, pace and contingencies of instruction (M. J. Hannafin, 1984) and more recently consideration has been given to control over depth of study, content, delivery media and time spent on learning (Doherty, 1998). The notion of learner control is intuitively appealing (Steinberg, 1989), can reduce learner boredom, anxiety and frustration whilst improving motivation (Steinberg, 1977), and can be regarded more as a collection of strategies rather than a unitary construct (Ross & Morrison, 1989). All learning environments offer some degree of learner control; the challenge in more restrictive systems is how to help students choose cognitive processing activities that will maximise performance (Merrill & Twitchell, 1994).

It has been argued by cognitive researchers that control is an essential aspect of effective learning environments (Kinzie, 1990; Vermunt & Verschaffel, 2000). In some teaching modes control is initially external – as a support mechanism – and gradually transferred as students take control over their learning.
External control tends to minimise students’ personal investment and the responsibilities they feel for their learning, hence a driving force behind the early use of learner-control in computer-based instruction was to give learners more opportunities to make their own choices and evolve greater responsibilities (M. J. Hannafin & Rieber, 1989). However, Hooper and Hannafin (1988) warn that the type of control that students are given is important. Control to skip sections of a learning sequence may have greater consequences than control over reviewing instructions or seeking additional help.

As students learn how to learn, the learning functions move from teacher to student (Vermunt & Verschaffel, 2000). In a computer-based environment there is no teacher present to relinquish control to the student; the parties in the dialogue are student and system. Whilst an appropriate balance of control between student and system is essential, it will be determined by the pedagogical design of the learning materials, the features of the software and the expertise of the student. With the appropriate use of technology, this can require the learner to become very active in the learning process and promote effective learning outcomes (M. J. Hannafin & Land, 1997).

Jonassen (1994; 1996) takes the idea of control a step further by arguing that we cannot expect that instructional programs, in which the user has poor control, to be effective. He supports this by commenting that most research into the use of technology as a conveyor of knowledge has produced ‘no significant differences’. This notion is also supported by related research into the use of hypermedia in learning (C. Chen & Rada, 1996; Dillon, 1996; Landauer, 1995; McKnight, Dillon, & Richardson, 1991; 1996). He argues that learning environments should employ software tools that are learner controlled, not teacher or technology driven. Jonassen argues that the process of learning is holistic and not amenable to simply analysing human responses to attributes of technologies that carry messages to be learned. He proposes the use of cognitive tools that support learners by placing them in the roles of designer and thinker. When computers are used as cognitive tools they support reflective thoughts (Norman, 1993) that help us make sense of our experiences. Others also emphasise the importance of reflection to learning in a similar manner (Laurillard, 1993; 1994; Oliver, 1996).

As an example of locus of control being applied to the use of a cognitive tool, consider a spreadsheet used to model a situation. The learner first designs the model and then uses it to explore its operation. The locus of control first resides with the learner as he or she enters formulae in the construction phase, or manipulates values in the exploration phase. The interactive nature of the spreadsheet means that control frequently moves to and fro from learner to system as data are inputted and responses given. The spreadsheet used this way becomes a powerful cognitive tool while the learner maintains control, interprets the responses, reflects on their interpretation, and considers the next action to undertake. However, if the learner’s skills with the spreadsheet, or understanding of the concepts being manipulated, are inadequate then this tool loses its power and risks becoming a confusing obstacle to learning.

2.3.2 The impact of control

How much control?

Learner control, including suitable feedback, can improve learner attitude and enhance performance (M. J. Hannafin & Rieber, 1989). However, a particular technology will not dictate how much control the
learner has, but only how much is possible (M. J. Hannafin & Land, 1997). The questions then arise of how much control the learner needs and what determines how much control he or she actually achieves.

In Weller’s (1988) paper on the essential components of interactivity in computer-based instruction, he distinguishes between the more obvious quantitative aspects of interactivity (frequency in Laurel’s model) and the more important qualitative aspects. Although there are many qualitative aspects, he identifies the degree of learner control as the most important. At that time, both Weller (1988) and Borsook and Higginbotham-Wheat (1991) regarded interactivity as essentially pacing & branching, resulting in increased efficacy, efficiency and planning, decreased anxiety and improved attitudes.

What is an appropriate amount of learner control to maximise the effectiveness of a learning activity? Weller (1988) states that control depends on learners’ characteristics as well as the content and complexity of the task, a view that is shared by others (Dillon & Gabbard, 1998; M. J. Hannafin, 1984). Schnackenberg and Sullivan (2000) carried out an experiment to test how the first two of these, the learners’ characteristics and the learning content, affected student behaviour in a learning task. Their experiment involved higher-ability and lower-ability groups working through an instructional program with two control conditions (‘program control’ and ‘learner control’) each offering two modes (full and lean). The program control condition led students through a sequence of learning screens, without any navigational options, as well as screens presenting practice with feedback. The lean and full versions had differing numbers of practice exercises. The learner control condition had choices: the lean version presented a default path that offered fewer practice exercises, but students could choose more by clicking the appropriate button; the full version default path offered additional practice exercises which the students could elect to skip. Analysis of the experiment showed that the higher-ability students scored better on a post-test than the others. This was an expected result due to their higher ability and the fact that those in the learner control condition chose more additional screens than the low ability students in that condition.

This experiment highlights an intrinsic difficulty in researching the impact on achievement of parameters like learners’ characteristic and control. The choices given to the students resulted in very different experiences in terms of time on task and number of practice examples completed. The higher-ability students achieved better results, but they also worked through a different set of learning experiences than the other students. Unfortunately there was no knowledge pre-test given to check that the two groups had similar initial knowledge of the subject domain hence we cannot be sure that the higher-ability students’ results were not due to their intuitive ability to interpret the answers to the questions provided, regardless of the screens that they had worked through. The strongest outcome from the experiment appears to be that the students preferred the learner-control approach and had significantly more positives attitudes than those under program control.

The experiment adds to the notion that learner-controlled instruction may not be advantageous over program-controlled instruction for lower ability students (R. D. Hannafin & Sullivan, 1995; 1996; Hicken, Sullivan, & Klein, 1992; Schnackenberg, Sullivan, Leader, & Jones, 1998). But the authors also point out a deficiency in this research that is also true of much of the research in this area to date. The learning environment utilised a stand-alone software environment (HyperCard). The students’ options of
'control’ were restricted to those offered by the software, namely, to opt for further practice examples or not. This notion of the particular software program determining the extent to which students can exercise control is common to almost all pre-Web research in which interactivity was studied. Videodisk was commonly the interactive medium used and ‘control’ implied having choice of path or alternative content. However, with the advent of the Web, learning conditions have changed in two very significant ways.

Firstly, the nature of the Web offers a degree of learner control, making students’ decisions much more complex (Schnackenberg & Sullivan, 2000). A Web environment in not ‘closed’; students are always free to explore beyond the restrictions of the software or program provided.

Secondly, the students themselves are now accustomed to environments in which hyperlinking is common. This has the potential to make them less reluctant to explore, as hyperlinking exploration is something that they are usually very comfortable with. Any uncertainties such as ‘what will happen if I click this button’ are offset by the common understanding that one can always ‘hit the back button’ and return to a known state. To date there has been little if any research that examines learning in this Web environment and explores the nature of students’ choices and explorations in the familiar environment of a Web browser.

A further issue with past research into the impact of control is the difficulty of manipulating the learner control variable. It is common for researchers to create different versions of a presentation and vary the way in which participants manipulate the information. Dillon and Gabbard (1998) report on various research projects in this area and conclude that degree of control is difficult to measure and hence is often varied simply by the use of selectable links and paths. In the projects they studied, they found little evidence that control affected learning outcomes, but did find a connection to students’ ability: high-ability learners appear to have a greater chance of benefiting from increased control than lower ability learners. Research of this type relies on the amount of control being predetermined by the design of the experiment. For example, participants have been put in different test environments offering different forms of navigation (McGrath, 1992); presented with different types of hyperlinking (Welsh, Murphy, Duffy, & Goodrum, 1993); given CAI or hypertext materials (Lanza & Rozelli, 1991); allowed linear movement through a tutorial or navigation using a graphical map (Quade, 1993); given recommendations as to which sequence to follow (Shin, Schallert, & Savenye, 1994). Whereas such research can label participants as being in high or low control environments, and even measure the differences in their interactions within those environments, it has difficulty (and therefore avoids) monitoring the amount of control that a participant has when engaging with a complex object, such as an online simulation.

The paucity of research in this area is not surprising as it is not only difficult to define the degree of control offered by such objects, but it is also difficult to know how the participant interprets the control offered. A highly complex simulation, with many user-controlled options or high interactive range (Laurel, 1993), may give one individual the perception of having full control to explore and experiment extensively. However, another individual, maybe of lower-ability, might feel quite out of control due to all the options provided by the software. The degree of control, and hence the degree of interactivity, is not externally determined by the software or environment, but rather by a combination of the environment...
together with the user. An important measure to research here is the perception of control that the user has rather than the characteristics of the environment itself.

**Locus of control**

The above discussion suggests that the locus of control should move between the learner and the computer and not rest too heavily with either one. Total learner control might be appropriate for those with high skills or who are very knowledgeable, but, in general, if control swings too far one way, interactivity will suffer (Borsook & Higginbotham-Wheat, 1991).

Gilbert and Moore (1998) bring the role of other people into the interactive environment. They recognise that interaction can take place between the learner and the content of the instruction, or between the learner and other learners or teachers. This classification of social interactivity and instructional interactivity is used as a framework within which to describe types of interactions. Learner control straddles these two categories. It appears as a description of interactions between students, students and teachers, and amongst the whole class, and refers to the full gamut of dialogues that might be available with or without the use of technology. Gilbert and Moore approach the issue of how much user control to offer by suggesting a design process that first defines the levels and types of social and instructional activity, followed by determining the personnel, technology and financial resources available, then defining the levels of teacher, student or group control desired over the interaction. A graphical model is used to relate various types of instruction to the levels of teacher/learner/group control. The model plots these along a scale from ‘directive’ (little or no social interaction), through ‘content interactive’, ‘directed collaboration’, ‘collaborative’ to ‘social’. Others have noted this content-social spectrum of interactivity: Berge (1999) describes it moving from teacher to student, Shedroff (n.d.) uses the term passive to active.

Whereas Gilbert and Moore’s (1998) model presents a clear description of the relation between the influences different stakeholders have over different forms of interaction, it doesn’t help in deciding how much control to give to the learner. Although their paper discusses allowing students to have varying amounts of control, along a continuum, the model implies that the amount of learner control afforded by interactions between content and the learner is fixed at the low end of an arbitrary scale. It suggests that, in order to achieve higher learner control, the interaction must be further along the directive-social scale and be ‘collaborative’ in nature. The concerns of Borsook and Higginbotham-Wheat (1991) and Weller (1988) that one can have too much or too little learner control is not addressed by this model.

Further light on the locus of control moving between user and system is provided by Sheridan’s (1998) review of automation and decision-making research. In this paper he produced a succinct analysis of dialogue control, and what the consequences for the interaction are likely to be with different loci of control. He used a taxonomy for complex human-machine systems that breaks a task into four stages:

- acquire information
- analyse and display
- decide actions
- implement action
To each of these stages he applied a level of control, from a scale of eight, ordered from locus of control fully with the computer to locus of control fully with the user. He called these ‘levels of automation:

1. The computer offers no assistance: the human must do it all.
2. The computer suggests alternative ways to do the task.
3. The computer selects one way to do the task, and
4. …executes that suggestion if the human approves it, or
5. …allows the human a restricted time to veto before automatic execution, or
6. …executes automatically then necessarily informs the human, or
7. …executes automatically, then informs the human only if asked.
8. The computer selects, executes and ignores the human.

(Sheridan, 1998)

Sheridan suggests that a different level of control (automation) is often appropriate for each stage and also a different level is appropriate in different situations. He gives an example of holding an election of office bearers for an organisation. For this process, the acquire stage involved manual data collection from individuals (control level 2); the results analysed by computer and decided automatically (both level 8); then the transfer of power effected with minimal computer assistance (level 2). The locus of control moves significantly during the interaction.

This view of control, showing how the locus of control changes during a task, has a significant implication for learning systems. It suggests that, even within a task, the locus of control can swing dramatically between human and computer. Whereas we might glibly describe a learning system as having high learner control, in reality that control will move amongst the relevant parties as the task progresses. Weller (1988) noted that the optimal degree of control will depend on the learner’s characteristics, the content and the complexity of the task; Sheridan’s work suggests that we should also consider a finer-grained view of how the control changes within the task. These views sit well with the concerns of both Weller (1988) and Borsook (1991) that a balance is important and that this balance will depend on, and be determined by, the expertise of the learner.

**Interactivity and control**

Interactivity and control have been shown to have a significant impact on learning. Kettanurak, Ramamurthi, Haseman and Polatoglu explored this relationship and argued that an interactive multimedia learning system should improve learners’ attitudes towards learning and that this should moderate their learning outcomes (Haseman et al., 2003; Kettanurak et al., 2001). Recognising that the different learning styles preferred by different people might influence their reactions to varying levels of interactivity, they used learning styles as contingent variables in their study. The styles were taken from Kolb’s experiential theory of learning (Kolb, 1984) classifying a learner’s dominant learning style as Diverger, Assimilator, Converger or Accommodator (Kolb, 1976).

The experiment involved three groups of learners working with three levels of interactivity; high interactivity, low interactivity and no interactivity. Their definition of interactivity was based on Laurel’s (1993) notion of first personness (frequency, range and significance) but with significance replaced by *modality* – the use of different sensory systems by both the system and the learner. No clear explanation
is given of why modality was chosen to replace significance. Given the strong link between modality and hardware, this is not a choice that would be supported by Schwier and Misanchuk (1993) who suggested that levels of interactivity should not be tied to hardware. Kettanurak et al.’s postulate of how interactivity might support learning draws from all aspects of an interactive dialogue: high levels of interactivity promote active learning; feedback reinforces learning; attractive multimedia presentations promote enthusiasm and heighten attention which further increase the motivation to learn; the ability to make choices and regulate pacing give a sense of control resulting in a positive attitude and sense of exploration leading to better performance.

Kettanurak’s et al.’s research provided strong evidence that interactivity positively influenced users’ attitudes by giving them a greater level of control. However, the differences between the degrees of interactivity were slight. The research also showed that there were differences based on the learning style of the users. Interestingly, those perceiving higher control showed poorer performance improvement. This is attributed to the freedom of choice the users had to not review some of the content if they chose. This tendency of too much control having a negative impact on learning has been noted elsewhere in early studies of learner control (Borsook & Higginbotham-Wheat, 1991; Park & Tennyson, 1980). It should be noted that control over sequencing and pace might produce different outcomes in this sense than control over a complex artefact such as a simulation. Whereas the former might tempt users to skip over parts of the material, the latter might be expected to attract the user to explore the simulation more fully. In this sense, these two applications of learner control are very different.

Modality, in the above context, refers to the use of ‘different sensory systems by both the system and the learner’ (Kettanurak et al., 2001 p. 549). The substitution of significance with modality might indicate that it was hard to vary, or even identify, significance within the materials used in the experiment. Much of the interaction for the low interactive mode involved control of instructional sequence and pacing in which one might argue that the various controls (back buttons, next buttons, etc.) had similar significance. However the highly interactive mode involved some highly significant interactions – topic boxes presenting topic content, buttons to jump to particular slides, glossary, and feedback from multiple choice questions that not only indicated whether a response was correct or not, but also gave an explanation as to why it was wrong. Although the content was identical for each group, it appears that the highly interactive group received substantially more information than the other groups. This highlights an intrinsic difficulty in researching interactivity in that interactivity is a dialogue and a dialogue must involve an exchange of information. Hence greater interactivity, effected in part by greater feedback, must result in a substantial difference in the content delivered to the groups.

A further interesting interpretation of this research is that of the interactivity dimension interaction range. Laurel’s (1993 p. 21) description of this quantity is that of an input presented to the user. However Kettanurak et al. give examples of an output from the system as an indication of range: for example, the system responding with ‘true-false’ or with ‘an explanation of the answer’ (Kettanurak et al., 2001 p. 549). This illustrates the importance of locus of control in describing such interactions. On the one hand, a simple, low interaction range input (e.g. clicking on a multiple-choice test item answer) can put the locus of control firmly with the system as it pours out reasoning about why the response is wrong. On the
other hand, a high interaction range input (e.g. operating a mouse with essentially infinite number of positions) could keep the locus of control with the user as he or she simply navigates a cursor around the screen. The question of whether a system is more interactive when the user is presented with high range choices as an input or as an output comes back to the notion of balance – the locus of control cannot afford to rest too heavily on either the user or the system if the dialogue is to be maintained in a balanced and highly interactive manner. That the control can move so readily from user to system, and back, reinforces the value of Sheridan’s (1998) levels of control changing throughout a task.

2.4 Summary and conclusion

Interactivity clearly has much to offer learning systems, yet it is not well understood how to achieve an appropriate balance of the various dimensions to gain maximum effect. Consequently, we still have a poor understanding of the role of technology in the design of student-centred learning environments (M. J. Hannafin & Land, 1997). The literature has highlighted a paradox in that we believe that interactivity is good for learning, yet it is poorly defined and poorly understood. Learner control, so important in a general learning context, becomes more complex when technology is involved. The technology opens up more ways in which a learner may control, or be controlled by, interactions with learning materials. No researcher suggests that learner control is undesirable, yet the research findings give very mixed results at to its impact.

Research over the last twenty years comments on the importance of learner control in the application of interactivity, with and without computers, and the significance of getting the balance right (Borsook & Higginbotham-Wheat, 1991; Gilbert & Moore, 1998; M. J. Hannafin, 1984; R. D. Hannafin & Sullivan, 1996; Jonassen, 1985; 1999; Weller, 1988). There is agreement on the importance of learner control in the application of interactivity, with and without computers, and comment that getting the balance right is a crucial aim. Sheridan (1998) has given us a taxonomy with which to describe the dynamic control process. Kettanurak (2001) has given us a significant experiment that sheds light on the interaction between control and interactivity in the learning environment.

However, two issues within the domain of interactivity and control remain poorly understood. The first relates to the relative newness of the Web environment and the increasing sophistication of students’ computing skills. Much of the research into interactivity predates the Web, tending to focus on videodiscs and involving predominantly the selection of paths and control over pacing and content. For many students at that time, the computer-based learning environment was novel and motivating. The highly engaging interactions now possible with Web-based materials has changed both the nature of interactivity and the skill set that students bring with them. Commonly used programming environments, such as Flash and Java, have opened up a wide range of innovative techniques of interaction that were only previously possible in specialised environments. We now have a novel situation in that students are highly experienced in using such richly interactive environments and competently interact with and explore them on a routine basis. However, the research to date does not yet reflect this nor has it explored the nature of these interactions. Even Kettanurak et al.’s experiment reported in 1997 does not make use
of the highly interactive objects now possible and common. It was limited to the learning of factual information, not the complex concepts that can be explored using a sophisticated simulation.

The second issue relates to the nature of the ‘control’ that we can now offer students. Sequencing, pacing and control over content was part of the earliest Web-based environments. In those environments, the degree of control that students had could be manipulated by the designer and the effects studied. However, once a student engages with a highly interactive object, such as a simulation, learner control resides more with the student than the system. The student may take a cursory look and move on, or may explore in depth, making full use of all the possible inputs and outputs provided. This immerses the student in a very free, learner-controlled state until he or she decides to leave. The interactions may be fruitful or not; they may be strategic or random. We know very little about the interactions in this state, the choices students may make, or the impact these interactions may have on the students’ overall experiences.

From these two issues several questions arise such as: What are the patterns of interactivity that students exhibit while using highly interactive objects in such an environment? What choices will they make if offered different amounts of control? What is the impact of these patterns and choices on their learning? How might their initial confidence or skill in the domain area affect such patterns and choices?

It is against this background that the first experiment for this thesis was designed. I have defined ‘interactivity’ as describing the potential for a system to hold the learner in a non-trivial, engaging experience in which they have a degree of control over what they do and where they go. This initial experiment was exploratory. Its purpose was to provide a deeper understanding of how students worked in an online learning environment and to suggest avenues worth pursuing to deepen our understanding of the role of interactivity. The environment was Web-based and gave information about the navigational and exploratory choices that students made.

The experiment took heed of Kettanurak et al.’s (2001) suggestion that the influence of interactivity on learning might depend on the nature of the learning task (e.g. factual, conceptual, procedural, problem-solving). The task chosen was hence conceptual rather than factual in nature, which was expected to be more appropriate for interactive, exploratory learning environments (Kettanurak et al., 2001).

The main question to be addressed was:

**RQ1:** What are the influences on learner interactions in an online interactive learning task?

This was broken down into four questions.

**RQ1.1:** What are the interactivity patterns that students show whilst working through an interactive learning environment?

**RQ1.2** What are students’ patterns of choice between navigation paths offering differing degrees of learner control?

**RQ1.3:** What are the effects of interactivity on learning outcomes?
The final question examined the effects that the domain knowledge confidence of the students had on their interactivity choices and outcomes. Whereas physics knowledge might have influenced choices that the students made, their confidence in their knowledge might also have been an important factor:

*RQ1.4 What are the effects of the domain knowledge confidence of students on their interactivity choices and outcomes?*
Chapter 3

Experiment One: exploring interactivity and motivation

“Intrinsically motivating instruction is elusive regardless of the delivery system, but some proponents seem convinced that the Web will motivate learners automatically, simply because of the integration of music, voice, graphics, text, animation, video, and a user-friendly interface.”

(Reeves, 1997)
3.1 Introduction: interactivity and learning

‘Interactive multimedia’ is a phrase often used to describe some of the desirable features of online learning environments. This is particularly true in the area of science learning where computer-based simulations have been used during the last three decades to motivate and engage students as they grapple with complex scientific concepts. Whilst these simulations provide potentially rich learning resources, numerous factors determine whether an individual student will benefit from them: motivation to learn; interest in the topic; students’ facility with the computer system; degree of engagement; appropriateness of the simulation to the learning task; and so on.

It would be naive to assume that the greater the complexity or sophistication of the simulation, the greater the learning outcome of the student. For some this may be true, in that a complex simulation might enable a curious mind to probe more deeply, pose questions and view responses, explore ‘what if’ scenarios and ponder the results. Yet a less interested student, completing a set-learning task, might find the complexity of a simulation daunting rather than cognitively challenging. Choices of input, interpretation of output, knowing what questions to explore, might all lead to a frustrating experience and lack of useful learning.

At the other end of the ‘interactivity spectrum’, the situation may be no better. To present online learning tasks in a low-interactive, ‘textbook’ style of simply text and images may offer no opportunity for either an interested or a disinterested student to engage with the learning material, no opportunity to pose questions and see the system’s response to them. On the other hand, a seemingly ‘unhelpful’ system might appeal to some students’ learning style in that it forces a deeper mental engagement with the concepts and, eventually, the reward of having ‘constructed’ their own mastery of the material presented.

Again, there needs to be an appropriate balance between the challenge of the learning task, the ability and motivation of the student, their emotional feelings at the time and the adequacy of the content presented by the medium.

One question that arises is ‘what is an appropriate level of interactivity to support learning in an online environment?’ In this first experiment I took an exploratory approach with several general questions in mind: How can I monitor the degree of interaction of students? If students are given control over the nature of the learning materials, will they elect a more interactive experience in preference to a static ‘textbook’ style experience? Given control over the navigation through their learning activity, will they proceed in a linear fashion or skip around? What strategies will they use when interacting? What will be the effect of the amount of interaction? What will be their learning goals as they progress through a learning task? How will their goals and emotions change as they progress?

Not all of these questions could be answered from a single experiment, yet I needed to gather exploratory data on several of them in order to find the most fruitful areas on which to focus later. In order not to inhibit any behaviour by students, I chose to restrict their interaction with the environment as little as possible. They were given full control over how they navigated through the materials, as well as control over the nature of the materials they worked with – a highly interactive mode or a more static, electronic textbook, mode.
This chapter describes Experiment One that explored students’ interactions in an environment where they had significant control. Section 3.2 acknowledges contributions to the research by a colleague. Section 3.3 presents the aims of the experiment followed by the method used (Section 3.4) and the design of the learning environment (Section 3.5). The analysis of the data is presented in Section 0 and a discussion and conclusions in sections 3.7 and 3.8 respectively.

3.2 Acknowledgement of contributions to this experiment

This experiment was designed by myself and a colleague (Dr Mary Ainley²). My research interest was to establish an environment from which I could explore students’ interactivity during online learning; Dr Ainley’s research interests were to use this environment to study students’ goals and motivations during such an activity. In order to clarify our respective contributions to this research, I describe below the contributions and aims of each of us.

One of my objectives was to establish a test-bed Web environment from which to explore issues relating to interactivity during online learning – to establish methods for monitoring students, to write software to analyse their actions, and to generate a visualisation of their interactions within a learning task. My contribution was to set up the learning and Web infrastructure to monitor students working through the learning materials in interactive and non-interactive modes. This involved designing the web-based physics content, the site structure, pre-test and post-test, post-questionnaire, the system for capturing navigation and other data, and writing the software to analyse those data.

My aim was to carry out an exploratory investigation that would shed light on students’ movement through, and choices within, an interactive learning environment. I also wanted to use this experiment as a test-bed for a later more detailed study (Experiment Two). I wanted to find indications of what aspects of an interactive learning environment, and what aspects of students’ reaction to it, were worthy of a more focused investigation.

Dr Ainley’s interests were in student ‘interest’ and ‘motivation’. She designed, or assembled from a range of sources, the survey instruments to measure students’ learning goals, interest and learning strategies as well as the emotion and goal probes. She carried out significant analyses on the data collected by these instruments, which are reported elsewhere (Ainley, 2002a; 2002b; Ainley & Hidi, 2002; Pearce & Ainley, 2002). Her analyses and ideas are gratefully acknowledged here as they helped to shape the design of the experiments that followed, as described in Chapter 5 and Chapter 6.

The design of the ‘Waves’ simulation was done in collaboration with a colleague in the School of Physics³ and the JavaScript to drive the navigation bar was written by a programmer⁴.

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³ Dr Michelle Livett, DipEd, PhD. Senior Lecturer in the School of Physics, The University of Melbourne.
⁴ Mr Stephen Ainley, BAppSc (Multimedia Technology).

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3.3 Aims

The broad aim of this experiment was to set up an exploratory environment in which I could begin to examine the engagement of students with an online interactive learning system. The principal research questions was:

RQ1: *What are the influences on learner interactions in an online interactive learning task?*

This was divided into specific issues relating to students’ behaviour during a learning session and the design of an environment to monitor this behaviour. These are addressed in turn below.

3.3.1 Exploring students’ behaviour in an interactive environment

My specific interest in students’ behaviour in an interactive environment was to understand the choices they made navigating and interacting, the effects on their learning and the impact their confidence had on these choices.

Within an interactive environment there are typically many choices that a student can make. Some choices relate simply to navigation or choice of path: whether to move back and review earlier material, or jump ahead to preview what is to come. A non-linear environment might allow students to choose their own path through the materials by the use of hyperlinks. Other choices relate to how students interact with an object, such as a simulation. In a learning task with guided instructions, such choices might be a response to finding the answer to a question, or an effort to determine the outcome when suggested variables are changed, or simply a desire to explore the simulation in an unstructured ‘play’ mode out of curiosity or interest. Given the different learning styles preferred by students, any useful investigation of this should allow the student to choose whether to work with an interactive object or not. Hence a question arises relating to what choice students make and whether they stay with that choice when the non-chosen path remains available; to observe the patterns of their interactions when one of the choices was whether to work in an interactive mode or not.

A second question was to explore whether an interactive object offered any advantage over a static, non-interactive object for students’ learning. This issue has been addressed by others for a considerable time without definitive outcomes. Part of the reason for this is the highly variable, and poorly defined, nature of interactivity. But the nature of learning also varies over a wide spectrum as described by learning taxonomies (Anderson, Krathwohl, & Bloom, 2001; Bloom, Mesia, & Krathwohl, 1964). The focus here was in learning of a conceptual nature involving a relatively high degree of complexity as is often found in physics courses. I wanted to begin to understand whether interactivity was a help or a hindrance to students’ learning of conceptual material.

The third question in this research related to confidence. An interactive environment offers students a choice to take control and make their own choices as to the paths to follow, the interactions to make and the extent of any exploration. A student lacking in confidence might be expected to adopt a conservative strategy and stick to guidelines and suggestions offered by the text and follow a well-directed linear path though the learning materials. A confident student might explore more, take risks and possibly deepen their learning as a result. Alternatively, an interactive object might entice ‘play’ giving a student a sense
of confidence in their abilities not warranted by the actual learning that has taken place. Their confidence might impact on both the choices they make as well as the learning that takes place. Hence my third aim was to explore the confidence that students had in their physics knowledge and the impact it had on the choices they made as well as the learning that took place.

Specifically, the research questions I addressed were:

**RQ1.1**: What are the interactivity patterns that students show whilst working through an interactive learning environment?

**RQ1.2**: What are students’ patterns of choice between navigation paths offering differing degrees of learner control?

**RQ1.3**: What are the effects of interactivity on learning outcomes?

**RQ1.4**: What are the effects of the domain knowledge confidence of students on their interactivity choices and outcomes?

3.3.2 Developing a ‘test bed’ learning environment

In order to explore the above questions I needed to design and test an environment that could be used to monitor students’ progress through an online learning activity and capture data relating to their learning goals, emotions and strategies. This was an important aspect of the experiment, as the environment would be used in subsequent experiments; it needed to be designed, developed and tested. Using this environment, I aimed to gain a richer understanding of students’ use of interactivity and the emotions that they experienced as they worked through a prescribed sequence of learning.

In this experiment I wanted students to freely move between two modes of interactivity according to what they considered suited them. Hence the environment had to allow choice of interacting with highly interactive objects or their equivalent in a non-interactive form. A Web-based learning environment was created which presented a sequence of learning activities to students and monitored their interactions both whilst navigating the environment and whilst exploring an interactive object. The environment recorded pre-test, post-test and survey information. Since this would be used both on-campus and-off camps (in secondary schools, for further research by Ainley) the system needed to gather data, identified by the student, remotely over the Internet. Software was written to analyse the computer log data in order to display the information in a useful format.

3.4 Method

3.4.1 Overview

This first study aimed to explore the way in which students interact in an online environment and also to identify some relations between known variables. Hence it merged explanatory and exploratory techniques as is common in research of this type (Neuman, 2000). It was appropriate to carry out an experiment, using a positivist approach, in order to find the causal relations between the known variables and to identify aspects of students’ interaction experiences that would become the focus of the second
experiment. Little was previously known about how students behave in such an interactive online learning environment hence a system was designed that enabled the collection of a wide variety of data about students’ interactions, emotions, goals, pre and post knowledge, as well as demographic information.

Some of the data from the analysis represented patterns of student interactivity during a learning activity. There was no formal technique available to analyse such data. Each student’s pattern was scanned visually looking for commonalities and similarities between them. The value derived from this was not only gaining insights into their patterns of interaction but also in helping to understand the nature of the learning software that would need to be developed for the following experiment.

3.4.2 Sequence of the experiment

The experiment involved students working through an online physics learning exercise in a computer laboratory setting. This is represented by Figure 3-1. Reading from the left of the figure, it shows the sequence of four screens that gathered data on students’ background, approaches to learning, interest in the topic, their physics knowledge together with confidence in their answers. After this the students made a choice between the ‘interactive’ or ‘non-interactive’ mode of working (I will refer to the non-interactive mode as ‘static’). This was not a random allocation to modes as it was not intended to draw firm conclusions as to the impact of interactivity on learning, but rather to explore students’ choices and strategies. Twice during the 7 pages of physics content their emotions and goals were measured using probes that popped up on the screen. This was followed by a post-test measure of their physics knowledge and a survey of their learning strategies. Throughout the session the interactions of students were monitored using computer logs.

![Figure 3-1 Diagram of the entire session for a student](image)

3.4.3 Participants

It was appropriate to use statistical techniques to identify parameters that would form the basis of the follow-up study. This required sufficient participants to give statistical significance in the analysis. Advertisements were placed over a period of several weeks to attract tertiary students to work through the activities in a computer laboratory setting. As if often the case with studies of this type, these participants do not represent a cross-section of learners and their motivations for participating might not be the same
as typical learners. However, the conclusions to be drawn from the analysis were not intended to be
generalised but rather to identify possible issues and factors to be followed up and to help refine the
following study.

The participants in this study comprised 109 tertiary students who were all studying first year psychology
and took part in the study as part of their compulsory hours of research participation in a psychology
course. This number was sufficient to give meaningful statistical results in the analysis. There were 77
female and 32 males; average age was 19 years.

3.4.4 Procedure
The students worked in a computer lab or classroom. On entering the room they were presented with a
booklet in which they could make notes if they wished (Appendix A-2). All instructions were provided on
the screen. After individually completing the exercise, they submitted their booklets and left the room.

3.5 Design of the learning environment

The learning materials were designed to teach how water waves from two sources interfere to produce
interference lines referred to as ‘nodes’. This domain of physics was chosen as I have had experience in
physics education for many years. The task was developed to provide the potential of significant
interactivity enabling students to spend time exploring the environment in order to develop an
understanding of the concepts presented. The exercise was aimed at upper secondary students or tertiary
students who had not studied the topic previously. The entire exercise was Web-based and involved
student survey, pre-test, learning activities, post-test and occasional probes questioning students’ feelings
and learning goals.

The movement of students through the site was tracked using information from Web log files (Appendix
A-3). These also recorded their specific interactions within a simulation of wave interference. The
students’ responses to questions were collected in a separate log file and analysed.

This section describes the Web environment that students worked through and then looks at the ways in
which interactivity data were analysed.

3.5.1 Pre-test section

After logging on to the Web site, the students were presented with was a screen asking for information
about their background: age; courses studied; prior school physics scores (if any); language spoken at
home (Appendix A-4).

This was followed by twelve questions to gather information on the students’ approaches to learning
adapted from the work of others (Harackiewicz, Barron, Tauer, Carter, & Elliot, 2000; Midgely et al.,
1998; Stipek & Gralinski, 1996) (Appendix A-5). They were asked to respond to each question using a 5-
point scale from ‘Not at all’ to ‘A lot’. The specific dimensions measured by this scale will be described
later when I discuss the findings on student motivation and learning with ICT.

The next screen described the context of the learning sequence. In this case the topic was ‘Waves’ and the
context showed a bee in a pond flapping its wings to cause water waves to radiate. The pattern formed on
the surface of the water is not the common pattern of circular waves radiating outwards, but it shows a classical ‘interference pattern’ comprising lines of calm water (see Figure 3-2). Students then had to respond to the question ‘How interesting do you expect this learning task will be?’ using a five-point Likert scale from ‘Not at all interested’ to ‘Very interested’. The purpose here was to be able to investigate whether students’ initial interest in the task influenced their later choices and performance.

![Waves](image.png)

**Figure 3-2 Context screen from the learning exercise**

Before starting the learning sequence, students were presented with a pre-test of prior physics knowledge in this area together with a measure of their confidence (Appendix A-6). The test was reviewed by a content expert from within the School of Physics resulting in some changes. Whilst this falls short of a thorough validation of the test, it provided an adequate instrument with which to make comparative measures of learning before and after the session.

The test comprised eight multiple-choice questions relating to water waves, wave patterns, nodes and interference. Each question had two drop-down menus associated with it: one from which to select the answer, and the other to indicate the degree of confidence that the student had in their answer. This latter choice was a simple scale of:

- just a guess (scored 0)
- bit unsure (scored 1)
- quite confident (scored 2).
The confidence measure was included to provide data in relation to the research question RQ1.4.

Finally students were offered a choice between two modes to start working through the Web pages. One mode, referred to as the ‘static mode’, let students work through Web pages that presented a structured sequence of information, much like a textbook, with descriptions and images. The other mode, referred to as the ‘interactive mode’, offered Web pages presenting a series of interactive activities with an embedded simulation. The students’ initial choice determined only their starting point. They were free to swap from the static to the interactive mode at any time during the learning sequence.

3.5.2 The learning sequence

The learning sequence was designed to teach some basic ideas of how water waves interfere to form the nodes that can be observed as lines of calm water along the surface. It comprised seven screens that students could work through in any order. In practice, most worked straight through in sequence from start to end (as was the intention). The first such screen is shown in Figure 3-3. At the top a navigation bar allowed students to switch from the static to the interactive modes, or to skip forwards or backwards in the sequence.

![Figure 3-3 An ‘interactive mode’ content screen](image-url)
In the interactive mode students were presented with the sequence of seven Web pages (screens) each comprising an interactive simulation together with two or three questions to explore and make notes on in their worksheet. The simulation was a Shockwave applet\(^5\) that presented a view of a cork floating on the surface of water (left side of Figure 3-3). On the left side of the image was a source of the waves that could be adjusted by dragging to become two sources, at varying separations, as shown. The rest of the image showed the wave patterns produced. Students could also vary the wavelength of the waves, turn on and off an indicator showing the path from each source to the cork (shown ‘on’ in the figure). They could drag the cork around the pattern to explore the effects on the wave pattern in real time. Two graphs below the pattern showed the waveform from each source and a third graph showed the combined (summed) waveform at the position of the cork.

Students answered the questions on each screen by writing into their worksheet, then moved on to the next screen, in sequence, or could jump back (or forward) to any other screen.

This learning environment provided options for students to vary their paths through the materials both by skipping forwards or backwards and also by changing modes, hence providing data on the interactivity patterns for research questions RQ1.1 and RQ1.2. The simulation provided sufficient opportunity for interactivity (making inputs to the system and observing the resulting response) and learning to inform RQ1.3.

For the static mode, the simulation was replaced with still images of the applet, shown with the appropriate settings to illustrate the questions posed by the text. The wording in each mode was as close as possible to the same, but with slightly more text and images in the static mode to illustrate the ideas that potentially could be ‘discovered’ in the interactive mode. The static mode experience was similar to reading a textbook on screen, in that the only interaction was the ability to move forwards or backwards in the sequence of screens. Appendix A-7 shows a screenshot of the ‘static mode’ alternative to Figure 3-3.

Both groups of students, static and interactive, could elect to move to the other mode at any time. This was achieved by the navigation bar at the top right of the screen that also displayed their progress through the exercise (static pages A2 to A8; interactive pages C2 to C8).

At two points during the session a ‘probe’ screen would pop up asking students about their feelings and their learning aims (Figure 3-4). This occurred the first time they changed modes (or after the third screen if they hadn’t changed modes) and after the sixth screen. The purpose of this was to gather a snapshot of their feelings at a time when they elected to change modes or at least at two times during the exercise. The basis of selection for the emotions was Izard’s differential emotions theory (Izard, 1972; 1977) and his work on the measurement of emotions in children and adults (Izard, 1972; Izard, Dougherty, Bloxom, & Kotsch, 1974). The predictive validity of these measures has been confirmed (Ainley & Hidi, 2002).

\(^5\) The design of the Shockwave applet was a collaborative effort between myself and Dr M Livett, School of Physics, The University of Melbourne; the programming was coded by a multimedia developer, Mr Daniel Robertson, Multimedia Education Unit, The University of Melbourne.
3.5.3 Post-test section

On completion of the learning sequence, the students were presented with the same questions as in the pre-test (multiple-choice) together with confidence measures. Two extra questions were added that required students to type in an extended answer (Appendix A-8). Whereas the earlier eight questions required recall of specific concepts presented during the learning session, these last two questions required the students to transfer their water wave knowledge to a new situation involving sound waves. These questions are later referred to as a measure of the students’ ‘transfer learning’ on the topic. The answers to, and marking scheme for, these questions in presented in Appendix A-9.

A final exit-survey (Appendix A-10) gathered information about the strategies students used during their learning time.

3.5.4 Collection of interactivity data

All the data that were entered on-line by students, as well as their movement through the learning site, were recorded on Web server log files. These data comprised two sets. One set (survey data, pre and post-tests and probes) was sent to a CGI script that recorded them as a time-stamped text file. This file was later read into Excel, manipulated and then exported to SPSS for analysis.

The other set of data (page navigation and actions taken within the Shockwave applet) was recorded on the regular Web server log files in a similar time-stamped format. The Shockwave applet was designed to send information to the server when specific actions occurred:

- wave source separation changed (new separation value logged)
wavelength changed (new value logged)
cork dragged around pattern (coordinates logged)
path length displays to each source turned on or off.

The data gathered this way were extensive and buried within the vast amount of data normally collected by server logs (pages visited, pages exited, images loaded, errors logged, browser information, etc.). Hence software was written to analyse these logs, extract the relevant data and produce numerical data of interactions together with a visual timeline of the activities of each student. This software is discussed briefly in the next sub-section. A short extract from such a Web log can be found in Appendix A-11.

3.5.5 Software to analyse interactivity data

The software I wrote to analyse the computer Web log files, *iFilter*\(^6\), had to perform four tasks:

- search the log for each user logged into the server;
- filter and extract data relating to pages of interest visited, or to specific actions within the simulation;
- collate the data into time-stamped sequential lists for each user;
- display the data in usable formats (navigation path, interactivity, timing).

The students each logged on with a unique identifier, hence identifying which lines of the log related to each student was straightforward. However, these logs contained vastly more information that was required for my analysis and the main task of the software was to sort through to extract this information on a student-by-student basis. To maintain flexibility for future experiments, I wrote the code to look up a set of keywords stored in a separate text file. These keywords were unique words that would appear in the Web-page address of the pages that I wanted to track, or words that would be sent by students’ actions within the simulation. By using this text file of keywords, I was able to easily define which actions I wished to track in the analysis and also define features of the display that related to those actions (for example, whether to label them on the output plot, colours, to use, etc.).

The software gathered the required data by student identifier giving options as to how the output should be displayed: several forms of numerical data, summary data or graphical display. Figure 3-5 shows the screen from which to make these selections.

\(^6\) *iFilter* was compiled in *RealBasic* for the Macintosh computer, comprising 1860 lines of code.
A typical graphical display output from the interactivity analysis for one student’s session is shown in Figure 3-6 (next page). The text at the top of the display shows date and time information, student ID, interaction time (i.e. time spent actually dragging the cork in the simulation), total time and the number of clicks the student performed.

The graphical part of the display is a timeline representing the duration of the student’s session, measured in seconds. The upper half of the graph shows boxes representing visits by the student to the static pages; the lower part shows boxes representing visits to the interactive pages. Each successive page through the learning sequence is represented by a box positioned further away from the central horizontal time-axis of the plot. This particular student first visited three interactive pages, jumped to the static equivalent of the third page, then continued on interactively for two more pages, jumped to a static page again, back to interactive, and so on.

The colour-coded triangular markers on the lower part of the graph indicate discrete interactive events; that is, changing settings in the simulation (wavelength, source separation, path difference display). The shaded (green) bands indicate the continuous interactive event of dragging the cork. More detailed statistics were made available as a text output file that could display various combinations of data.
Figure 3-6 A student’s interactivity pattern
3.6 Data and analysis

Data from this experiment comprise information on interactivity, learning outcomes, confidence, and the affective measures of motivation, emotions and learning strategies. Interactivity, learning outcomes and confidence are discussed in detail in the next three sub-sections. The fourth sub-section summarises some of the relevant findings from further analyses carried out by Ainley. I conclude with a discussion on the findings.

3.6.1 Exploring interactivity (RQ1.1 and RQ1.2)

The aim was to understand how students engage with an online activity by observing their movements through and within the environment. The main questions I addressed were:

**RQ1.1** What are the interactivity patterns that students show whilst working through an interactive learning environment?

**RQ1.2** What are students’ patterns of choice between navigation paths offering differing degrees of learner control?

The following descriptive statistics provide an overview of the students’ choices of interactive versus static approaches to the exercise. Students began in the mode of their own choosing, interactive or static, and could swap back and forth between modes at any time. Many took up this option. Of the 109 data sets, 69% (75) of the students initially elected the interactive mode and 31% (34) the static mode (Figure 3-7). During the exercise, most stayed with their initial choice of mode, but 25% changed between modes (labelled ‘mixed’) reducing the percentage working consistently in one mode to 54% for interactive and 21% for static. That is, of the 25% who changed modes during the session, 59% came from the initial interactive choice and 41% from the initial static choice. This indicates that most students chose to remain with their initial choice. However, twice as many students initially opted to use the interactive mode compared to the static mode. These students were also more inclined to have a look at the alternative mode than were the initially static mode students.

![Figure 3-7 Representation of students' movement between modes](image)

The question is raised as to what other differentiating factors could be found between the mode which students started in and their decision whether to switch or not. For example, were one group of ‘mixed’
students less confident than the other? Did one group explore using a greater number of mouse clicks?

Was there a difference in their pre and post-test scores? The numbers in each group were too small to test
for statistically significant differences for any of these questions (only 11 mixed students started in text
mode, 16 started in interactive mode).

Exploring the nature of the interactivity patterns for the students showed a large variety of different
interactions and a wide range of times taken to complete the exercise. Table 3-1 shows summary statistics
of some of the interactivity data collected for each student. It presents the total time students spent to
complete the session, the percentage of that time that was interactive (which, in effect, means the
percentage of the time dragging the cork since this was the only continuous action that they could
perform with the simulation) and the number of mouse-clicks they performed. Since all students had to
perform a minimum of 8 clicks to navigate through the pages of the site, this number has been subtracted
from the total to give a measure describing the number above this threshold, labelled ‘significant clicks’.
Other clicks used in responding to the question probes or beginning the dragging of the cork were not
included in this total. (Not all students recorded a valid time for the duration of their session due to
computer crashes, accidental quitting and other minor glitches. Hence the number of students in the table
is 101 rather than 109).

<table>
<thead>
<tr>
<th>Table 3-1</th>
<th>Descriptive statistics of interactivity data for the whole cohort (minutes)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
</tr>
<tr>
<td>Total session time</td>
<td>101</td>
</tr>
<tr>
<td>Interactivity time</td>
<td>101</td>
</tr>
<tr>
<td>Number of significant clicks</td>
<td>101</td>
</tr>
</tbody>
</table>

**Session times**

Table 3-1 shows the total session times varied from 19.2 minutes to 50.9 minutes. The interactivity
pattern for the student having the shortest, 19.2 minutes, is shown in Figure 3-8. The plot shows that this
student used only 8 clicks to work very quickly though the static pages with no diversions to the
interactive mode, and no backtracking to previously visited pages. This pattern shows the student in an
‘electronic page-turning’ mode; this student worked through the exercise with minimum clicks – no other
interactions beyond navigating quickly from page to page.
In contrast, the longest time taken for the task was 50.9 minutes and is shown in Figure 3-9. This more complex map shows a student working steadily through the interactive pages making significant use of the interactive features of the simulation, as is shown in the figure by the small triangles (a change to simulation settings) and dark (green) bands (dragging the cork). This student’s time spent dragging the cork was about average for the interactivity group (12.5% of total time; average was 13.8%) but this student performed many more ‘significant’ clicks than the average (48 compared to an average of 14.3 for the whole group and 21.1 for the interactivity group) indicating more extensive use of the simulation. This is consistent with the longer time and illustrates a student who was very careful to exploit the features of the environment during the session. It shows significantly higher measure of interactivity from the viewpoints of all four dimensions: the interactions are frequent; the degrees of freedom are moderately high in so far as the cork can be moved freely in two dimensions and the other sliders offer several settings; the interactions are significant in that they make changes to the simulation resulting in pattern changes that require interpretation; and the locus of control is well balanced between user and system as the effects of the interactions are continuously monitored and responded to.

The session times and number of clicks are examined below for each of the three modes: interactive, static and mixed.
Interactive group. The largest group were those who initially chose the interactive mode and stayed with that choice (54 of the 101 students). Table 3-2 shows that their times ranged from 20 to 50.9 min (mean 35.1 min; s.d. 6.7) and that their number of significant clicks also had a wide range of values (0 to 55). A typical interactivity plot has already been seen in Figure 3-6.

<table>
<thead>
<tr>
<th>Mode</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Mean</th>
<th>Std. Dev.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interactive</td>
<td>Total session time</td>
<td>20.0</td>
<td>50.9</td>
<td>35.1</td>
</tr>
<tr>
<td></td>
<td>(% N = 54) % of time dragging cork</td>
<td>0.0</td>
<td>25.9</td>
<td>13.8</td>
</tr>
<tr>
<td></td>
<td>Number of significant clicks</td>
<td>0</td>
<td>55</td>
<td>21.1</td>
</tr>
<tr>
<td>Mixed</td>
<td>Total session time</td>
<td>20.5</td>
<td>46.7</td>
<td>34.6</td>
</tr>
<tr>
<td></td>
<td>(% N = 25) % of time dragging cork</td>
<td>0.0</td>
<td>25.5</td>
<td>8.2</td>
</tr>
<tr>
<td></td>
<td>Number of significant clicks</td>
<td>0</td>
<td>36</td>
<td>9.0</td>
</tr>
<tr>
<td>Static</td>
<td>Total session time</td>
<td>19.2</td>
<td>43.4</td>
<td>30.9</td>
</tr>
<tr>
<td></td>
<td>(% N = 22) % of time dragging cork</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td></td>
<td>Number of significant clicks</td>
<td>0</td>
<td>3</td>
<td>0.2</td>
</tr>
</tbody>
</table>

Mixed group. The next largest group was the ‘mixed’ group who swapped at some stage between modes. They took a similar time to work through the exercise (mean 34.6 min) and they used fewer significant clicks (mean 9.0 clicks). This was to be expected since some of the pages they visited had no interactions to perform. An example of this style of interaction is shown in Figure 3-10. This pattern shows a student who appeared to use a deliberate strategy of checking the non-interactive version every second page.

Static group. Finally, the static mode students were the quickest to work through the exercise (mean 30.9 min) and rarely used more than the minimum number of clicks. An example has been shown in Figure 3-8.
The 5-minute difference in the average times that the interactive mode students took to complete the exercise can be attributed to the extra time that these students took to ‘play’ with the simulation. Table 3-3 shows that, when the times spent dragging the cork are subtracted from the total mean times, the mean times for each group are the same within 1 minute. The significance of this is that, whilst the interactive groups had more to do, they did not extend by much the time taken to complete the tasks. They spent an extra five minutes dragging the cork, and associated thinking, otherwise the reading and thinking time for each mode was about the same. There was no evidence that the effect of the simulation made that group spend excessive time exploring the simulation. On average they spent less than one minute moving the cork on each page. This use of the simulation was probably, in part, balanced by the extra time that the static group had to spend reading the additional explanatory text and studying the additional images.

<table>
<thead>
<tr>
<th>Table 3-3 Modified times for each mode</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
<tr>
<td><strong>Interactive</strong> (N=54)</td>
</tr>
<tr>
<td><strong>Mixed</strong> (N=25)</td>
</tr>
<tr>
<td><strong>Static</strong> (N=22)</td>
</tr>
</tbody>
</table>

**Comparing interactions**

The data for the different groups displayed in Table 3-2 shows a wide range for many of the scores. This illustrates, in part, the very diverse strategies used by students when given a choice of modes of interaction. An excessive number of clicks in the interactive mode may indicate a lack of confidence, or uncertainty about what to do. For example, Figure 3-11 shows a student who spent a relatively long time in the interactive mode (43 minutes) and carried out numerous clicks (100, about 85 of which were ‘significant’). Very little time was spent dragging the cork. The interactivity score of 1.1% is represented visually by the shaded (green) bars in the plot. Since dragging the cork was what provided crucial information required for understanding the properties of waves, it appears that this student did not explore in a very effective manner. His clicks were used to drag the two wave sources apart, choose different wavelengths and turn the paths display on and off – these actions on their own do not provide extensive exploration of the properties of waves.
In contrast, the pattern in Figure 3-12 shows a student who took a similarly long time (43 minutes) using only 40 significant clicks, and about 25% of his time being spent dragging the cork. The pattern shows extended periods of time where the only actions were cork drags – solid (green) bars on the plot. From these responses we can conclude that this student was exposed to the effect of the motions of the cork and the resulting wave patterns, and was confronted with experiences from which important relationships could be deduced. This student was exposed to information about the critical relationships that the previous student, although also in the interactive environment, was not exposed to.

Two more interactivity patterns serve to illustrate the variety of strategies used by students. Figure 3-13 shows a student who started in the interactive mode, made a few interactions, then changed to the static mode. After working with four of the static screens he changed back to the interactive mode. The increasing frequency of the vertical lines, bars and triangles indicates that the intensity of his use of the interactive component increased as he progressed through the task.
Finally, Figure 3-14 shows a student who began in the static mode but spent a relatively long time on screen four. After a while, he backtracked to check two of the earlier screens. Later, on screen five, he switched to the interactive mode but did not make use of any interactive features. He is one of the relatively few students to make use of the feature of backtracking to check earlier screens.

**Summary**

By selecting some of the interactivity patterns, we have seen how they differ in important ways suggesting differences in how students engaged with the learning activity. We have gained some valuable insights into the choices students made when presented with options for the way they work. What was striking was the range of differences in their manner of interaction: time taken, number of mouse-clicks and navigational patterns. Students were given control over their method of working through the activity and yet the lure of an interactive mode was not attractive to all students, twenty-percent electing to work through in ‘electronic textbook’ style. For those who were attracted to the interactivity, it required only a small overhead in time compared to the static mode. There were significant differences in the manner of use of the simulation with some students using it in a relatively ineffective manner. Finally, almost all students elected to work straight through the exercise in a linear fashion with very few using the facility of going back to earlier screens.
3.6.2 Learning outcomes (RQ1.3)

The third research question posed was:

**RQ1.3:** What are the effects of interactivity on learning outcomes?

The measures that related to the students’ learning were pre-post test scores and the confidence ratings that they gave to their answer for each test item. These are addressed in turn below.

**Pre-test and post-test**

The pre-test, post-test analysis showed that the group, as a whole, made some learning gains during the exercise. A paired samples t-test showed that the mean test scores, from a maximum possible score of 8, improved from 3.77 (s.d. 1.6) to 5.29 (s.d. 1.59), \( p < 0.001 \) (Appendix A-12). The pre-test score was particularly low indicating that the students had very little knowledge of this subject area before the session.

To explore whether the interaction mode had an effect on the students’ learning gains, as measured by the improvement of the post-test scores over the pre-test scores, a one-way analysis of variance was carried out with the mode as independent variable (Appendix A-13). Since the students were not randomly allocated between the modes the results might be weakened somewhat. Table 3-4 shows the test scores and improvement values for each of the groups (expressed as percentages from here on for clarity).

Although the use of the simulation appeared to have little effect on their learning gains, there is not sufficient evidence to conclude that there was a significant difference.

It is interesting to note that the pre-test mean score for the static group is lower than for the other groups. This possibly suggests that the lower ability students were less prepared to take on the more challenging mode of working within an interactive environment.

<table>
<thead>
<tr>
<th>Table 3-4</th>
<th>Mean pre- and post-test scores, and improvement, for each mode of interaction</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre-test</td>
</tr>
<tr>
<td><strong>Interactive</strong> (N=54)</td>
<td>49%</td>
</tr>
<tr>
<td><strong>Mixed</strong> (N=25)</td>
<td>50%</td>
</tr>
<tr>
<td><strong>Static</strong> (N=22)</td>
<td>42%</td>
</tr>
</tbody>
</table>

However, the final two questions on the post-test, designed to measure students’ ability to transfer their knowledge of water waves to sound waves, did show differences between the modes. A one-way analysis of variance was carried out on the total scores for these two questions (Appendix A-14). To control for any effect of the independent variable *pre-test*, this variable was included as a covariate in the test. The maximum score possible on these two questions was 8 (5 + 3) and Table 3-5 shows that the mean score was higher for the group that made greater use of the interactive pages (\( p < 0.01 \)). The difference in the means between the static and interactive modes is significant (\( p < 0.001 \)). The R-squared value was 0.287
indicating that 29% of the variance in the scores can be attributed to the mode of interactivity. Whilst the absolute scores are not very high, and do not indicate mastery of the topic, they do suggest that some learning took place as they used the simulation that was different from, or more effective than, the learning achieved in the static mode.

<table>
<thead>
<tr>
<th>Table 3-5</th>
<th>Mean scores for Q9 and Q10 in each mode of interaction</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Question 9 &amp; 10 scores</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Interactive</strong></td>
<td>41%*</td>
</tr>
<tr>
<td>(N=54)</td>
<td></td>
</tr>
<tr>
<td><strong>Mixed</strong></td>
<td>32%</td>
</tr>
<tr>
<td>(N=25)</td>
<td></td>
</tr>
<tr>
<td><strong>Static</strong></td>
<td>18%*</td>
</tr>
<tr>
<td>(N=22)</td>
<td></td>
</tr>
<tr>
<td>*p &lt; 0.001</td>
<td></td>
</tr>
</tbody>
</table>

The notion that learning is affected by the degree of interactivity is also supported by the measure of significant clicks. This measure correlates weakly with the transfer question scores for the two modes using the simulation (r = 0.244, p = 0.03). Significant clicks did not correlate significantly with the knowledge question scores. This provides further evidence that the degree of interaction with the simulation had an impact on learning, but only as measured by the transfer questions on the test. This suggests that the exploratory nature of the students’ interactive investigations supported learning that was different in nature to that of the non-interactive pages. Whilst there was no difference in their ability to answer questions of recall and understanding, when asked to apply their knowledge to a new situation, the interactive group showed greater ability.

### 3.6.3 Confidence (RQ1.4)

The fourth research sub-question posed was:

*RQ1.4: What are the effects of the domain knowledge confidence of the students on their interactivity choices and outcomes?*

The students in this experiment were not studying physics, hence it was of interest to gauge their confidence in answering the test questions before and after the experience. Each multiple-choice question had a menu from which students could indicate the degree of confidence that they had in their answer using a scale of: just a guess (scored 0), bit unsure (scored 1), and quite confident (scored 2).

The tally of these scores gave a maximum score of 16 for the pre-test, 20 for the post-test (including an extra 4 for the additional two questions, 9 and 10, on the post-test).

The pre-test confidence scores showed the students to have low confidence, as expected for their weak physics background, and a relatively large standard deviation. Table 3-6 shows the confidence scores alongside the test scores. The mean confidence score (for those students who also went on to complete the
post-test) was 5.17 out of 16 (or 0.62 out of 2 – a little below the ‘bit unsure’ level). There was no detectable difference between the confidence of those who elected to start in the interactive mode and those who elected to start in the static mode. Similarly, the pre-test confidence did not predict which students would elect to change modes later.

Table 3-6 Pre- and post-test mean % correct and confidence scores for the 3 modes (standard deviations in parentheses)

<table>
<thead>
<tr>
<th></th>
<th>Pre-test (Q 1 to 8)</th>
<th>Post-test (Q 1 to 8)</th>
<th>Post-test (Q 9 &amp; 10)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Test</td>
<td>Conf (2)</td>
<td>Test</td>
</tr>
<tr>
<td>Interactive</td>
<td>49%</td>
<td>0.66</td>
<td>68%</td>
</tr>
<tr>
<td>(N=49)</td>
<td>(21)</td>
<td>(0.48)</td>
<td>(19)</td>
</tr>
<tr>
<td>Mixed</td>
<td>50%</td>
<td>0.70</td>
<td>68%</td>
</tr>
<tr>
<td>(N=23)</td>
<td>(21)</td>
<td>(0.53)</td>
<td>(20)</td>
</tr>
<tr>
<td>Static</td>
<td>42%</td>
<td>0.56</td>
<td>62%</td>
</tr>
<tr>
<td>(N=16)</td>
<td>(19)</td>
<td>(0.50)</td>
<td>(23)</td>
</tr>
<tr>
<td>Total</td>
<td>48%</td>
<td>0.65∗</td>
<td>67%</td>
</tr>
<tr>
<td>(N=98)</td>
<td>(21)</td>
<td>(0.49)</td>
<td>(20)</td>
</tr>
</tbody>
</table>

∗p < 0.001

(Number are slightly lower than previously due to missing data in matching test scores to confidence ratings)

The students’ measure of confidence showed differences between pre-test and post-test (Appendix A-15). When analysed as paired samples for those who completed both tests (N = 98), students were significantly more confident of their answers to the post-test than the pre-test (means of 1.45 and 0.65, respectively; p <0.001).

This increased post-test mean level of confidence for the whole cohort (1.45) lies midway between ‘bit unsure’ and ‘quite confident’. This increase in confidence was not determined by the mode in which they interacted. A univariate analysis, with the pre-test confidence as covariate, showed the confidence score means for each mode to be very similar.

However, the confidence that students showed in their answers to the transfer questions (Q 9 and 10) differed depending on which mode they had worked in (Table 3-6). A one-way analysis of covariance was performed using the pre-test confidence scores as covariate (to remove any dependence on this variable) but this result was not significant (p = 0.171; Appendix A-16). The table shows that, whilst the mode of interaction did not appear to impact on the multiple-choice test item scores (Q 1 to 8), there was a trend for the confidence and learning gains measured by the transfer-style questions (Q 9 & 10) to increase with the degree of interactivity.

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7 From here on, each confidence score will be converted to a 0 – 2 scale, to make easier interpretation of meaning, as coded above.
In summary, students began the exercise with a very poor knowledge of the subject matter and with a feeling of very low confidence with the questions in the pre-test. All students achieved small learning gains as measured by the post-test and were more confident about their answers. However, these did not relate to the mode of interaction with the materials. The benefit of using the interactive materials was in the support they gave to a deeper form of learning – learning that enabled a transfer of skills to a new situation. For this style of question, students using the interactive features of the software showed improved learning outcomes as well as a (non-significant) higher level of confidence in their learning.

3.6.4 Analysis of affective measures

The data
In addition to the learning and interactivity data discussed so far, this experiment collected a significant amount of data relating to students’ learning goals, interest and emotions. This enabled the monitoring of what students brought to a learning task, to see how these personal orientation variables interacted with specific interest and emotions triggered by the task, and to determine what impact this had on their learning. These data were collected using the two probes that students responded to during their learning task providing a finer-grained view of how these variables changed through the exercise. This analysis was carried out by Ainley (2002a) and is described below in order to justify the conclusions I have drawn from the research that helped to define the direction of my further experiments.

Analysis of data
The analysis process was reasonably complex and hence I have represented it in a diagram that will be referred to in this discussion (Figure 3-15). The strategy of the analysis comprised three stages. The first stage was to identify experience profiles for students using the emotion and goal probes presented during the learning session (the ‘During’ data set in Figure 3-15). The next stage was to relate these profiles to learner characteristics derived from the goals, interest and pre-test data collected at the start of the session (the ‘Before’ data set in Figure 3-15). Finally, the profiles were related to learning outcomes (the ‘After’ data set in Figure 3-15).
'During' data set: Exploratory factor analysis was applied separately to each set of eleven probe responses to identify a smaller meaningful set of factors. Each of the two probes, with its 7 emotion items and 4 task goal items, yielded three factors with only minor differences in strength and order of factors across the two probes. The factors were labelled boredom, a bipolar factor in a bored-interested and 4 task goal items, which we have labelled three factors, with only minor differences in strength and order of factors.

Figure 3.15: Representation of Ainley's data analysis.

Data Sets

Before
- Learning goals (12 items)
- Topic interest (1 item)
- Physics confidence (8 items)
- Physics pre-test (8 items)

During
- Emotions probe 1 (7 items)
- Task goals probe 1 (4 items)
- Emotions probe 2 (7 items)
- Task goals probe 2 (4 items)
- Physics post-test (8 items)
- Physics post confidence (8 items)
- Physics transfer test (2 items)

After

Factor analysis

Factor analysis

Factor analysis

Factor analysis

ANOVA

Learner Characteristics

Factors
- Mastery
- Performance
- Work avoidance

Factors
- Topic interest
- Physics knowledge
- Confidence

Factors
- Boredom - Interest
- Mixed feelings
- Goals

Factors
- Boredom - Interest
- Mixed feelings
- Goals

Cluster analysis (hierarchical & k-means)

Cluster analysis (hierarchical & k-means)

Discriminant function analysis

Experience profiles
- Cluster 1
- Cluster 2
- Cluster 3
- Cluster 4
- Cluster 5

Differences in learning outcomes
dimension; mixed feelings, comprising the set of more complex feelings (challenged, frustrated, confused and surprised); and goals, which grouped the two performance and mastery goal items. From these factors student profiles were identified by using clustering procedures with the factor scores from each of the six dimensions (2 probes by 3 factors) as clustering variables. Five profiles were identified in this way. They are described later.

‘Before’ data set: The second stage involved using discriminant function analysis to determine specific functions that provided maximum discrimination between the profiles defined in terms of the experience reported during the task. Three achievement goal scores were derived from the 12 items of the learning questionnaire by performing a principal components analysis. An additional three scores were made up of the topic interest ratings, the physics pre-tests and the confidence scores. Two functions were produced. One was characterised as confident learner (strong positive correlation with mastery goal orientation and knowledge confidence, and negative with performance goal orientation), the other as interest in specific topic (very strong positive correlation with topic interest, and also with performance goal orientation as well as mastery goal orientation).

‘After’ data set: The final stage was to relate learning outcomes to the five on-task experience or probe. Probe profile was used as the grouping variable for analysis of effects on the post-test and transfer question scores. To control for prior knowledge physics pre-test scores were entered as covariate (ANCOVA).

Discussion of Ainley’s analysis

The cluster analysis of the three factors boredom-interest, emotions (or mixed feelings) and goals from the two probes, produced five experience profiles that showed interesting differences between students. These are best examined by comparing their mean scores for the probe items. Figure 3-168 shows the mean scores for the five group’s individual probe items relating to boredom-interest and emotions. The left-hand column of the figure shows the boredom-interest ratings for each group. This factor also included the work avoidance goal item ‘Right now I want to finish quickly’. The right-hand column shows the emotion ratings. A quick visual scan of these plots shows interesting similarities between the right-hand ‘emotion’ plots of groups A and C, in contrast to groups B and D; and also similarities in the left-hand ‘boredom-interest’ plots of groups A and B, in comparison to groups C and D. The final pair of plots, group E, are quite different from the others. These are discussed below.

---

8 For clarity, I have changed the numbering and ordering of the groups from Ainley’s (2002a) analysis. My groups A, B, C, D and E correspond to Ainley’s groups 1, 2, 5, 3 and 4 respectively.
Figure 3-16  Group mean Boredom-Interest and Emotion and scores
The top two left-hand plots show that both groups A and B had a similar profile in relation to the boredom-interest measures. Their factor scores relating to goals (not shown in the figure) also indicate that they both had relatively high task goals. The students were reasonably interested, yet showed a moderate amount of boredom. However their emotions (right-hand plots) were very different. Group A were particularly confused, challenged and frustrated, while group B were not. For both groups these emotions increased by the second probe. These groups were motivated but not engaged.

In a similar manner, the left-hand plots of groups C and D show both these groups to be bored and disinterested, wanting to finish quickly. Their goals factor scores show them to have very low task goals. Yet, as with the previous two groups, they distinguish between themselves by one of them (group C) giving extremely high emotion ratings and the other not.

Thus two pairs of groups have been identified, one pair reasonably interested and motivated (A and B), the other quite bored and unmotivated (C and D), each pair splitting into a group showing high emotional responses and a group showing very low emotional responses. What distinguishes these groups? The initial physics skills of groups A and C indicate that they were the least well prepared for the exercise. Table 3-7 shows the mean pre, post physics scores and transfer questions, as well as each group’s mean confidence ratings for each question (data for the table is taken from Ainley (2002a), with confidence scores added).

<table>
<thead>
<tr>
<th>Table 3-7</th>
<th>Means and standard deviations (in parentheses) for prior knowledge, learning measures and confidences: probe profile clusters, adapted from (Ainley, 2002a)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Probe profiles</td>
</tr>
<tr>
<td>Physics knowledge pre-test</td>
<td>(Max = 8)</td>
</tr>
<tr>
<td>Physics knowledge post-test</td>
<td>(Max = 8)</td>
</tr>
<tr>
<td>Transfer questions</td>
<td>(Max = 8)</td>
</tr>
<tr>
<td>Confidence score</td>
<td>(Max = 16)</td>
</tr>
<tr>
<td>n</td>
<td></td>
</tr>
</tbody>
</table>

Note: groups with same superscript significantly different at p<0.05.

From this table we can see that both of these groups (A and C) scored lowest on the pre-tests, on the transfer question test, and also had the lowest confidence scores. Groups B and D, in contrast, had the highest pre-test scores and relatively high post-test, transfer-test and confidence scores. The patterns
suggest that the difficulty of the task might have heightened the emotional responses of these students (e.g. confused, frustrated, challenged).

Group E is interesting in its difference to the other groups. This was the only group that showed a pattern of engaging with the task. They were interested, not bored and were reasonably confident of their pre-test answers. Even though they felt challenged and became increasingly more confused as the task progressed, they maintained their interest throughout the task. They did not become frustrated by it. They were the group who scored the highest on the transfer questions; this being significantly higher than the weakest group (group C). The discriminant function analysis showed them to have well above average confidence, similar to group C, but also having well above average interest in the topic, in contrast to group C’s very low interest.

The interesting question to arise from this analysis is why do groups having similar interests and task goals show such different emotional responses to the task. Why does one group maintain its interest in the face of mounting confusion and increasing challenge? A possible explanation relates to the skills that that each group brings to the task. In this experiment we did not measure this well in that we made only one skill measurement (pre-test) and had no record of how students perceived their skills during the exercise. This latter point is significant in that any mounting frustration or challenge is likely to come from the students’ perception of their skills, rather than their actual skills as measured by a test. The confidence items in the pre-test gave some indication of this perception, but it was a one-off measure relating to the underlying physics concepts, rather than the how well prepared the students felt for each task that they were to come across. As students struggled to interpret what they were seeing on the screen, we gathered no data as to how far each new challenge exceeded their perceived skill level. As a further complexity, the timing of the probes was determined by when students switched from one mode to another (or reached the half-way mark) and hence was not at the same point for each student. These issues are addressed in Experiment Two.

**Summary**

This analysis has shown the emotions felt by students to be both complex and dynamic – changing between the two measurement points in the learning task. The groups with the strongest difference in learning outcomes both reported being quite challenged and not very surprised, yet one group reported confusion and frustration throughout the exercise, whilst the other reported increased confusion while maintaining only a low level of frustration. The latter group reported the task as being difficult yet was engaged and improved their knowledge and understanding. Two of the other five groups also reported the experience as being both challenging and frustrating and did not achieve strong learning outcomes. The fifth group reported being not very challenged and their low level of frustration becoming stronger as the exercise progressed. Of significance here is the relation between challenge and frustration and their possible impact on engagement. This is a significant factor that is taken up in the next experiment.

### 3.7 Discussion

The main aim of this study was to examine the interactivity patterns that students chose as they worked through an online learning environment and to begin to understand the impact that such interactions
might have on their learning. Their interactions have been described in terms of a four-dimensional definition of interactivity. An underlying theme throughout this thesis is ‘control’. It was used here in the context of one of the four dimensions of interactivity, and also as an important aspect of a well-designed learning activity. In the previous chapter, ‘locus of control’ was introduced as the fourth dimension added to Laurel’s (1993) concept of ‘first-personness’ (frequency, degrees of freedom and interactive significance). In terms of learning theory, control was introduced in the context of ‘learner control’ – the placement of sufficient control in the hands of learners that they may take responsibility for their actions and construct (learn) new ideas in response to them.

How interactive was the environment presented to students in this study? The environment was highly interactive from two perspectives. First, it presented interactive options at navigational and functional levels. ‘Navigational’, being the most basic form of interactivity, refers here to the options that students had to move through learning screens. Although the content was designed to be worked through in a linear manner, there was the option of jumping backwards or forwards, as well as switching to view the opposite mode (interactive or non-interactive) at any time. Whilst many switched modes, few opted to jump back to review previous material. This can be interpreted in different ways: students felt content with what they had learnt and saw no gain in looking back; the materials didn’t suggest to them that backtracking would offer any useful information even if they were unsure of what they had learnt; or maybe the artificial nature of the learning situation meant that they were keen to work though the exercise, finish the test, and leave the activity. ‘Functional’ interactivity was presented via the nature of the WAVES interactive object. The students set their own goals of how to use it to answer the questions presented. It responded to their inputs and gave feedback in the form of images that they had to interpret in order to understand the physics. When this learning activity is viewed in this manner it suggests a reasonably high level of interactivity.

An alternative perspective is to consider the interactivity from its four dimensions of frequency, degrees of freedom, interactive significance and locus of control. From this point of view, this activity also rates as highly interactive. The frequency of interaction was quite high for students in the interactive mode – apart from page clicks, there were three settings to be adjusted on the simulation (source separation, wavelength and path display) and the ‘cork’ had to be moved around in order to gain any useful information to help understand the concepts. ‘Degrees of freedom’ is a slightly ambiguous concept in that it can be applied at a coarse-grained level to the whole environment (i.e. how many options are there at any time for the user to choose from) or at a fine-grained level (i.e. for any particular control element, how many settings or values are there that the user can choose from). At the coarse level there were many choices for the user to make: navigation, switching modes, options within the simulation. At the finer level, the simulation itself offered many degrees of freedom. For example, the wavelength setting had four possible values, the source separation four, and the position of the cork many hundreds.

The data recorded in the experiment show how the students reacted to the interactive opportunities presented. Naturally, the interactive-mode students showed more highly interactive patterns of use and also spent a longer time on the activity, consistent with the research of others (Haseman et al., 2003). Their frequency of mouse clicks was greater, the simulation offered a more significant response to their
actions as well as a higher number of degrees of freedom, and the locus of control was more firmly in their hands as they took control over the simulation. The impact of this greater interactivity was some improvement in learning, but only slight. Consistent with comments made by others (Jonassen, 1988) it appeared that the more interactive nature of the simulation gave better support to students when they were required to invoke a ‘deeper’ style of learning, compared to the simple recall of fact. This is likely to be due to, not just the interactive nature of the simulation, but also the control that students were given to explore the specific instances necessary to understand the questions presented. The increased ‘locus of control’ also gave them greater ‘learner control’.

In this study, ‘locus of control’ more aptly described the students’ interaction with the simulation presented by the software than their control over navigation. It added to a measure of interactivity by describing where the control lay between student and system. This is not particularly useful when the user’s choices were simply navigating pages, but when presented with the simulation we could examine where the control was focused and how it moved between student and system. If the control was heavily weighted towards either student or system, then the environment had reduced interactivity – either the student was in control regardless of the output from the computer, or the computer was in control with little chance for the student to respond. Both of those situations were non-optimal as far as maximising interactivity was concerned. Interactivity, in the sense of a dialogue, needed an appropriate balance between student and system (Borsook & Higginbotham-Wheat, 1991; Weller, 1988).

The WAVES simulation was one in which students had a well-balanced level of control with the system. Students could click several options and get an immediate response (wavelength change, paths on or off, source separation change) or they could drag the cork and get continuous feedback via the graphs. Neither party was excessively ‘in control’. For example, there was no interaction in which the student would change an input and then have to wait while the system outputted various sets of data, or while the system directed the student to carry out the next action. Hence, for this simulation, I regard the locus of control to be firmly with the students, and the students to be receiving rapid responses from the system. They had to make a decision as to which input to change, effect the change, view the immediate response and interpret its meaning in terms of their learning. In terms of Norman and Draper’s (1986) stages of action, this is a very tight evaluation/execution cycle. What the students observed related closely to what they should have been looking for, as prompted by the text. Given that there were several inputs to change, that these could be easily and frequently changed by the student, and that at least one of them resulted in quite a significant change to the output display (graphs), we can conclude that this was a highly interactive object offering the student significant control.

‘Learner control’, in this context, refers to the degree to which the student was given freedom to make and carry out choices regarding navigation, interactions, and how to approach the learning required for the prescribed task (Weller, 1988). In other contexts the phrase might offer choices relating to the content to be learnt, in addition to how it is to be learnt, but in this study the learning content was non-negotiable. Learner control is an important feature of any learning activity, but is does not indicate a measure of interactivity. In this study, the interactive-mode learner had no control over what was to be learnt, had little control over how it was to be learnt, and had reasonably high control over what to look at within the
simulation, but all within a fairly restricted environment. In short, one could argue that the interactive-mode learner had more control than the non-interactive-mode learner, but only minimally so.

One issue relating to control that was not explored here was whether the amount of control was optimal for learning. The interactive-mode environment put the learner firmly in control of the WAVES simulation – possibly too much control for many to benefit from. The simulation’s response to an action was immediate and visual, but it required interpretation. It did not suggest whether the student’s exploration was ‘right’ or ‘wrong’, ‘appropriate’ or ‘inappropriate’. The learning effect on the student might have been improved had the simulation been able to take on more control at times and guided the student as to how to move the cursor in order to see outputs that might help them interpret the physics. This illustrates one of the difficulties in trying to predetermine how much control the student has or should have. Although the simulation did not offer the outputs suggested above, in some ways the supporting text on the screen did, in that it suggested what to explore with the simulation. In order to gauge the degree of control we need to take a holistic approach to the whole environment.

This discussion suggests that a student’s perception of control may be a more useful concept than trying to decide objectively the degree of control offered by a particular object or environment. Whilst some students might have perceived the freedom to explore as synonymous with control, others may have felt threatened and been more comfortable, and hence more in control, with fewer options and fewer ways in which to ‘go wrong’. I did not question students as to what degree of control they felt that they had – that was to be followed up in the next study.

The analysis carried out by Ainley has raised several issues as being important in examining students’ learning in this online environment. We have seen student groups for whom the level of challenge appeared to relate to whether the students experienced boredom or frustration. For some groups heightened emotions suggested an anxious experience that increased through the task. For one group, whose emotions were not at either extreme, something supported their engagement with the exercise and maintained their interest and confidence through to the end.

There are still several unknowns relating to this study. We do not understand what roles were played by the attitudes and skills that the students bought with them. Clearly they started with a range of emotions, interests in the topic, and competencies, but these changed during the task and we only caught snapshots at two instances. Challenge appears to be an important emotion: too high related to frustration, too low to boredom, and for one group, a middling value accompanied engagement.

The data on interactivity was detailed and suggested that students adopted diverse strategies, but gave little insight into how these strategies impacted on their learning. Use of the simulation did not appear to affect the learning of straightforward knowledge, but appeared to have a positive impact on the more challenging transfer-style questions, in agreement with suggestions put forward by Jonassen (1988) and experiments carried out by Mayer et al. (1999). One group of students, distinguished by increasing task performance goals and high engagement, performed well on these transfer questions. There is a suggested association here between an interactive learning object, engagement, and deep learning – but one that is present for only a small fraction of the students.
3.8 Summary and conclusion

From this experiment I have explored a range of issues relating to interactivity and gained two significant outcomes. First, I have established a system whereby students can be monitored as they work through a Web-based learning task and have information about them gathered as they progress. The monitoring provides data on their page navigation, time on tasks, and their interactivity within a simulation. Survey and test data can be collected and probe data logged at specific points as they progress through the task. From these data a rich picture can be formed of each student’s progress, activity and performance. By using this system it was observed that an interactive path through learning materials was preferred by most, but not all, the students – many chose a textbook style and opted not even to look at the simulation at all. Most worked through the materials in a linear path. This in itself is interesting in that not all students were attracted by the ‘lure’ of interactivity. There was a link between the amount of interactivity and learning outcomes. This was subtle and suggested that an interactive simulation mode has advantages over a non-interactive mode for a particular type of learning involving the transfer of knowledge. No such advantage was observed for simple knowledge-based learning.

Second, I have obtained insights into the dynamics of motivation and goals during a learning task. Rather than using interviews or questionnaires, students’ emotions and goals were monitored as the exercise progressed. The initial state of students was clearly not adequate to predict their engagement with a task. Even though I had information on their learning goals, physics background, confidence and topic interest, these attributes together with their feelings changed significantly during the task.

This exploration highlights the need to improve our understanding of the roles that challenge, frustration and other emotions play in these situations. For example, did one group become more frustrated because the challenge remained too low for their individual skill levels, whilst another group became more frustrated because the challenge increased yet their skills were ill equipped to cope?

This research suggests that a promising approach to unlock the relation between learning and interactivity might be to measure more carefully some of the emotional characteristics of students and to monitor more closely how they change during a learning session. Whilst the approach taken in this experiment began this process, it has left several questions open and suffered several deficiencies that need to be addressed.

From the interactivity perspective, students were able to choose between two modes of working and decide if and when they would switch between modes. To establish whether the level of control offered by each mode was a significant contributor to their engagement with the task, I need to predetermine the mode in which students work and measure their perception of control and how they work in these different conditions.

The background of the students in this first experiment was diverse and not controlled; they had different skill levels and hence experienced different challenges during the exercise. This was a contributing factor to the profiles of the student groups, which related, in part, to the students’ prior knowledge and confidence in their physics. To identify the impact of this, students with stronger physics background need to be compared to those with weaker knowledge.
The data analysed by Ainley cast a wide net to measure several emotions, but at insufficiently frequent intervals. The five different groups identified had very different mixes of task achievement goals, physics competencies, topic interest and intensities of emotions. From these, one group was identified whose emotional mix suggested that they engaged with the learning materials and learnt from them. However, no established model was used to identify their engagement, nor did I identify what they became engaged with. Was it the simulation? The waves topic? Or maybe the novelty of the situation they were immersed in? Although I developed a tool to explore the mechanical interactions of the students, I did not have an adequate method to explore the way in which they engaged with the materials.

Finally, I gathered valuable information from the two emotion probes, but these occurred only twice during each student’s session and happened at times determined by their activity – not at regular predetermined times. The interactivity patterns recording students’ movement through the learning exercise presented what the students were doing, and showed some impact on their learning, but did not give any insights as to how they were reacting to the learning materials at the time. We need to obtain a more fine-grained view of the process of students’ movement through a learning exercise that would allow closer tracking of their emotions and hence develop a better understanding of situations that engage their learning. To do this, probes that appear more frequently and at regular intervals are required.

In summary, the main research question addressed by this experiment was:

**RQ1: What are the influences on learner interactions in an online interactive learning task?**

The question was broken down into questions relating to students’ interactivity patterns and choices, and the impact that these choices had on their learning outcomes. The outcomes from the experiment showed that only a minority of students elected to follow a static sequence of activities when an interactive one was available. These students were those with lower ability or confidence in the subject area. The degree of students’ interactions with the materials varied significantly, as did the time that they spent actually using an interactive object. In the kind of exercise provided, the facility to backtrack and review earlier material was not commonly used. The learning of basic knowledge was not dependent on the sequence a student elected to follow. However, those who immersed themselves in the interactive features were likely to perform better in test questions requiring them to transfer their knowledge to different contexts.

In the next experiment I addressed the deficiencies identified earlier by refining both the data collection tool as well as the nature of the data collected. Two cohorts of students with differing skill backgrounds were used and were pre-allocated to a learning task with different expected levels of control. A theoretical model was chosen to help refine the ways in which engagement was identified. The data collection tool was modified to make more frequent measurements and thus help identify the process of students moving through the learning materials. Such a process view will be seen to lead to a better understanding of the role that interactivity plays in maintaining students’ interest and engagement.
Summary of findings for Research Question 1

RQ1: What are the influences on learner interactions in an online interactive learning task?

RQ1.1: What are the interactivity patterns that students show whilst working through an interactive learning environment?

F1.1: For the activity provided, students showed a great variety of patterns of interactions and completion times. Those who visited the interactive materials took slightly longer to complete the exercise commensurate with the time spent actually using the simulation. Few availed themselves of the option to vary their sequence through the activity.

RQ1.2: What are students’ patterns of choice between navigation paths offering differing degrees of learner control?

F1.2: The availability of an interactive option in the learning materials was not attractive to all students. A minority elected not to look at the interactive version at all. Whereas most students stayed with their initial choice, about one quarter swapped modes repeatedly as they progressed through the activity.

RQ1.3: What are the effects of interactivity on learning outcomes?

F1.3: Students using the interactive materials showed improved learning outcomes in transfer-style questions compared to those in the static mode. No difference in learning outcomes was observed for questions relating to recall.

RQ1.4: What are the effects of the domain knowledge confidence of students on their interactivity choices and outcomes?

F1.4: The confidence of the students increased after completing the activity but it did not relate to their mode of interaction. There was a (non-significant) suggestion that the greater use of interactivity led to greater increase in confidence for the transfer-style questions.
Chapter 4

Flow in a learning environment

“...students do not experience alienation and disconnection during all encounters with learning. Certain conditions may promote excitement, stimulation, and engagement in the learning process.”

(Shernoff, Csikszentmihalyi, Schneider, & Shernoff, 2003)
4.1 Introduction: Flow as a framework

The experiment described in the last chapter used the concept of interactivity defined in terms of frequency, range, significance, and locus of control. These dimensions describe how a learner interacts with a system by considering the nature and impact of the interaction and the locus of control between partners in the dialogue at any point in time. In addition, the probes into the emotional and affective states of the learner showed that these are important variables in any learner interaction that are often missing from considerations of interactivity on learning. Laurel described these missing elements as comprising a ‘more rudimentary measure of interactivity’ (Laurel, 1993 p. 20). These elements need to account for the emotions and motivation of learners as they go about their task. They need to describe what will engage the learner to stay focussed on the task at hand and feel sufficiently immersed to interact with the ideas being presented for learning.

To deepen our understanding of the roles played by interactivity in a learning context we need to adopt a theoretical model on which to base further study. The model needs to accommodate the salient features arising from the Experiment One. That is, it needs to describe affect – the moments of enjoyment, the moments of frustration, the possible times of boredom. It also needs to capture the sense of engagement that students experience as they take control of their environment and are challenged to create new knowledge and develop new ideas. It should recognise the importance of exploration and yet distinguish itself from play – two attributes that are so often associated with computer-based environments.

Flow theory (Csikszentmihalyi, 1975) provides such a theoretical framework on which to base the following studies. In this chapter I present the concept of flow and its applications in several diverse areas, discuss the problematic issues relating to the measurement of flow and then explore the relevance of flow in learning contexts such as the one used in the subsequent two experiments.

4.2 The concept of flow

In 1975 Csikszentmihalyi coined the term ‘flow’ to represent ‘optimal experience’ events in which a person enters a mental state of complete absorption or engagement in an activity (Csikszentmihalyi, 1975). Writings on flow have signalled the expectation that flow is related to interactivity through control and intrinsic interest (Trevino & Webster, 1992) and that it is particularly important in educational settings (Clarke & Haworth, 1994; Csikszentmihalyi, 1975; Csikszentmihalyi, Rathunde, & Whalen, 1997; Sernoff et al., 2003; Webster et al., 1993). This is supported by more recent research showing that flow occurs more often during study and schoolwork than other daily activities (Massimini & Carli, 1988). In spite of this, there is no well-formed model of flow that can be applied directly to learning nor a well-established measurement technique in this domain. In this section I present the relevant research on flow leading towards the representation of flow to be used in this thesis.

4.2.1 Describing flow

Flow describes a state of complete absorption or engagement in an activity. It is a highly enjoyable state. The genesis of the concept came through Csikszentmihalyi’s reflections on how totally enthralled an artist
becomes when painting, yet this deep engagement is not in anticipation of a reward, such as the finished painting (Csikszentmihalyi, 1975). Often, on completing one painting, the artist would put the canvas aside and begin another. The motivation was the intense enjoyment of the activity for its own sake; one, which Csikszentmihalyi (1975) reflected, was common in many activities in life.

This concept of flow was initially explored through the study of people involved in common activities such as rock climbing, dancing and chess (Csikszentmihalyi, 1975). The concept has since been studied in a wide range of endeavours spanning the disciplines of HCI, psychology, information systems and education. For example: Web use and navigation (H. Chen & Nilan, 1998; H. Chen, Wigand, & Nilan, 1998; H. Chen et al., 1999; Pace, 2000); Web marketing (Hoffman & Novak, 1996; Novak et al., 2000); in everyday life (Csikszentmihalyi, 1975; 1997); in group work (Ghani et al., 1991); technology use in information systems (Agarwal & Karahanna, 2000; Artz, 1996); in HCI (Webster et al., 1993); and in instructional design (Chan & Ahern, 1999; Konradt & Sulz, 2001; Konradt, Filip, & Hoffmann, 2003).

A ‘flow activity’ is one in which the mind becomes effortlessly focussed and engaged on an activity, rather than falling prey to distractions. Flow is not an ‘all-or-nothing’ state, nor is it constant, but can be thought of as forming a continuum from no flow to maximum flow which people move in and out of as control, content and motivation vary (Hoffman & Novak, 1996). Csikszentmihalyi (1975; 1993) originally summarised flow experiences as comprising nine elements. Some of these are requirements for flow; others reflect the flow experience itself:

- a clear set of goals that require appropriate responses;
- feedback that is immediate and relevant;
- skills required for the task that are fully involved in overcoming a challenge that is just about manageable.
- the activity involves merging of action and awareness;
- distracting thoughts or irrelevant feelings are excluded;
- the person has a sense of control;
- the activity becomes worth doing for its own sake (‘autotelic’);
- there is no self-consciousness;
- awareness of time might become distorted.

A fundamental feature of a flow experience is an activity that offers a person an appropriate balance of challenge and skills. If the challenge is too great for the person’s skills, he or she will become frustrated; lose interest and stop flowing. If the challenge is too low, the activity ceases to be interesting and boredom can result. The goals for the activity must be clear and provide quick and unambiguous feedback in order to flow. The resulting focused concentration can lead to a ‘merging of actions and awareness’ in which ‘one does not have enough attention left to think about anything else’ (Csikszentmihalyi & Csikszentmihalyi, 1988 p. 32). Other common features of flow are a distorted sense of time, either seeming much longer or much shorter than it actually is, and, because of the deep concentration, the
person can lose the awareness of self that often intrudes into one’s consciousness. The combination of these effects leads to a feeling of intrinsic enjoyment – an autotelic experience.

The nature of flow is elegantly put by Massimini:

‘The stream of ordinary experiences, ranging from the faintly pleasant to the boring, and the anxious, is made up of a random collection of discordant notes. Occasionally the notes fall into a harmonious chord – when that happens, information in the consciousness is ordered, and we experience flow.’


4.2.2 Refining the concept of flow

The nine elements listed above provided a way to operationalise flow based on the degree to which they were present for an individual (Csikszentmihalyi, 1975). Later studies recognised that some of these elements were prerequisites of flow, and others represented aspects of the experience itself. Hoffman and Novak (1996) identified four antecedents of flow, two categories of flow and four consequences of flow. Two of these antecedents are considered to be critical: that skills and challenges be perceived to be congruent and above a critical threshold, and that focused attention is present. This concept of the balance of challenge and skills is central to flow theory. It was proposed in Csikszentmihalyi’s (1975) original work and was later refined to require to these variables to be above a mean threshold value (Csikszentmihalyi & Csikszentmihalyi, 1988; Csikszentmihalyi & LeFevre, 1989). This issue is discussed in more detail in Section 4.3.

Hoffman and Novak (1996) found that flow will be enhanced if two additional antecedents, interactivity and telepresence, are also present. ‘Telepresence’ is the mediated perception of an environment (Steuer, 1992), in contrast to ‘presence’, which refers to the natural perception of the immediate physical environment. Telepresence is induced by interactivity (Sheridan, 1992) and together they enhance flow (Hoffman & Novak, 1996). From this theory, the consequences of flow are expected to be ‘increased learning, increased perceived behavioural control, increased exploratory and participatory behaviour, and positive subjective experiences’ (Hoffman & Novak, 1996).

Chen, Wigand and Nilan (1999) went step further and categorised flow into three stages labelled antecedents, experiences and effects. They based their stages on the nine elements of flow listed above. The first stage, antecedents, comprised a clear set of goals, timely and appropriate feedback, and, most importantly, a perception of challenges that are well matched to the person’s skills. The second stage, experience, comprised a merging of action and awareness, a sense of control over the activity, and concentration. The final stage described the individual’s inner experience: loss of self-consciousness, time distortion, and a feeling that the activity becomes worth doing for its own sake (‘autotelic’).

Whilst both these views of flow have much in common, they also have their differences. They agree on the importance of an appropriate balance of challenge and skill as an essential precursor to a flow experience. Chen et al. emphasise the importance of clear goals and immediate feedback. Hoffman et al. agree that goals are important and describe two categories of flow: ‘goal-directed’ and ‘experiential’.

These categories reflect the different tasks in which the users may be engaged. A ‘goal-directed’ activity is allied with extrinsic motivation and is characterised by the user having a particular task in mind, such
as searching for an item on a Web site. An ‘experiential’ activity has a stronger exploratory component and hence more intrinsic motivation, such as general browsing of a Web page. Interestingly, Hoffman reports other research that presents conflicting opinions as to which of these two types of activities resulted in greater positive experiences for the users.

The interactivity and telepresence of Hoffman et al. aligns with the merging of action and awareness of Chen et al. Similarly the positive subjective experiences of Hoffman et al. concur with the autotelic experience and distortion of time of Chen et al. All agree on the importance of a sense of control and a state of concentration during the tasks.

The above discussion illustrates how flow is regarded as a malleable construct – one that has no agreed precise definition, yet it represents a state that can be identified and offers value in the description of interactive environments. Its inclusion of control and focused concentration give it a valid place in learning environments where ‘learner control’ and ‘engagement’ are central concepts. It also represents other important attributes desirable in any learning environment: clear goals together with immediate and helpful feedback; appropriate challenges matched to the individual’s skills; a degree of intense concentration. The more experiential aspects of intense enjoyment, not being distracted by one’s environment and getting ‘carried away’ by the task, are highly desirable and sought after outcomes by any designers of educational activities.

4.2.3 Flow versus play

Flow is often compared to the notion of ‘play’, which has been described as the ‘flow experience par excellence’ (Csikszentmihalyi, 1975 p. 37). Playfulness is difficult to define and measure (Carroll & Thomas, 1988; Rieber, 2001) but is often used to represent a person’s subjective experiences that involve perceptions of pleasure and involvement (Starbuck & Webster, 1991) which can enhance learning (Miller, 1973). Whereas playfulness can contribute to creativity (Csikszentmihalyi, 1975) it can also have negative consequences such as lengthening task completion times due to exploratory behaviour (Miller, 1973; Sandelands, 1988). Webster, Trevino and Ryan (1993) note that playfulness may result in longer time for task completion, even to the extent of neglecting other tasks. Whereas this might not be a problem in a marketing context in which one wants users to explore a site (Hoffman & Novak, 1996) it could be of concern in a learning context where deliberate learning goals have been set by a designer with the specific intent that they be achieved. Although this is an issue with both play and flow, we need to consider the concept of play and distinguish it from flow.

Webster, Trevino and Ryan (1993) use flow as a theoretical foundation on which to explore playfulness with the use of technology in the workplace. Whilst they do not clearly distinguish between the concepts of flow and playfulness, their experiments imply that they regard playfulness as being affected by perceptions of flexibility and modifiability of the software, experimentation and a sense of enjoyment that leads to further voluntary interactions.

Play is an example of an optimal flow experience which relates to learning (Miller, 1973; Rieber, 2001; Rieber & Matzko, 2001b; Webster & Martocchio, 1992; Webster et al., 1993). Rieber and Matzko (2001a; 2001b) consider play in a physics learning context and define serious play as being an intensive
and voluntary learning interaction consisting of both cognitive and physical elements. Flow activities also often involve physical elements, for example, in chess, rock climbing, surgery (Csikszentmihalyi, 1975), but there are also flow activities that require no such physical interaction with an object, for example, a conversation, reading a book, watching a movie. Given the common features between play and flow, this suggests that a flow activity might be regarded as being either playful (e.g. chess) or not (e.g. surgery) distinguished by the motivation and goals of the person – for leisure or for work. Rieber (2001) sees play as a means for understanding the relationship between learning and motivation in a holistic manner and concludes that they are inseparable with motivation being the more important of the two. He describes a rewarding learning experience as being satisfying and enjoyable. Whether being carried out by a child or adult, he regards the best word to describe this as being ‘play’.

The distinction in meaning between flow and play are subtle but significant. We can consider flow to extend the sense of playfulness (Csikszentmihalyi, 1975; Csikszentmihalyi & LeFevre, 1989; Miller, 1973) by incorporating the extent to which users perceive a sense of control, focused attention and cognitive enjoyment (Webster et al., 1993). It fits well with a constructivist model of learning by adding these three attributes beyond those of play (Webster et al., 1993). The tight link between goals and feedback drives and supports learning activities. Flow suggests a greater sense of purpose and intention, whereas play emphasises enjoyment and activities that might lack direction and outcome (Ghani, 1995). Hence, in this thesis I have used the term ‘flow’, and not ‘play’, and use the well developed constructs that it brings as the theoretical underpinning of my research.

4.2.4 Flow models & representations

Three broad approaches have been taken to construct models of flow. Causal models identify some of the inputs that might support or encourage flow. Research in this area often explores only some of the causes resulting in useful, but incomplete, models of flow (for example, Ghani et al., 1991; Trevino & Webster, 1992). Conceptual models attempt to build a complete conceptual description of flow usually based on structural equation modelling. Such models tend to be complex, but offer valuable insights into the factors at play and suggest studies to explore their interactions (for example, Novak & Hoffman, 1997; Novak et al., 2000). Finally, flow channel segmentation models represent flow as a set of states defined by the balance between challenge and skills (Carli, Fave, & Massimini, 1988; Massimini & Carli, 1988; Novak & Hoffman, 1997).

Each of these three representations of flow provides insight that helps shape the conceptualisation used in this thesis, and also motivates the two techniques that will be used to measure flow.

Causal models

Causal models seek to inform us how different activities might support or encourage flow in an individual. They usually require a measurement of flow based on the experience perceived by an individual and relate to this several variables of interest that might affect the extent to which flow happens. Given the task oriented nature of the workplace and of Web use, many studies have taken the workplace environment as a basis from which to investigate flow (Allison & Duncan, 1988; H. Chen &
Causal models differ in the way the flow experience itself is measured. Ghani, Supnick and Rooney (1991), in their exploration of the differences in flow between computer-mediated groups and face-to-face groups during a work-related task, measured flow as the sum of *enjoyment* and *concentration* measures. Skill, perceived control and perceived challenge were used as inputs to their model. Trevino, Webster and Ryan (1992; 1993) used two similar constructs named *cognitive enjoyment* (encompassing curiosity and intrinsic interest) and *attention focus*, but added *control* as a third dimension of the experience. Ellis, Voelkl and Morris (1994) regarded enjoyment and positivity of affect as more reliable indicators of flow. All regard control as a key factor, but Trevino et al.’s inclusion of it as part of the flow experience itself highlights the conceptual difficulties researchers have had in defining precisely the nature of the experience as distinct from the factors that cause the experience.

Ghani, Supnick and Rooney’s (1991) study examined the differences in flow between computer-mediated groups (CM), and face-to-face groups (FTF) given a simple work-related task. Flow was found to be more intense for the computer-mediated group than the face-to-face group, the difference being attributed to a greater perceived challenge from the computer-mediated group. Flow related positively to perceived control, and skills, but there was a positive relation for challenge only for the face-to-face group, not the computer-mediated group. This highlights differences between flow behaviour in computer-based environments compared to non-computer environments. Trevino, Webster and Ryan (1992; 1993) also confirm the role that computer technology, and its ease of use, plays in enhancing flow in the workplace compared to non-technological activities.

These researchers present confused findings on the role of skill in supporting flow. Ghani, Supnick and Rooney (1991) used path analysis to develop a model in which skill has a direct effect on flow for the computer-mediated group but only an indirect one through perceived control for the face-to-face group (Figure 4-1). In contrast, Trevino and Webster (1992) found skill to negatively influenced flow. This apparent contradiction emphasises the importance of tightly integrating challenge-skill measures in order to make valid predictions of flow. Trevino and Webster attributed the negative influence of skills to the participants’ relatively high average computer skill level. They did not measure the perceived challenge that the participants felt to match their skills and hence could not establish how the balance of challenge and skills might have contributed to flow.

![Figure 4-1 Model from Ghani 1991 (Ghani, Supnick and Rooney 1991)](image-url)
Ghani, Supnick and Rooney (1991) did measure challenge and found that it had direct impact on flow for only one of the groups (FTF). Whilst this result might indicate a difference in the way that such groups work, it was confounded by the role of the technology in the experiment. Whereas the tasks presented to both groups were the same, the computer-mediated groups had the added complexity of the computer to deal with. However, the measurement instruments for challenge, skill and control (Likert scale questions) did not distinguish whether the level of skill that the computer-mediated group reported related to the skill required to carry out the task, or the skill in manipulating the computer. Similarly, their level of perceived control might have related to the task, the computer or, in the face-to-face case, the other participants. This need to distinguish between the cognitive task at hand and the physical environment (software, computer, people) is a theme that we will see emerge through other aspects of this literature review.

The different impact that challenge had on flow for the two groups suggests that it was not clear to the participants what the term ‘challenge’ related to. Flow theory is clear that the challenge refers to the level of challenge that the person perceives necessary to carry out a specific task. The meaning of ‘challenge’ and ‘skills’ must be situated in time and space depending on what the participant is doing and what goals they are pursuing (H. Chen et al., 1999). This issue is discussed further in Section 4.3.3.

The concept of control is clearly an important, and perhaps the most salient, element of the flow state (Csikszentmihalyi, 1975 p. 191). In this sense, Csikszentmihalyi regarded control as ‘a temporary sense of mastery based on a selective structuring of the world’ (Csikszentmihalyi, 1975 p. 192). In a computer environment control encourages exploratory playful behaviour by adapting to feedback from the individual in a manner not possible with more static media (Webster et al., 1993). In the above model Ghani, Supnick and Rooney (1991) regard control as a causal input to flow, as they also do in a subsequent study which collected survey data from computer-users to explore how task characteristics affect flow and exploratory use (Ghani & Deshpande, 1994). In this later experiment, they found perceived control and challenge again had strong impact on flow, although the impact from control was less strong for ‘low task scope’ users – that is, those doing work which had lower motivating potential, less variety, less autonomy (Griffin, Welch, & Moorehead, 1981). Flow was shown to lead to greater exploration and extent of use. Again, this study has a weakness in the nature of the survey questions used to collect the data. Whilst their measure of flow, the sum of enjoyment and concentration, was straightforward using a simple survey, they did not capture the richness of the flow concept – merging of action and awareness, lack of self-consciousness and a sense of time distortion. It is possible that it was not flow that was being measured here at all. The single item used to measure challenge was very non-specific, relating to the general challenge of using computers rather than any particular challenge relating to the tasks at hand.

Using control as one of the dimensions of the experience of flow itself (H. Chen et al., 1999; Csikszentmihalyi, 1975; Trevino & Webster, 1992; Webster et al., 1993) helps distinguish flow from a simpler construct such as that used by Shernoff, Csikszentmihalyi, Schneider and Shernoff (2003) describing concentration, interest and enjoyment. Incorporating control helps distinguish between flow and play by adding a sense that the environment is responding to deliberate, considered actions rather
than playful actions which, while still being enjoyable, might not be desired or intentional. In a learning context, the addition of control adds a valuable measure that draws on the notion of learner control.

As was observed with the terms ‘challenge’ and ‘skills’, it is important to consider the participants’ interpretation of the term ‘control’ (H. Chen et al., 1999). In flow theory, control relates to a sense of confidence, a sense of knowing about what one is doing, rather than notions of loss of self or timelessness. Chen’s (1999) experiment related to flow in a Web environment and the interpretation of control was often related to control over the environment itself, or navigation and information retrieval. The former of these suggests a higher level of control than that relating to the task itself. Again there are issues relating to how the term ‘control’ is being interpreted by participants, similar to the issues relating to challenge and skills. Interestingly, 20% of respondents did not know what a sense of control meant to them.

Webster’s notion of cognitive enjoyment (Webster et al., 1993) is incorporated in Ghani’s (1995) concept of flow as cognitive spontaneity (see Figure 4-2). This is recognition of the distinction between perceived task challenges, skills and control, and factors relating to individual traits. Cognitive spontaneity is the most important facet of general playfulness (Webster & Martocchio, 1992). In Csikszentmihalyi’s original work he describes an autotelic experience as one that is intrinsically rewarding – enjoyable for its own sake (Csikszentmihalyi, 1975). He also defines autotelic activities as those that maximise intrinsic rewards to the participant and autotelic personalities as people who are able to enjoy what they are doing regardless of any external rewards (Csikszentmihalyi, 1975; Logan, 1988). Consequently, a complete model of flow should incorporate cognitive aspects and flow measurements should consider personality differences (J. E. Voelkl & Ellis, 1998). Ghani (1995) addressed this through the addition of cognitive spontaneity as an input to flow in his model, as shown in Figure 4-2.

![Figure 4-2 Ghani’s (1995) model of flow](image)

The focus of this thesis is the nature of the learning tasks and the students’ interactions with them rather than measuring personality traits of the individual. The learning tasks were designed to maximise the opportunity for flow by encouraging autotelic experiences. The autotelic aspects of the activities were provided by their playful and exploratory nature.
Conceptual models

An alternative approach to defining the concept of flow has been to develop comprehensive conceptual models, often using structured equation modelling techniques (Novak, Hoffman, & Yung, 1997; Novak et al., 2000). These are complex models but offer insight into a flow study by virtue of their exploration of relations between different variables.

Hoffman and Novak (1996), working within a marketing context, proposed a conceptual model for flow within the hypermedia environment of the Web. After toying with the concept of ‘play’ as a parallel construct to flow, they proposed a model that initially presented interactivity as a precursor to flow and used Steuer’s (1992) model of mediated communication that suggests that the primary relationship is ‘not between the sender and the receiver, but rather with the ‘mediated environment’ with which they interact’ (Steuer, 1992). This introduced the idea of telepresence, which is the ‘mediated perception of an environment’. It refers to the interaction that a user has with the environment. The two components of telepresence are the perception of the physical environment, and the environment defined by the computer-based interaction. The strength of telepresence refers to how much one feels present in the computer environment rather than in the physical environment. Steuer (1992) also added the construct of involvement; this provides some measure of intrinsic motivation and is influenced by whether an activity is goal directed or experiential.

In Hoffman and Novak’s (1996) model the consequences of flow were increased learning, perceived behavioural control, an exploratory mindset and positive subjective experience. Later, Novak, Hoffman and Yung (1997) used structural equation modelling to revise their model based on data collected from a large survey of Web users. This model (Figure 4-3) was specifically formulated to represent the general customer experience in online environments and introduced some significant changes. This illustrates how the concept of flow can change depending on the purpose to which it is being used. Play was seen to take on a different role than flow leading to lower control and lower positive affect and was later dropped from the model, as shown in the figure. Focussed attention did not directly predict flow. In setting up this revised model they kept skills, challenge, interactivity, telepresence, arousal and focused attention as being always antecedents, and positive affect and exploratory behaviour as always consequences of flow. Interactivity was presented as three components: speed, range and mapping. ‘Range’ has the same meaning as defined in Chapter 2, however, ‘speed’ simply refers to how quickly the system responds to the interaction, and ‘mapping’ refers to the naturalness of the interaction. Of these, only speed remains in the final model and is supported by others as having indirect impact on flow (Skadberg & Kimmel, 2004). Whilst speed can be important for online studies where server access might be slow, in situations where network access is fast this is unlikely to have significant impact. Control was moved from being a consequence of flow to being an antecedent.
Figure 4-3 Simplified representation of Novak, Hoffman and Yung’s (2000) revised conceptual model

This is probably one of the most well-researched and complete models of flow. Although it is specifically designed to relate to marketing variables, such as product information search and online shopping behaviours, it offers valuable comment on the relations between the various constructs. However, such modelling must be treated cautiously since it relies on broad Web surveys which, by their very nature, represent a particular group of users within the online community, and draws on none of the rich data available from observations and interviews.

It is interesting to contrast this model with the limited set of constructs described by others who researched particular aspects of flow (H. Chen et al., 1999; Ghani, 1995; Ghani & Deshpande, 1994; Webster & Martocchio, 1992; Webster et al., 1993). Some of these researchers also found skill, challenges and control to be important antecedents to flow, but with slight variations (1994; Ghani et al., 1991; Webster & Martocchio, 1992; Webster et al., 1993). We have seen earlier how Ghani, Supnick and Rooney (1991) found that skill led to control which led to flow. Skill and challenge also directly affected flow. Webster also regarded control as an antecedent and give support to this position by arguing that computer technologies provide a feeling of control through clear goals and feedback, something not possible with more static technologies. Chen (1999) also emphasised goals and feedback. Challenge is regarded as an important antecedent by all.

The consequences of flow are defined less consistently by the researchers. Novak and Hoffman (1999) propose the consequences to be positive affect and exploratory behaviour; Ghani et al. (Ghani & Deshpande, 1994; Ghani et al., 1991) agree that enjoyment (positive affect) is a consequence, but add concentration, which is shown as an antecedent in Novak’s model. Webster, Trevino and Ryan (1993) have similar flow constructs of cognitive interest (curiosity and intrinsic interest) and attention focus (concentration). Novak, Hoffman and Yung (1997) combine challenge with arousal as one of their antecedents. Webster et al. (1992; 1993), together with Novak et al. (1997), regard play, or exploratory behaviour, as an important consequence of flow.

The four dimensions of interactivity can be mapped onto the diagram of flow shown in Figure 4-3. Frequency of interaction is not well represented in this model, but can be expected to impact on focused attention and exploratory behaviour. Range is also not represented by the model but might link loosely to
challenge as a greater range of interactions might present greater challenge to the user. *Significance* relates to importance, which affects flow though focused attention. One might also expect significance and range to have some impact on challenge and arousal. This is because an interactive object requiring choice of inputs, which will have significant impact on the system, is likely to challenge and stimulate the user. Finally, the extent to which the *locus of control* resides with the system or the user has significant impact through the skill and control path. It is clear that the control should not only be appropriately balanced between these two, but also relate well to the skill of the user and the challenges being perceived.

Telepresence is a construct with some similarity to the sense of ‘oneness’ described by Laurel (1993). Hence, if the above interactivity dimensions are present in optimal amounts, one might expect impact on the telepresence experienced by the user. The model does not show a path leading that way. However, a highly interactive experience will likely lead, through flow, to exploratory behaviour as the model shows.

In Novak’s (1997) model interactivity was represented by interactive speed (how quickly the system responds) and telepresence (a perception of the environment through the medium of the computer). This is a limited view of interactivity, but this model is tailored towards interaction in a marketing Web environment where the nature of the interaction is limited.

The above shows that a highly interactive system has many attributes that can lead to flow. The link between flow and interactivity is predictable from this model, and has been shown to have a moderate causal relationship (Skadberg & Kimmel, 2004), but as yet the nature of this relationship is not well understood.

**Flow channel segmentation models**

From the earliest writings on flow, challenge and skills have been regarded as fundamental concepts both as descriptive and causal factors (Csikszentmihalyi, 1975; Csikszentmihalyi & Csikszentmihalyi, 1988). Flow happens when one’s perception of the challenge required for a task is in balance with, or slightly greater than, one’s perception of the skills one has to complete the task. This concept leads to a dynamic relationship between challenge and skill that defines flow models based on the relative intensity of each concept. It is the dynamic nature of this relationship that is an important factor in suggesting that flow should be a state supportive of learning. For this reason it is valuable to discuss in further detail the flow models that are derived from this concept.

The earliest, and simplest, model representing flow as a ‘channel’ is presented in Figure 4-4 (Csikszentmihalyi, 1975). The flow channel separates the two other states of ‘anxiety’, when perceived skills are too low for the perceived challenge, and ‘boredom’, where skills are too great for the challenge. Whilst the term ‘boredom’ is still used in many flow studies, Ellis, Voelkl and Morris (1994) found that a measure of the mean positivity of affect for a group was slightly higher under the boredom condition than under the flow condition. This suggests that boredom is not an appropriate descriptor for the high skill/low challenge condition. In a more recent work, Shernoff, Csikszentmihalyi, Schneider and Shernoff (2003) use the more appropriate term ‘relaxation’.
The dynamic nature of flow derives from the prediction that this model makes as to the changes that must take place if one is to stay in flow. A learner having skills that can almost cope with a challenge might strive to improve those skills to achieve that challenge; this is the learning process. Ideally, the challenge should then increase to prevent the improved skills making the challenge appear too easy, as is represented by the region labelled ‘boredom’ in Figure 4-4. As this process continues, the learner’s path will progress up the flow channel as new challenges stimulate the development of new skills (Csikszentmihalyi, 1975).

Models of flow based on this concept have gone beyond dividing the challenge-skill space into only three regions (Csikszentmihalyi & Nakamura, 1989). Massimini and Carli (1988) proposed that flow would only happen when challenge and skills were in balance and above a certain threshold. This led to a four-state model, still referred to as ‘channels’, in which flow describes the quadrant of high-skills and high challenges, and apathy the quadrant of low skills and low challenges (Figure 4-5). This model has been confirmed by other researchers showing that flow differs from the three other states in virtually all indicators of positive affect (Ellis et al., 1994; LeFevre, 1988; Nakamura, 1988; Wells, 1988).
The model has been extended further to eight channels, as shown in Figure 4-6, and later to sixteen channels (Ellis et al., 1994; Massimini & Carli, 1988; Novak & Hoffman, 1997).

It might appear that the three-channel flow model is contradicted by these four-channel or eight-channel models. This is not the case. The original three-channel model describes flow as simply the balance of challenge and skills, including the state of low challenge and low skills. The models with more than three states explicitly describe flow as a state in which challenge and skills are not just in balance but also are high. The low challenge and low skill state is named ‘apathy’. The reason that these models are not in contradiction is that the three-channel model describes flow in a single activity as the experience proceeds through time (Csikszentmihalyi & Csikszentmihalyi, 1988 p. 261). The models with a greater number of states are better suited to flow studies that monitor life experiences over extended periods of time (days) in which states of flow are interspersed with some or all of the other states. This will be discussed later in Section 4.3 on measuring flow.
In the context of learning activities the three-channel model has an important place because it represents how the process of flow might develop through a single activity. Initially, as a novice, one might have minimal skills and need appropriately low challenges in order to help develop better skills; these ‘novice’ experiences are sometimes referred to as ‘microflow’ (Csikszentmihalyi, 1975). As the skills increase, so must the level of challenge in order to maintain flow. Hence the model shows the time progression as one continues to learn a new skill or technique and progresses up the flow channel. If the level of challenge increases too fast, then there is danger of anxiety; if the skills develop quickly and level of challenge is not increased then there is a danger of boredom.

4.2.5 A flow model for this thesis

The three approaches to modelling flow, causal models, conceptual models and channel models, each have made a valuable contribution to this thesis. The causal models, though incomplete, offered insight into factors that might determine flow and suggested ways of measuring the experience itself through monitoring control, enjoyment and concentration. The conceptual models have shed light on some of the complex factors that comprise flow and shown how interactivity might play a role in supporting flow. The channel models have provided a strong theoretical motivation that flow should support learning and suggested an alternative method for measuring it by monitoring challenge and skills directly.

Before discussing the techniques available with which to measure flow, I present the following simple conceptualisation that represents the model to be used in the rest of this thesis. Figure 4-7 shows the experience of flow being represented by enjoyment and concentration (Ghani, 1995; Ghani & Deshpande, 1994; Ghani et al., 1991). Rather than include control as a flow experience (Trevino & Webster, 1992; Webster et al., 1993) I have chosen to keep it as a dimension of interactivity and hence an antecedent to flow, as is more customary. Nevertheless, in one of my experiments I will explore whether it adds to the description of flow in the manner of Trevino and Webster (1992). Challenge and skills are fundamental antecedents to flow in most of the approaches studied. Interactivity is included as it is a broader and more encompassing term than telepresence (Hoffman & Novak, 1996; Sheridan, 1992) and has the potential to represent aspects of a learner’s engagement that might not be captured by the other inputs. The consequences of flow are strong positive affect and time distortion, as is agreed by most researchers. Exploration (Ghani, 1995; Ghani & Deshpande, 1994) is considered important especially in a multimedia learning context where there is ample opportunity to explore in a hypertext environment.
Chapter 4

Figure 4-7 A representation of flow used in this thesis

Models of flow have been developed in many diverse areas of endeavour, but none has been develop specifically with online learning in mind. The model just presented is not being put forward as being complete nor as one to be tested. It is an interim model simply to establish a common understanding of how the term ‘flow’ is being used in the thesis. At the end of the thesis I will propose a different description of flow in a learning context.

4.3 Measuring flow

Describing the various approaches to modelling flow illustrates inconsistencies and differences in how researchers approach the concept. Whilst the models suggest techniques for measuring flow, they also signal that the measurement will not be a straightforward matter. This section discusses three main approaches to measuring flow: the experience sampling method (ESM) which gathers data on a variety of life experiences usually over an extended time of several days (Carli et al., 1988; Csikszentmihalyi, 1975; Ellis et al., 1994; Shernoff et al., 2003; J. Voelkl, Ellis, & Walker, 2003; J. E. Voelkl & Ellis, 1998); survey methods which rely on responses to user surveys reflecting on their past activities (H. Chen et al., 1999; Ghani, 1995; Ghani & Deshpande, 1994; Konradt & Sulz, 2001; Novak et al., 2003; Novak et al., 2000; Trevino & Webster, 1992; Webster et al., 1993); and methods which use direct measurements of challenges and skills (Ghani et al., 1991; Konradt et al., 2003; Novak & Hoffman, 1997). It is from these approaches that techniques are derived for the Experiments Two and Three in this research.

4.3.1 Experience Sampling Method

In early research into flow, Csikszentmihalyi (1975) studied dancers who had been assigned to two groups based on whether or not they were thought likely to experience flow (based on earlier interviews). By interviewing the dancers, the researchers found significant differences between the two groups that confirmed a model of flow based on the elements of flow described earlier (control, distractions, time and self-consciousness) as well as a congruence of challenges and skills. This early work set the scene for the development of measurement techniques that would be less vulnerable to the vagaries of memory than retrospective interviews, especially when it comes to reflecting on events that have taken place only in consciousness (Csikszentmihalyi & Csikszentmihalyi, 1988).
A new tool was developed, the Experience Sampling Method (ESM), that probed subjects throughout the day for periods of several days at a time (Csikszentmihalyi, Larson, & Prescott, 1977). This tool gathered data by paging the subject at random times requiring them to complete a questionnaire focusing on the activity they were doing at the time. The data gathered were extensive: descriptive data on the current activity, Likert-scale data on flow elements, as well as moods and physical states of the participant. It has become an accepted method for measuring flow (Csikszentmihalyi & Csikszentmihalyi, 1988; Csikszentmihalyi & LeFevre, 1989; Ellis et al., 1994; Mannell, Zuzanek, & Larson, 1988) and has been experimentally validated (Csikszentmihalyi & Larson, 1987; Moneta & Csikszentmihalyi, 1996). A measure of perceived challenges and skills was included in this method to help distinguish flow from a simple measure of positive states of consciousness. The challenge-skill measure did not give a satisfactory indication of flow in those early experiments. It was a refinement by Massimini and Carli (1988) to normalise challenge-skill measures and require them to be above a certain threshold that gave validity to that measure. Since then several studies have explored the relationship between challenge-skill measures and ESM measures of flow (Carli et al., 1988; Csikszentmihalyi & Nakamura, 1989; Massimini & Carli, 1988). This issue is discussed more fully in Section 4.3.3.

The Experience Sampling Method is an intrusive one and hence is not suitable for a short duration activity such as a learning task. Whilst the nature of the data recorded is rich, the participants are required to stop what they are doing, record their activity, reflect on their mood, and answer several questions relating to affect, emotions and feelings. Chen, Nilan and Wigand (1998; 1999; 1998) used a digital version of the ESM in which computer-based ESM-style questionnaires popped up during participants’ online work. Whilst this had benefits of ease of distribution of the materials to respondents, it also had its drawbacks. The ‘pop-up’ application was reported as being annoying, the questionnaire too long and Web users appeared to have little patience to read the long explanatory text (H. Chen & Nilan, 1998). Chen (1998) concluded that ‘ESM is a good tool for studying some day-to-day experiences and not an appropriate tool for a specific activity with an ephemeral occurrence.’.

A significant concern of Chen’s was that, even with pop-up questionnaires of relatively short duration, participants lost track of experiences immediately prior to the questionnaire (H. Chen & Nilan, 1999). This poses a problem for the design of ESM-style methods for use in learning activities. Any intrusive data probe needs to be of very short duration and in close temporal proximity to the tasks. It signals an even greater problem of obtaining reliable data from end-of-session surveys in which many of the situated perceptions of the participants might be lost.

In Experiment One a probe was used to gather emotion data, the nature of which was not unlike that from ESM probes. A post-survey was also used to gather further information. The research of Chen and Nilan (1999) suggests that this technique needs to be refined to obtain reliable data relating to flow in a learning context.

4.3.2 Survey measurement of flow

A second approach to measuring flow has been to survey participants retrospectively about past activities that might include flow experiences. This has been done using data from large scale online surveys of general Web usage (e.g. Novak et al., 2003; Novak et al., 2000) as well as smaller surveys targeting a
particular workforce (e.g. Ghani & Deshpande, 1994). Research of this nature contributes to our understanding of the concept of flow and provides models as discussed in Section 4.2.4. However this approach is often very broad in that it asks general questions about challenges, skills and affect without relating them to specific activates. Flow should be operationalised as a situated experience rather than a general experience of Web users; this questions the validity of results using this approach (H. Chen et al., 1999).

The use of retrospective surveys is taken up by others in a more focussed manner (Ghani, 1995; Trevino & Webster, 1992; Webster et al., 1993). Surveys are conducted immediately after an activity, often in a laboratory setting, requesting similar information relating to challenge, skills and affect. This approach adds the benefit of being able to focus participants’ minds on the tasks they have just completed, and to do it at a time soon after the activities in the hope that their reflections on their feelings remain reasonably accurate. Although this does not completely address Csikszentmihalyi and Csikszentmihalyi’s (1988 p. 252) concerns about the difficulty of reflecting on events that only take place in consciousness, it locates the reflection closer to the event than broad retrospective Web surveys and enables the researcher to specify the particular tasks on which the participants should comment.

Research of this nature has shifted the emphasis of flow research from one of exploring when and where flow happens in everyday life activities to one of examining the nature of flow during specific, and often controlled, activities. For example, research using the Experience Sampling Method has shown that schooling and study are often flow activities (Carli et al., 1988; Larson, 1988; Massimini & Carli, 1988; Nakamura, 1988). Whereas adolescents rarely regard studying as a complete flow activity, due to the extrinsic nature of the motivation, they nevertheless report many instances of flow while studying (Massimini & Carli, 1988). In their research into flow in daily experience, Massimini and Carli (1988) describe 18% of students’ flow occurrences as happening during study and 16% during class work (measured using challenge and skill data from the ESM recordings). But studies of this nature, whilst giving a snapshot of flow, do not inform us as to the nature of the flow experience itself, nor how it evolves with time. By following up designed classroom activities, or computer laboratory experiences, with survey data collection, we can begin to probe into when flow happens during a learning session, as well as what the experience of flow looks like for these students. The reflection of the student can be focussed on a recent experience, and provide more reliable data from that experience.

Data collection using surveys is still, however, a coarse instrument for measuring a process that might change during an activity. To gather reliable information about flow it is important that it be measured either during or immediately after an interaction (Webster et al., 1993). To gather detailed information of flow experiences during an activity, we need to make frequent measures, yet in a manner that will not disturb the experience that the students are having. A technique to achieve this is discussed in the following section.

4.3.3 Challenge-skill measurement of flow

Amongst the various studies researching flow, an ongoing issue has been to find a method for measuring flow independently from the positive states of consciousness (such as enjoyment, concentration, control, lack of self-consciousness, lack of distraction). One solution has been to use a measure of the balance
between the challenge of an activity and the participants’ perception of their skills to carry out that activity. A key aspect of this is that it is based on participants’ judgements, not those of the designers of the activity (J. Voelkl et al., 2003). The perception of these challenges and skills has been described as ‘theoretically, the most meaningful reference point for the presence or absence of flow’ (Massimini & Carli, 1988). This method has an advantage over other methods for use in a learning context in that it has minimal impact on the participant and is hence least likely to interfere with flow experiences.

Whilst this challenge-skill method has been validated in a Web Marketing context (Novak & Hoffman, 1997) and used extensively (e.g. Ellis et al., 1994; Ghani et al., 1991; Konradt et al., 2003; J. E. Voelkl & Ellis, 1998), there are several concerns that need to be addressed. These relate to determination of the ‘flow states’ that an individual might be in; accommodating individual differences; and the interpretation of the words ‘challenge’ and ‘skills’ and how they are applied. These will each be addressed in turn.

Flow states

If challenge-skill perceptions are used to measure flow, one needs to consider how many possible ‘states’ might be represented by the measure. The original 3-channel flow model was reformulated into a higher number of states, or ‘channels’, to account better for the application of the theory to day-to-day life, rather than a ‘one way street towards increasing complexification’ (Csikszentmihalyi & Csikszentmihalyi, 1988 p. 262). This reformulation led to the four-, eight, and higher-channel models discussed earlier, two of which are reproduced here for reference (Figure 4-8 and Figure 4-9).

![Figure 4-8 Four-channel flow model](image1)

![Figure 4-9 Eight-channel flow model](image2)

Two significant differences are apparent between these models and the original 3-channel model. First, the greater number of ‘channels’ or ‘states’ redefines the three original states of flow, anxiety and boredom. For example, comparing the four- and eight-channel models, individuals reporting flow by the four-channel model might be described as experiencing arousal or control by the eight-channel model.

The choice of number of channels is an arbitrary one and depends on the depth of analysis required (Massimini & Carli, 1988) and clearly has an impact on any analyses that report the frequency of states.

One way to avoid this problem of nomenclature is to describe the ‘location’ of a subject’s experience in ‘challenge-skill space’ – to map their movements on a challenge-skill plot. This is the approach taken in
Experiments Two and Three. More emphasis is given to the location in ‘challenge-skill space’ than to verbal descriptions of each particular ‘state’.

**Individual difference**

Of more significance is the way these higher-channel models handle individual differences in response to the scaled challenge-skill items. The centre-point of these models (challenge = skills) represents the average challenge-skill value for the day-to-day experiences of the individual (Ellis et al., 1994; Massimini & Carli, 1988). The data describing challenge and skills are normalised, and standardised z-scores are used to compare deviations from individual means. This is done to cater for different degrees of ‘autotelic personality’: some individuals will strive to meet challenges presented to them while other decide not to bother (Csikszentmihalyi, 1988; 1997). The justification for this comes, not from theory, but from seeking to make a large number of ESM studies fit a model of challenge-skill predicting flow (Csikszentmihalyi & Csikszentmihalyi, 1988 p. 260).

Some researchers are critical of the use of these reformulated models due to the loss of information on the individual due to use of standardized scores (Ellis et al., 1994; Moneta & Csikszentmihalyi, 1996) and the potential for standardised scores to inaccurately identify occurrences of flow (Ellis et al., 1994). Ellis, Voelkl and Morris (1994) carried out two studies and concluded that the challenge-skill ratio explained only a very small portion of the variance of measures of subjective experience and that variables representing the autotelic nature of the person and affirmation of self (good, happy, pleased, content) contributed a considerable amount of additional variance to that obtained from the challenge-skill measures. They noted that respondents typically reported a higher mean on skill than challenge, adding further doubt to the validity of normalising these data to the respondent’s mean.

Ellis, Voelkl and Morris’s (1994) analyses were from ESM studies carried out over several days. The problem is more acute for short studies (one hour) during which time normalising challenge-skill scores would be even more inappropriate. For example, if during a learning activity several challenge-skill measures were recorded and the scores normalised to the mean of the individual, then a person who flowed throughout the entire activity would appear the same as one who was bored throughout entire activity. Nor is it appropriate to compare an individual to the mean of the whole sample, as was done by Konradt, Filip and Hoffman (Konradt et al., 2003). This simply makes flow a state relative to others in the sample and is then not possible for all or none to experience flow.

**Validity of challenge-skill measures**

The research reported in this thesis specifically relates to flow in a learning context within a Web environment. However, we must be careful in applying models and ideas from other research without considering the differences between the contexts of use. Many flow studies have focussed on a single task, for example reading and writing (Larson, 1988), but in a Web environment the tasks can be many and diverse. Several of the studies reported earlier analyse data from large Web surveys questioning participants about flow in a general online work environment (for example, Novak & Hoffman, 1997; Novak et al., 1999). Chen, Wigand and Nilan (1999) are very critical of this approach as it fails to recognise that the Web is a ‘multi-activity’ medium: simply knowing that a participant had a flow
experience whilst Web browsing does not inform us about what they were doing at the time, nor what aspects of their activity contributed to the flow.

The measurement of challenge and skills is particularly problematic in this regard. The original conceptualisation of challenge and skills as an indicator of flow related to the skill that a person perceived, and the challenges required, to carry out a specific task (Csikszentmihalyi, 1975). This meaning of challenge and skills is necessarily situated in time and space (H. Chen et al., 1999). Some research produced particular problems in this regard by asking participants to rate their responses to very general questions about challenge and skills; e.g. ‘Using the Web challenges me’ and ‘I am extremely skilled at using the Web’ (Ghani, 1995; Novak et al., 1997). There was no attempt to relate these responses to particular experiences(147,166),(855,263), nor to relate the skills to the challenges.

The underlying basis of using challenge and skill as an indicator of flow is that the participants reflect on their own perceived challenge required to carry out a task and how well they perceive their skills to do this (Csikszentmihalyi, 1975). Chen, Wigand and Nilan (1999) criticise flow studies where flow is regarded as a general experience, rather than a situated one, and where the concepts of perceived challenge and skills are not operationalised as dynamic counterparts to each other (for example, Hoffman & Novak, 1996; Hoffman & Novak, 1997).

Challenge and skill are multidimensional constructs (Csikszentmihalyi, 1975; 1990; Moneta & Csikszentmihalyi, 1996) and often have ambiguous meaning (H. Chen et al., 1999). For example, ‘challenge’ might be interpreted in a negative sense as ‘difficulty’, or in a positive sense as ‘cognitively stimulating’; it might be reflected on as referring to various different aspects of what the subject is doing.

This issue is taken further by Finneran and Zhang (2002) who recognise that in a computer-mediated environment there is a third actor involved beyond the person and the task; this is, the computer application or artefact. They propose that we should consider the person, the task and the artefact when studying flow.

The flow experienced by the person is done so in the context of the task and the artefact used. They argue that the balance of challenge and skills is not only between the person and the task, but also the person and the artefact. In a later paper they propose a model that re-conceptualises flow in terms of person-task-artefact to account for this unique nature of computer-mediated environments (Finneran & Zhang, 2003).

Considering this together with Voelkl and Ellis’s (1998) work on validating challenge-skill measures, we should be cautious in using these measures. The measurement items should at least refer to a specific task, if not also to which aspect of the task is holding the user’s attention at the time. Voelkl and Ellis (1998) comment that often research has not been careful to make this distinction and highlight the danger with the surprising finding that a challenge-skill measure was a significant predictor of flow when used in relation to an activity, but not when used in relation to focus of attention.

The problem of participants’ focus of attention is illustrated in the work of Ghani, Supnick and Rooney (1991) in which their instrument to measure challenge and skill refers specifically to ‘the activity’ but it is not clear how the participants interpreted that activity. Research using open-ended questionnaires
suggests that participants often focussed on the task, rather than challenges of the hardware and software, when talking about flow (H. Chen et al., 1999). The use of these terms needs to be clearly defined in relation to the tasks at hand.

Finneran’s (2002; 2003) proposed person-artefact-task model, whilst not yet validated empirically, is a valuable one to consider in an online learning environment. Web learning tasks are far better defined than those targeted in general Web surveys, but they still have two very different components: the learning tasks and the software artefact being used to present the tasks to the student.

The discussion above illustrates that the use of challenge and skills to measure flow must be approached with caution. The constructs are complex and might not be well represented on a one-dimensional scale (Ellis et al., 1994). Their meanings must be clear. When a participant is asked to respond to challenge-skill measures, the focus of the words must direct them to relate to a particular activity so that the dynamic relationship can be assessed. The research described in Experiment Three was designed in a way that recognised this distinction between the person and the artefact when studying flow.

4.4 Flow and learning

It is common amongst flow researchers to suggest a strong link between flow and learning (for example, Chan & Ahern, 1999; Clarke & Haworth, 1994; Csikszentmihalyi, 1975; Csikszentmihalyi et al., 1997; Rieber, 2001; Sedighian, 1997; Shernoff et al., 2003; Webster & Martocchio, 1992; Webster et al., 1993). This notion can be argued from theoretical aspects of flow and from empirical studies.

4.4.1 Flow theory suggests learning

The concept that a flow activity could be a powerful vehicle to support learning is an expected one given the control/engagement/enjoyment nature of flow. Flow describes a state of self-motivation which is considered by many to be the best way to learn (Lepper & Malone, 1987). A theoretical basis for flow supporting learning rests on the relationship between challenge and skills that is required to produce flow; the ‘balanced tension’ that is required to focus attention (Csikszentmihalyi, Rathunde, & Whalen, 1993 p. 233). Flow will occur when the ‘one’s skills are neither overmatched nor underutilised to meet a given challenge’ (Shernoff et al., 2003 p. 160). Learning occurs as one improves skills in order to meet slightly increased challenges. If the activity is to remain challenging, and hence maintain flow, the level of challenge needs to be continually increased to continue stretching the level of skill. Put another way, if a person can maintain flow during an activity, there is a good chance that the conditions are right to promote learning rather than the person slipping into a state of anxiety or boredom. (Csikszentmihalyi, 1975; Csikszentmihalyi & Larson, 1984; Nakamura, 1988).

A second link between flow and learning is its correlation with perceived control (Ghani et al., 1991). Control offers a sense of mastery ‘based on a selective structuring of the world’ (Csikszentmihalyi, 1975 p. 192). Flow has been reported to happen very infrequently for students during lecture sessions when the locus of control is firmly with the lecturer, but students report being much more engaged during individual and group work when they have greater control (Shernoff et al., 2003). ‘Ideal learning
activities should be challenging and relevant, yet also allow students to feel in control of their learning environment and confident in their ability’ (Shernoff et al., 2003 p. 173).

Finally, an important aspect of learning is reflective cognition: the opportunity that a student has to reflect on and consolidate learning that is taking place (Laurillard, 1993; Norman, 1993). The learner needs to reflect on the meaning of the feedback in relation to the goal of a task, to reflect on the goal in the light of feedback from the last action, and so on (Laurillard, 1993 p. 64-65). Feedback itself is regarded as one of the most critical components of computer-based instruction (Azevedo & Bernard, 1995). The application of flow theory can encourage reflection through increasing challenge. To meet increasing challenge, a student is led to pay attention to finer and more specific details. This increasing challenge is proportional to the student’s need for increasing reflective thought (Sedighian, 1997). One of the challenges in applying flow theory in this manner is how to design a learning artefact so that it actively promotes reflection while not compromising the characteristics of the flow activity (Sedighian, 1997); so that it encourages reflection on the concepts to be learnt and not just the features of the computer-based interactions taking place.

4.4.2 Studies of flow and learning
Despite the expected link between flow and learning, little research has been published to establish this relationship. Studies using the Experience Sampling Method cover an extended time period hence usually report on the frequency of occurrence of flow during learning as well as the other day-to-day activities (for example, Carli et al., 1988; Massimini & Carli, 1988; Shernoff et al., 2003). Such studies provide a snapshot of people’s lives from the point of view of the dimensions of flow. They tell us that, of all the main activities we engage in, each of them is represented in each of the various flow channels (Massimini & Carli, 1988). Any activity can produce flow; any activity can produce boredom. The frequencies with which activities are recorded in each channel, of course, vary significantly. It is in this context that such research is valuable in informing us about the comparative quality of people’s lives. Comparisons between different cultures, such as American and Italian teenagers, show interesting differences between their degree of positive affect in the flow state, how these relate to challenge and skills, and the relative time spent in flow while studying compared to other states (Carli et al., 1988). However, apart from confirming that intense flow experiences are possible while learning, these studies do not shed much light on flow at the task level of analysis nor on the nature of the learning activities that encouraged the flow state.

Csikszentmihalyi, Rathunde and Whalen (1993) used the Experience Sampling Method to carry out an extensive study of school children exploring the ecology of talent during adolescence. The findings from this study indicate a strong link between talent development and optimal experiences. Flow in students’ talent areas was significantly related to engagement and was associated with the perception of high and balanced challenges and skills. This study paints a rich picture of the importance of flow experiences to talent development and informs us that, for these highly talented students, their learning often took place during a flow experience. It suggests that an environment that encourages flow might be a stimulating environment for learning, but cannot tell us whether setting up such an environment might encourage students into a state of flow, and hence learning that they otherwise would not have obtained. It does not
focus down to the task level to ask the question ‘can we design learning tasks which will encourage flow and hence encourage learning?’.

Classroom studies have been carried out exploring how instructional practices influence flow (Turner & Meyer, 2000) and how activity content and interactivity of presentation affect flow experiences (Chan & Ahearn, 1999). Whilst such studies inform our knowledge of what affects flow and motivation in a learning environment, they each acknowledge the inadequacy of depending on a survey immediately after the learning session has taken place. Reports of flow elements in these studies relate to the whole session – essentially an averaging out of effect – losing details of how moments of flow might relate to moments of learning.

In contrast, ESM studies, although an interruption, often capture evidence of students flowing while studying. Massimini and Carli describe a case of a student studying physics as ‘a moment of extreme experiential congruence: concentration was still high, but it was also easy; instead of being confused, Paolo reported being clear and in control’ (Massimini & Carli, 1988 p. 281). However, they go on to report that such instances are rarely complete flow experiences since motivation for a student studying is usually extrinsic.

Skadberg and Kimmel (2004) report on research that does find a positive link between flow and learning. They surveyed almost 300 participants on various aspects of flow and analysed their data using a structured equation modelling method. Whilst they confirm flow experience was positively related to increased learning about a Web site, they failed to contextualise challenge and skills to particular tasks (H. Chen et al., 1999) and found challenge and skill not to contribute to the flow experience. More significantly, the measure of learning was based on self-reported perceived learning (e.g. ‘After visiting the Web site I feel I have learnt more…’) rather than objective tests. Ghani (1995) also provides evidence that flow is linked to perceived learning. In his research flow was measured using affective measures together with measures of challenge and skills. As with Skadberg and Kimmel’s (2004) research, these latter measures were not contextualised. For example, the questions asked were quite general, such as ‘Indicate how you felt about this session: Challenges of the activity; Your skills in the activity’ (Ghani, 1995 p. 310).

Both of the studies mentioned above involved learning material that was relatively low in complexity and for which the participants might well have been able to judge the extent of their learning for themselves (learning about a Web site and learning about programming and word processing, respectively). However, for tasks requiring greater judgement by students’ of their understanding of complex concepts, self-reports of learning might not reflect the true extent of their understanding. In the area of physics education, for example, the misunderstandings of the physical world learnt during early life are well documented (Arons, 1990; Halloun & Hestenes, 1985b; McCloskey, 1982) as are the misconceptions learnt in more formal learning environments (McDermott, 1991). In these cases there is still a perception of learning, but it can be an inaccurate one.

Although there have been numerous studies of flow and online behaviour few have addressed learning as a specific focus. One study that has explored flow in a hypermedia learning environment used three flow measures during a one hour learning session (Konradt & Sulz, 2001). They found that activation,
concentration, satisfaction, and motivation were the key factors that resulted in the state of flow. However, they note that affect was not significantly higher in the flow condition and suggest that this is a feature of a learning activity; they suggest that the nature of flow may be different for different tasks and that learning tasks are associated with high effort and medium affect. The intense enjoyment associated traditionally with a flow activity might not be so strong during learning. Of more significance, whilst the high number of participants obtaining flow (over 30%) supports the notion that learning systems can be designed to motivate use through flow, they found no relation between flow and learning. Their interpretation of this result is two-fold: whilst flow may have supported learning, the other conditions did not detract from learning. The relatively high initial skills of the participants may have created a ceiling effect in which it was difficult to detect any significant differences in learning outcomes. They identify the need for further research with either more difficult tests or more novice participants.

Whilst playfulness may produce longer task completion times (Bateson 1955; Miller 1973; Sandelands 1988) and playful computer systems may be so enjoyable that employees neglect other tasks (Hoffman & Novak, 1996), no studies specifically warn that flow might be an undesirable state in a learning context. However, some suggest that we should be cautious (Ghani, 1995). Chan and Ahern (1999) studied the content of activities and the quality of its presentation in computer-based instructional design. They found that the quality of presentation enhanced the flow experience for low content relevance activities. This is consistent with flow theory in providing motivation to what might otherwise become a boring experience. However, in contrast to Skadberg and Kimmel’s (2004) finding of attractiveness being the most important factor leading to flow experience, they reported that high quality presentation elements could be distracting when the content relevance was high and adequate challenges were already provided to students. This suggest that a well-designed learning activity can encourage flow by virtue of its content alone – a level of engagement that is conducive to learning – but that adding too much ‘glitz’ to the activity can move the students’ focus from the learning task to trivial presentation aspects of the software.

The outcomes arising from the work of Konradt and Sulz (2001) and Chan and Ahern (1999) suggest a more complex picture of flow in a learning environment. Flow supporting learning might be represented by a different balance of elements of flow in other contexts, with concentration becoming a more dominant element that affect. Recognising flow might not be simply a matter of identifying these elements, or measuring challenge and skills. It might involve more careful consideration of the various aspects of an activity that become the focus of one’s attention and identifying which of these are contributing to the flow experience at any point in time. Existing research has only scratched the surface of the roles that flow can play in this area and how we can use flow theory to help design learning activities to maximise the opportunity for learning.

One important issue to come from the foregoing discussion is the way in which an online activity can be designed to support flow experiences, and how those experiences be conducive to learning rather than simply to play. The flow experience itself is not adequate if it does not encourage the mind to focus on the specific concepts to be learnt. Sedighian (1997) used the flow principles of clear goals, continuous feedback, and increasing challenge and reflection to motivate the design of a game approach to learning mathematics for grade 6 children. In this study he interprets challenge and skill in a learning context as
relating to ‘required knowledge’ and ‘constructed knowledge’ respectively. However, in a multimedia learning environment, we add an additional layer beyond the conceptual ideas: that of the artefact or interface through which the student interacts with the concepts. The mode of interaction is often one of ‘direct manipulation’ (Norman & Draper, 1986; Shneiderman, 1998) of a graphical representation. In an HCI context this introduces a different perspective on the Gulf of Execution and Gulf of Evaluation between system and user (Norman, 1991; Norman & Draper, 1986). Rather than simply trying to bring the system and user closer together and minimise cognitive effort, we need to entice and motivate the user with the attractiveness of, and control presented by, the interface, but at the same time maximise cognitive effort directed at learning. In a continuation of Sedighian’s (1997) research, Sedig, Klawe and Westrom (2001) comment that whilst minimising cognitive effort through direct engagement interfaces may be desirable for productivity tools, it is not yet clear whether they are also desirable for the design of instructional interfaces. In their research comparing direct manipulation focused on the object, the concept and a reflective view of the concept, they conclude:

‘In learnware, HCI designs should aim at reducing learners’ cognitive load for performing non-content-related tasks so as to enable learners to allocate more cognitive resources to understand the educational content.’

(Sedig et al., 2001 p. 54).

Their approach to maintaining students’ engagement on the learning task was to readjust the distance across the Gulf of Execution in a ‘stepwise manner’. In a flow context we would describe this as gradually increasing the challenges to promote students to increase their levels of skills to cope.

The challenge in designing activities that use flow to promote learning is to achieve the appropriate balance. To provide the learner with an increasingly challenging sequence of activities using an attractive artefact that engages and produces intrinsic motivation. Yet, at the same time, challenging their thinking and moving their minds away from the artefact towards the concepts presented for learning.

4.5 Summary and conclusion

Although academic research into flow has a relatively short history of thirty years, its expansions into areas as diverse as marketing, surgery, sport and on-line activities makes a comprehensive review of the literature a challenging prospect. Part of that challenge stems from the different emphases that researchers put on the various elements of flow as they devise methods to explore it. The detailed structural equation modelling approach of Novak, Hoffman and Yung (2000) resulted in very different models from the partial models of Ghani, Supnick and Rooney (1991) and Webster, Trevino and Ryan (1993) who focused on specific aspects of flow in order to deepen our understanding of the experience. Flow has been well researched, but is still a rather nebulous concept with ephemeral characteristics that have been hard to tie down. It requires further research in specific domains in order to provide benefits from our understanding of it. Learning is one such domain that has had very little such research to date. Flow is conceptually close to play and has the attractions of intrinsic motivation that play brings to a task, yet it also has elements that potentially can focus a learner’s mind on conceptual aspects of a task beyond the superficial.
From the literature reviewed, three significant areas emerge which require further investigation.

The first of these relates to gaining a closer view of learners’ flow experiences during a task. Whilst some have measured flow at several points during a learning task (Konradt et al., 2003) we still do not have a good picture of how the indicators of flow vary as learners grapple with complex learning material from a relative novice viewpoint. We do not have a fine enough view of this process to guide the development of instructional materials. There is limited research that begins to unravel the questions relating to task and artefact as proposed by Finneran and Zhang (2002; 2003) and alluded to by other researchers (Chan & Ahern, 1999; H. Chen et al., 1999; Ghani et al., 1991; Sedig et al., 2001). There is a need to explore the changing nature of learners’ challenge-skill perceptions as they work through an online learning task.

Secondly, the well-established techniques with which we measure flow are not well developed for a learning context. The Experience Sampling Method is intrusive and designed for longitudinal studies; surveys often suffer from not recalling the emotions of the moment, and challenge-skill measures have been questioned on the basis of their method of usage (H. Chen et al., 1999). We need to develop better measurement techniques and gain a deeper understanding of the information they provide. The repeated use of challenge-skill measures during a learning activity can allow us to monitor the process of flow throughout the activity, with minimal interruption, and hence provide a more detailed picture of a learner’s behaviour. A valuable contribution to this area would be to compare flow measurements obtained this way to those obtained from data gathered by survey after a learning activity.

Finally, there is the question of understanding how flow relates to an individual’s learning. Although the literature is optimistic about this relationship, it has been a difficult one to establish (Konradt et al., 2003). The evidence that the relationship does exist often involves relatively shallow or knowledge-based learning (Skadberg & Kimmel, 2004) or a coarse-grained association between daily flow experiences and learning activities (Shernoff et al., 2003). There is a need to explore how specific flow measures relate to learning outcomes.

In addition to exploring the three areas mentioned above, this thesis seeks to understand a student’s view of flow from within an online learning activity; to understand the features of such as activity that maximise the potential for flow and to construct a descriptive model for flow that represents students’ interactions in an online environment.

The experiment described in the next chapter addresses the three significant areas outlined above: to examine flow throughout a learning task, to do this by developing a monitoring technique that can be compared with other flow measurement techniques, and to relate these measurements to learning outcomes. The main research question focuses on three aspects of flow that are particularly pertinent to learning: control, challenge and skill. Specifically it states:

**RQ2:** Of those influences on learner interactions, how do the flow concepts of control, challenge and skill describe learner interaction?

The final experiment reported in this thesis will address the further issue relating to understanding the students’ views of flow and how it can be used to enhance a learning activity.
Chapter 5

Experiment Two:  
Charting Flow

“...providing instruction that engages students is a challenge worth achieving, and with the necessary instructional skills, can become a rewarding and flow-inducing experience that produces positive educational outcomes for learners.”

(Shernoff et al., 2003)
5.1 Introduction: The place of flow

The first experiment described in this thesis made several suggestions:

- students’ emotions and goals vary throughout an online learning task;
- understanding the patterns of these changes might offer valuable insights into students’ engagement with the task; and
- significant factors emerging in this process were: boredom/interest; challenge/frustration; learning goals; and a mix of other affective emotions.

Emotions such as challenge, boredom, frustration, and pleasure all contributed to the experience of the students. Students with poor skills and low confidence in the topic area found it boring and challenging and readily became confused and frustrated. They did not perform well in the learning outcomes test. Students with more confidence in their physics knowledge found the task interesting and developed stronger motivation to achieve well and understand the topic as the task progressed. These students responded to an increasing challenge in a different manner to the others and made significantly stronger learning gains.

The experiment described in this chapter used the theoretical construct of ‘flow’ to examine students’ interactions more closely. Flow is an appropriate construct to employ here since it links the perceived challenges and skills of a student to many of the emotions mentioned previously. Flow theory also provides a methodology through which we can explore the engagement of a student with a task. Engagement emerged from the first experiment as an important factor, but we had no methodological way in which to explore it.

The principal research question addressed in this second experiment relates to the influences that flow has on learner interaction:

**RQ2:** Of those influences on learner interactions, how do the flow concepts of control, challenge and skill describe learner interaction?

Ideally, the challenges presented by a learning exercise should be well-tailored to the skills of the learner. Flow theory provided a method to monitor these challenges and skills and seek an optimal balance to support learning. It suggests how these measures might be expected to vary during a learning task and hence keep the learner both interested and engaged, and hence able to construct new knowledge.

Other research in this area often describes the frequency of flow states over an extended period of time (several days) or experiments in which a measure of flow is established after the event by interview or survey. However, drawing on the experience of the previous experiment, this current experiment did not just look for a state of flow, but aimed to map out the *process* of flow as the exercise progressed. It enabled comparisons to be made between flow as a process, and the more traditional overall-state measure of flow. This was done in order to understand the complex changes that happen to students during on-line learning. An approach based on the measurement of the *overall-state* is of little value in an education setting where one might want to understand the dynamic nature of students’ reactions to learning materials during a learning session of 40 to 60 minutes. I expected, from the results of my
previous experiment, that during such sessions students would move in and out of flow according to the nature of the materials presented, their interest in them, and their own ability to cope with the tasks. Yet past research has paid little attention to this process nor, in particular, to how the measures of flow vary as the task progresses.

In this chapter I describe a method for representing the frequently changing sequence of states that students exhibit by monitoring their flow states at several times during a challenging on-line learning task. The Web-based task in this experiment provided guided instruction in physics enhanced with two different levels of interactive multimedia: highly interactive and less interactive. I explored the measurement of flow by adopting a process view in which students’ states were monitored throughout the task, and contrasted it with an aggregate of factors obtained at the end of the session. I was interested in any link between flow and learning as well as any impact the degree of control offered by the software might have on the flow process.

The principle research question was divided into four sub-questions:

**RQ2.1:** How is the perception of control affected by features of a learning task?

**RQ2.2:** What is the changing nature of students’ challenge-skill perceptions through an online learning task?

**RQ2.3:** How does flow measured using challenge-skill ratios compare to flow measured from post-survey data?

**RQ2.4:** How do patterns of flow relate to the learning outcomes of the students?

The analysis of this experiment moves the focus away from the ‘how much did you flow’ question and addresses issues relating to the nature of the interactions that encourage flow and how learning outcomes may or may not be related to them. Through this we can start to appreciate the complex path that students take through a learning exercise as they ebb in and out of flow states. We can begin to address the vexed issue of designing tasks that maintain students’ engagement in online environments.

Section 5.2 describes the design and methodologies of the experiment in which an online learning task was presented to undergraduate students, and the methodologies used. Section 5.3 presents an analysis of the results and offers a view of flow based on process rather than an overall state judgement. Section 5.4 discusses these results and Section 5.5 presents a summary and conclusion to the experiment.

This chapter is based on a journal paper accepted for publication (Pearce, Ainley, & Howard, 2005).

## 5.2 Experimental design and method

### 5.2.1 Aims and justification

This experiment explored the relationships between flow, perceived control and learning, for a group of students engaged in an online learning task. By ‘perceived control’ I refer to the degree to which students considered themselves to be in control of what they were doing, as opposed to being ‘driven’ by the software.
My experiences from Experiment One suggested that in order to explore different levels of interactivity I should vary the degree of control that students have over their environment by allocating them to either an interactive or non-interactive mode of work, and ensuring that they should stay in that mode for the duration of the task. I clearly needed to gather more frequent data in order to monitor flow experiences during the exercise. Finally, having two groups of students, one with higher and one with lower levels of subject expertise enabled me to use information relating to the students’ knowledge background and observe its impact on the data.

The first of the four research sub-questions:

*RQ2.1: How is the perception of control affected by features of a learning task?*  
seeks to differentiate between the amount of control we offer students through the features of an interactive object, and the amount of control they perceive as they interact with it. Control is important to both flow and learning, but in both cases perceptions of control may vary between individuals for the same learning environment.

The second question:

*RQ2.2: What is the changing nature of students’ challenge-skill perceptions through an online learning task?*  
recognises that flow in a learning exercise is unlikely to be a state that endures from beginning to end. The situation for the participants is somewhat contrived and their motivation is likely to be different from ‘real’ students. Given the well-established link between challenge-skill measures and flow, a careful monitoring of these parameters should shed a different light on students’ engagement than could be obtained from more coarse-grained measurement techniques, such as post-surveys.

The third question:

*RQ2.3: How does flow measured using challenge-skill ratios compare to flow measured from post-survey data?*  
addresses two concerns. Whilst challenge-skill measures provide a recognised technique for flow measurement, their use in a learning context is not well studied. Learning contexts bring the complexity of extrinsic motivation, complex tasks, distinguishing what is learnt from what was intended to be learnt, together with the potential of a protracted sequence of tasks. We need to examine more carefully what challenge-skill measures inform us about the actions of a student in this situation. A survey after a learning session will provide an alternative view on the nature of a student’s experience and is contrasted in this experiment with the challenge-skill measures.

The final question:

*RQ2.4: How do patterns of flow relate to the learning outcomes of the students?*  
seeks to establish any links between a student learning in a flow state and their learning achievements. This is a particularly hard association to measure due to the expected movements in and out of flow, and the lack of precision in determining when, and if, learning takes place. A student may engage in an activity but not achieve any specific learning outcomes from it until later, when a subsequent activity, or
reflection, trigger an ‘ah-ha’ moment. Any learning that does take place might be very significant to the student, but might not be what was intended by the instructional designer and hence not what was tested in follow-up tests.

Given the above complexities in pinning down learning outcomes, both in nature and in time, the approach taken in this experiment was to look for desired learning outcomes (as determined by the design of the learning materials) and relate them to patterns of behaviour in terms of challenge-skills measures. A strong finding here would link flow to desired learning outcomes. A more likely finding would merely shed some light on the complex interaction between students’ experiences during a task and their learning of new concepts. Even though the risk of not obtaining a simple, clear finding was high, it was still considered an intrinsic and important aspect of this study to explore this link.

5.2.2 Approach taken

As with the previous experiment, the data required from this experiment related to objective measures of students’ interactions together with their subjective impressions of some of their feelings at frequent times during the experience. I took a positivist approach, as was appropriate to gather frequent numerical data over an extended period of time. The experiment was a 2 x 2 factorial design, testing two levels of control against two levels of expertise. Statistical and visual methods were applied to analyse the data.

This approach was based on other research in this area. Flow has often been explored by collecting data at random intervals over a period of days (Csikszentmihalyi, 1975; Shernoff et al., 2003; J. Voelkl et al., 2003), probing participants, via their computer, as they go about their daily work activities (H. Chen & Nilan, 1998; 1999; 1998), and by surveying or interviewing participants at the completion of a particular activity (H. Chen et al., 1999; Ghani, 1995; Konradt & Sulz, 2001; Novak et al., 2003; Webster et al., 1993). The approach I took in this experiment modified these three approaches in a way that was more appropriate for an online learning activity.

One aim of the research was to observe when flow happens. Whilst using interview techniques about a participant’s recent activity can be an effective method to gauge whether and when flow happened, my interest in seeing the potential motion in and out of flow during a 40-60 minute learning session made this impractical. Much of the detail of the experience would be lost by the time participants reflected on their experience in a post-interview. An appropriate compromise was to take an established and efficient measurement technique – the measurement of challenge and skills – and apply it at specific points during the activity. This provided data which could be automatically logged by the computer and that was also amenable to statistical analysis. Challenge-skill measures are regarded as a sound theoretical basis for the measurement of flow (Massimini & Carli, 1988) and have been validated in a Web Marketing context (Novak & Hoffman, 1997).

As a second method, for comparison with these frequent measures of flow, I collected survey data that would directly target questions relating to the emotional states of the participants. These were also based on established flow measurement techniques (Webster et al., 1993). Interviews might have provided richer data but I wanted sufficient data to make reliable estimates of learning outcomes. Hence a technique to gather data automatically from a large number of participants was required, with an option to interview some participants later or in a follow-up experiment.
These two methods differ in that the first measure was based on the antecedents of flow, the second on the participants’ experience of flow. The assumption here was that they would both be measuring the same phenomenon – one during the experience and the other reflecting on it – and hence some agreement would be observed.

Routine statistical analyses techniques were used to explore patterns of flow and learning. As in Experiment One, a logging technique was used to produce a visual representation of the path and activity of participants in their journey through the materials, and a new visualisation was created to represent their flow activities. The combination of these techniques gave a rich set of data from which to gain an understanding of participant’s behaviour and also to make some comparisons of flow-measurement techniques.

5.2.3 The online learning exercise

The learning environment was designed to present an environment that would be conducive to both flow and learning. The design was done in collaboration with a colleague in the School of Physics\(^9\); the programming was carried out by a multimedia programmer in the university’s multimedia design unit\(^10\).

Whilst most of the participants would be paid volunteers, and not studying physics, my aim was to give them an enjoyable experience that would present the physics in a sufficiently interesting manner that they would become immersed and appreciate the physics that they would learn.

The topic area chosen was kinematics: the motion of a cart along a track, with gravity and an external force affecting the cart’s motion. This was chosen for two reasons. First, it had the potential to attract and engage students through a visual representation of the motion of the cart and graphical displays of various quantities. There was an element of play associated with this in that there were many options to explore: strength of the push on the cart, adding fans to accelerate the cart, changing the slope of the track the cart ran along, as well as changing numerous parameters for the display of graphical quantities.

The second reason for choosing this topic related to the vast amount of physics education research into this area of physics. The concepts of speed and acceleration are not well understood by university students when they first encounter them often due to the persistent misconceptions learnt through 18 or so years of everyday experience (Clement, 1982; Halloun & Hestenes, 1985b). Nor is it well understood whether the approach to learning in this area should begin with a qualitative or quantitative analysis (B. Y. White, 1993; B. Y. White, & Frederiksen, J. R., 1998). Research by Thornton and Sokoloff has designed a series of ‘lecture-based demonstrations’ that have had significant success in addressing these misconceptions (Sokoloff & Thornton, 1997; Thornton, 1999; Thornton & Sokoloff, 1998). These demonstrations follow a set pattern:

- demonstrate a motion;
- ask students to make a prediction about the behaviour of a quantity and record it;
- students observe the motion using a computer to record and display parameters in real time;

\(^9\) Dr Michelle Livett, DipEd, PhD. Senior Lecturer in the School of Physics, The University of Melbourne.

\(^10\) Mr Daniel Robertson, Multimedia Education Unit, The University of Melbourne.
students discuss any discrepancies between their predictions and observations with their neighbour;

the motion is then discussed as a class.

Although the strength of this approach lies partly in the peer-to-peer interactions, I based the interactive simulation for this experiment on this style of interaction and used pre- and post-tests based on the Force and Motion Conceptual Evaluation that had been well validated through the research of Thornton (1999; 1998) and others. The peer-to-peer nature of the experience would be lacking, but the other aspects would all be present.

The students’ experience began with a short survey on age, gender, and educational background (screen shot Appendix B-1) followed by a physics pre-test (Appendix B-2) and then an introductory screen explaining the overall goals of the session and randomly directing them to follow either the interactive or non-interactive path (screen shot Appendix B-3). Finally, before starting the actual learning exercises, they were presented with a screen describing the operation of the simulation (screen shot Appendix B-4).

An overview of the learning sequence that the students followed for each of seven activities is:

1. Play a short movie clip of a moving cart and sketch in a prepared booklet their prediction of what velocity-time and acceleration-time graphs of the motion would look like (screen shot in Appendix B-5).

2. Use the simulation (in either an interactive or non-interactive fashion) to explore the motion and correct, if necessary, their predicted graphs based on what they observed (screen shot in Appendix B-6).

3. Respond to challenge-skill survey questions and move on to the next activity.

After working through seven activities, a final review screen was presented (screen shot Appendix B-7) before the post-test materials.

One aim of the research (RQ2.1) was to explore the effect of varying the degree of control that students had over their environment. Hence they were randomly divided into the two groups ‘interactive’ and ‘non-interactive’. Students each group began each task by viewing the same animation of a cart’s motion and then drawing on paper their predictions of the resulting graphs. This animation required only a mouse-click to operate. One group, the simulation group, then worked with a true simulation that allowed them to freely manipulate the objects involved: drag and release the cart to set it moving; vary the slope of the track; add fans to the cart to produce acceleration; and change the scales of the graphs. Figure 5-1 shows an annotated screenshot of the simulation screen.

The other group, the movie group, worked through the same activities except that the simulation was replaced by three or four video clips that presented animated screen-shots of the simulation showing the cart motions relevant to each particular activity (the movie-group screen shot in Appendix B-8 shows the movie mode equivalent to the simulation view shown in Appendix B-6). Participants could play these clips as often as they liked. I expected the movie group to perceive a lower degree of control than the simulation group because they were unable to directly manipulate the simulations. They had been offered fewer degrees of freedom and, as such, had less opportunity to exercise control.
Figure 5-1 Annotated screenshot of the simulation

Figure 5-2 (next page) shows a screen-shot from page 6 of the exercise, showing the interactive simulation on the left in context with the instructions on the right. The cart is shown moving towards the left, up the slope, with a fan added opposing the cart’s motion. The graphs show velocity and acceleration plots.

The entire exercise was piloted using two colleagues. They worked through the exercise in a laboratory setting, giving feedback comments on the tasks, tests and wording of survey questions. One colleague (Graham) followed up by writing some JavaScript code (Appendix B-9) to display the students’ final test score on the screen at the end of the exercise.

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11 I have referred to each screen as a ‘page’ rather than a ‘screen’ as the navigational context was one of a ‘page-turning’ exercise.
12 Mr Connor Graham, Mr Stephen Smith, both tutors, Department of Information Systems, The University of Melbourne.
5.2.4 How the learning activity promoted flow

The activity was designed in a way that would give students ample opportunity to experience flow. For the simulation-mode students, the simulation was simple enough to use. Any student could drive it to produce graphs and to vary several parameters. However, it had adequate complexity to engage students’ minds either through attempting to obtain a particular motion, or through trying to interpret graphs to understand the features of a motion.

Students in the non-interactive mode (movie-mode) were offered a similar range of engaging motions to view, but without the operational complexity of having to drive the simulation. They had the same interpretation challenges to cope with as the simulation-mode students.

Finneran’s review of flow studies (Finneran & Zhang, 2003) comments on a distinction between goal-orientated activities and experiential ones, as defined within the marketing literature (Hoffman & Novak, 1996; Novak et al., 2003). He states that flow can be expected to occur in both types of activities, but that goal-oriented tasks were more likely to yield flow. The exercises in this research were goal-oriented in the sense that students were asked to carry out specific tasks with an aim of understanding the resulting motions. However they also had an experiential component in the exploratory nature of the simulation. Motivation was largely extrinsic in that students were paid to participate, but it was hoped that some intrinsic motivation might have been generated by the playful nature of the simulation (for those working in simulation mode) or by the choice of movies to run (movie mode). Together these attributes provided a good chance of flow being observed at various times during students’ sessions.

Csikszentmihalyi (1997) comments on the importance to flow of intrinsic motivation, active learning, and feedback that is informational rather than controlling. The activities presented in this experiment provided intrinsic motivation through presenting an engaging and interesting multimedia object: seeing a cart run along a track, graphs being drawn, movies to watch. Active learning was encouraged through the interactive nature of the activities, namely, some fairly limited Web-page navigation, but more
importantly the opportunity to play movies and (for some) interact with the simulation. Feedback was
provided through watching the motion of the cart, and through observing the graphs. It was informational,
consisting of velocity and acceleration graphs being drawn dynamically as the cart’s motion progressed.
The feedback was not ‘controlling’ in the sense of instructing the students what do, or stating whether
they were right or wrong. Rather, with correct interpretation, it guided students’ thinking to answer the
questions that were being posed.

Steuer (1992) uses the phrase *telepresence* to describe ‘the extent to which one feels present in the
mediated environment’ and others have remarked that this is essential to maintaining the concentration
that is required for flow (Finneran & Zhang, 2003). This learning environment provided some potential
for telepresence through the direct-engagement nature of the simulation. To move the cart, the students
had to drag it to the desired speed then let it go. To adjust the slope, they had to click on one end of the
track and drag it upwards. Although there was no attempt to immerse the students in a virtual reality
representation of a moving cart, the experience was adequate to focus an attentive student’s mind and
engage them in the detailed motion of the cart.

Thus, through the design of this learning exercise, I set up an environment that had the potential to deeply
engage students in an enjoyable activity, provide goals and feedback, and thereby encourage flow.

5.2.5 Two flow measurement techniques

Method 1: measuring challenge and skill

I used the variables *challenge* and *skill* as primary data for repeated measures of flow during the learning
task. These have been reported to be reliable indicators for measuring flow (Novak & Hoffman, 1997).
However, the various flow models raise an important question in the use of the challenge-skill ratio when
studying flow in a short-time educational activity, such as the one-hour learning task used in this
research. How does one determine appropriate thresholds of challenge and skill from which to
‘normalise’ the flow diagram? For week-long studies that monitor flow throughout the day, an
individual’s average is a clearly appropriate choice. It represents the ‘background’ levels for an individual
and flow experiences can be expected to rise above these mean levels. However, there is no such valid
measure available for the 40 to 60 minutes that a student might undertake a learning activity. A session-
average value of the challenge-skill ratio would make a student who experienced flow through an entire
activity look the same as one who was consistently bored. Similarly, to standardise scores based on group
averages can cause problems if the group’s mean perception of challenge is not the same as their mean
perception of skill (Ellis et al., 1994). Hence for this study I used each student’s individual challenge-skill
recording without any normalisation.

This study, rather than attempting to attach fine-grained labels to the overall state of an individual’s
performance during an activity, took the approach of describing the progress of the individual in terms of
tracking challenge and skill recordings during the activity. Participants worked through a learning task
comprising seven activities lasting up to one hour in total. At the end of each of the seven activities a
probe, using 5-point Likert scale ratings, was presented to record their perceptions of challenge and skill.
The choice of a 5-point scale was considered to have sufficient resolution for students to record their
responses on, as has been used by others (Ellis et al., 1994). The probes were positioned one above the
other on the screen as shown in Figure 5-3 to increase the likelihood that participants would use consistent referents for both scales. Ellis, Voelkl and Morris (1994) expressed concern about ambiguity of the task that such measures refer to. That is, when asked to rate challenge in many experiments is was not clear which of several of possible tasks the participant might refer to in their response. This problem is minimised in this experiment by the focussed nature of the activities and the wording of the probe referring to ‘this last activity’ (Figure 5-3).

![Figure 5-3 Probe used to measure challenge and skills](image)

Data from these probes were used to map the movement of each student through the 2-dimensional challenge-vs-skills space during their interaction with the activities. This was consistent with Csikszentmihalyi’s (1975) model of a learner moving up the flow channel as they progress through a learning exercise.

In categorising students’ flow-states from these challenge-skill measurements, Csikszentmihalyi’s (1975) three-channel model of flow was used. This is consistent with his ideas that the flow channel appropriately represents the movement of a learner through an activity. Students were considered to be in flow when their rating of challenge and skill scores were equal, to be anxious when challenge was greater than skills, and to be bored when challenge was lower than skills, as represented in the 3-channel model discussed in the previous chapter and reproduced in Figure 5-4. The raw scores were used from these scales (Larson & Delespaul, 1990) in order to preserve any effects of individual differences due to autotelic personality disposition (Csikszentmihalyi, 1975; Csikszentmihalyi & Csikszentmihalyi, 1988).

![Figure 5-4 Csikszentmihalyi’s original model of flow](image)
Method 2: an overall-state measure of flow
The process measures of flow described above were compared with overall-state measures based on engagement, enjoyment and perceived control. This second measure was obtained using an 11-item survey administered at the end of the learning exercise, again using 5-point Likert scales. Previous work has validated these scales and proposed that these indicators can be used to provide an overall impression of flow during learning (Trevino & Webster, 1992). Appendix B-10 lists the 11 survey questions used and Appendix B-11 shows the questions within the context of the Web post-survey pages. Factor analysis was used to identify common factors from these questions. This provided a much coarser-grained view of each student’s state, but a reflective one more in line with Csikszentmihalyi’s (1975) original work on flow. More details on these measures are given in Section 0.

5.2.6 Participants
To ensure statistical validity, sufficient participants were required in two groups: a group with weak physics background and a group with stronger physics background. Finding sufficient participants with weak backgrounds was not a problem as a relatively large cohort of students studying Information Systems was readily available. However, I could not find as many as I would have liked with stronger backgrounds. This made it hard to draw significant conclusions from some aspects of the experiment.

The participants used were 42 first year Information Systems (IS) students and 17 first year Physics students. Forty-five percent of the participants were male students and 55 percent female students. All were paid volunteers and spent about one hour working through the set exercise in a computer lab. All the participants had studied physics at some time during the last two years of their secondary schooling; the physics group had also been exposed to the area of physics presented by the experimental materials earlier in the year as part of their university course.

5.2.7 Data collection procedure
Participants were randomly allocated to the simulation-mode group or the movie-mode group as they entered the laboratory session. All instructions were on a Web site that guided them through introductory materials, learning activities and posts-tests. Each participant worked individually. A small group of students was interviewed informally about their experience immediately after they finished the learning exercise.

Figure 5-5 shows the sequence of information-gathering Web pages presented to participants before, during and after the learning task. They were first presented with a screen requesting general background information about themselves followed by a pre-test to establish their prior knowledge of this area of physics (19 multiple-choice items, Appendix B-2). After an introductory screen, they worked through the seven physics learning pages each immediately followed by the challenge-skill probe asking them to rate, on a 5-point Likert scale, how challenging they found the last activity and their perceived skills to meet the challenge (as shown earlier in Figure 5-3, p.111). Next, they were presented with a post-survey asking them to reflect on their experience (the Web pages are presented in Appendix B-11). This comprised six questions. The first question was an 11-item set that gathered information about affective aspects of their experience. The remaining asked about their understanding of the meaning of ‘challenge’; the efficacy of the feedback; whether they had moments of learning and if so what were they; whether they experienced
a sense of loss of time; and whether they had any suggestions to improve the learning experience. They then completed a post-test that measured their learning gains using the same question items as the pre-test.

![Figure 5-5 Progress through the activity](image)

Participants’ movement through the Web pages and their detailed interactions with the simulation were recorded using Web-logs. Together, these logs recorded page navigation, mouse clicks, movies played, actions within the simulation as well as the time spent directly manipulating the simulation (dragging the cart, in this instance).

5.3 Results and analysis of data

The two sets of analyses reported here relate to the more traditional survey data gathered at the end of the task and the tracking of challenge-skill data throughout the task. These have been described in this section as an overall-state perspective on students’ flow experiences and a process perspective on flow, respectively. By analysing the data through these two approaches, the four research questions are answered.

5.3.1 Mapping challenge and skills onto flow space

Before addressing the first research question, a question arises in relation to the definition of flow. Should an indication of flow be restricted to a balance of challenge and skill, but only at high levels? Or should a balance indicate flow even if the levels are relatively low? Csikszentmihalyi gives a clue to the answer in his defence of his original 3-channel model compared to a normalised 4-channel model:

(It) is a composite diachronic model illustrating how the flow experience proceeds through time, in a single activity, (original emphasis) from enjoyment of small challenges when a person’s skills are limited, to an ever-complexifying enjoyment of higher challenges requiring increasingly rare skills.

(Csikszentmihalyi & Csikszentmihalyi, 1988 p. 261)

In a learning context it is crucial that a flow model allows for the situation in which a novice with low skills might flow whilst interacting with an appropriate low challenge task. It is thus appropriate to use a model that interprets flow as happening whenever challenge and skill are balanced, whether the individual values are high or low. Whether the lower extreme of these values (challenge = 1, skill = 1) should be regarded as flow or apathy is unresolved.
The first step in mapping the challenge and skill ratings was to cross-tabulate all seven pairs of responses from each of the 59 participants. The resulting patterns are shown in Figure 5-6, which is arranged to make easy comparison with the states of the 3-channel model shown next to it (Figure 5-7). Some participants did not complete all ratings.

![Figure 5-6 Likert scores for 59 students on challenge-skill measures (7 measures each)](image)

![Figure 5-7 The 3-channel model of flow](image)

The challenge and skill rating pairs were then classified as indicators of anxiety, flow, or boredom as defined by the 3-channel model of flow (see Figure 4-4 in previous chapter). The result of this classification is shown in Figure 5-8. It shows that flow accounted for about one-quarter of the 399 recorded experiences. There were also a substantial number of anxiety experiences reported (more than one third).

![Figure 5-8 Frequency of flow experiences](image)
5.3.2 Results 1: the overall-state perspective on flow (RQ2.1)

The first research question asked:

**RQ2.1: How is the perception of control affected by features of a learning task?**

The answer to this came from analysing the post-survey responses, which also gives one perspective on the flow experiences of the students. Since I wanted to find the minimum number of factors that would account for the maximum portion of the variance in the data, I chose to use principal components analysis to reduce the eleven items to a smaller set (Coakes & Lydall, 2001; Hair, Anderson, Tatham, & Black, 1998). The question of sample size for this sort of analysed has been argued by researchers for a long time, some looking at total number of subjects and others at the ratio of subject to items (Osborne & Costello, 2004). The sample size here was 59 students, which is a little low, however the subject to items ratio was just over 5, which is acceptable.

It was expected on the basis of previous research that the eleven items in the post-survey would distinguish factors of engagement, enjoyment and control that would then be used to produce a measure of flow (see Appendix B-10 for the specific items). However, the principal components analysis produced only two factors with eigenvalues greater than one and these two factors together accounted for 64.6 percent of the variance (details of the analysis are given in Appendix B-12). After varimax rotation two of the items did not load clearly on either of these two factors and were dropped (MSA <0.5). These two items were: (d) ‘I thought about other things’, and (h) ‘I was aware of distractions’. These two items were intended to load with item (b), ‘I was absorbed by the activity’, to produce the engagement factor. The two factors generated by the principal components analysis were labelled ‘enjoyment’, and ‘control’. Table 5-1 shows how these two factors relate to the survey items as shown in the rotated component matrix (items a, g and j are negatively weighted).

<table>
<thead>
<tr>
<th>Factor label</th>
<th>Item</th>
<th>Component</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Enjoyment</strong></td>
<td>Q (e) I found the activities interesting</td>
<td>.900</td>
</tr>
<tr>
<td></td>
<td>Q (b) I was absorbed intensely by the activity</td>
<td>.831</td>
</tr>
<tr>
<td></td>
<td>Q (c) I found the activities enjoyable</td>
<td>.815</td>
</tr>
<tr>
<td></td>
<td>Q (i) the activities excited my curiosity</td>
<td>.748</td>
</tr>
<tr>
<td></td>
<td>Q (g) the activities bored me</td>
<td>-.738</td>
</tr>
<tr>
<td><strong>Control</strong></td>
<td>Q (f) I was frustrated by what I was doing</td>
<td>.833</td>
</tr>
<tr>
<td></td>
<td>Q (a) I felt in control of what I was doing</td>
<td>-.799</td>
</tr>
<tr>
<td></td>
<td>Q (k) It required a lot of effort for me to concentrate on the activities</td>
<td>.758</td>
</tr>
<tr>
<td></td>
<td>Q (j) I knew the right thing to do</td>
<td>-.749</td>
</tr>
</tbody>
</table>

(Factors < 0.3 not included)

Reliability analysis gave Cronbach’s alpha of 0.86 for the enjoyment factor and 0.79 for the control factor. The psychometric properties of these factors could not be improved by removing any further items. The negative items were reversed then the scores on the two factors ‘enjoyment’ and ‘control’ were summed to produce a value for flow from the survey items. This score was labelled ’flow-final’ and represents the overall-state of flow as reported by the participants reflecting on their learning experience. Separate factor scores for both ‘enjoyment’ and ‘control’ factors were also used in the analyses.
The design of the study allowed for testing how the overall-state of flow was related to learning condition, movie or simulation, and to participants’ course of study, Physics or Information Systems. This produced a 2x2 design and analysis of variance was used to test whether learning condition and course of study were significantly associated with ‘flow-final’. Similar analyses were performed for the two component factors of ‘enjoyment’ and ‘control’. There were no significant differences in ‘final-flow’ associated with either learning condition or participants’ course of study, and there was no significant interaction between these design variables.

**Impact of ‘enjoyment’ and ‘control’**

When the separate ‘enjoyment’ and ‘control’ factor scores were analysed significant differences in ‘control’ factor scores were found to be associated with the participants’ course of study. T-tests were used to compare these scores; the general assumptions for such tests are that the data be at the interval or ratio level of measurement, randomly sampled and normally distributed in the population (Coakes & Lyndall, 2001). These conditions were appropriate for these data. Table 5-2 shows the results of t-test analyses comparing the mean control factor scores for the students, broken down by mode and cohort. The difference between cohorts for the whole group was significant (p<0.05), and almost significant between cohorts for just the movie mode students (p=0.06). The smaller number of students in the divided cohort made this statistic a less reliable one to measure.

<table>
<thead>
<tr>
<th></th>
<th>IS students</th>
<th>Physics students</th>
<th>All students</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Movie mode</strong></td>
<td>-0.34&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.40&lt;sup&gt;b&lt;/sup&gt;</td>
<td>-0.13</td>
</tr>
<tr>
<td><strong>Simulation mode</strong></td>
<td>0.05</td>
<td>0.52</td>
<td>0.12</td>
</tr>
<tr>
<td><strong>Both modes</strong></td>
<td>-0.19&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.46&lt;sup&gt;a&lt;/sup&gt;</td>
<td></td>
</tr>
</tbody>
</table>

<sup>a</sup>denotes p<0.05; <sup>b</sup>denotes p=0.06

The IS group scored a significantly lower standardised mean control factor score of –0.19 compared to the Physics group’s mean control factor score of 0.46 (F(1,56)=5.53, p<0.05). It was expected that Physics students would feel more in control given that they were more familiar with the physics domain than were the IS students. It was also expected that the simulation condition participants would report greater perceptions of control than the movie condition participants. Although the mean values of control for these two groups differed in the predicted direction (simulation: 0.12; movie: –0.13) this difference was slight and not statistically significant (p=0.35). The IS students consistently reported lower control scores than the Physics students, and the movie mode consistently lower than the simulation mode.

There were no significant differences between groups for the enjoyment factor but the average 5-point Likert scale score of 3.61 (s.d. 0.75) for these items indicated that participants enjoyed the experience.

**Flow state frequencies derived from challenge-skill measures**

The seven progressive measures of challenge-skill data provided information on students according to the frequencies of occurrences of the three flow states: anxiety, flow and boredom. Descriptive statistics, grouped by course (IS or Physics) and mode of interactivity (simulation or movie), were calculated by
categorising of each student’s probe responses into one of the three states. From the total of 59 students, each responding to seven probes, there were 399 valid responses.

Treating the 59 students as one cohort, 50 (85%) students recorded at least one instance of flow, the rest being evenly distributed between boredom and anxiety. A Chi-square test was appropriate for non-interval data of this type (Coakes & Lyndall, 2001) and was carried out assuming the expected frequency of the three states to be equal. Out of the 396 recorded states, the frequency of anxiety was slightly higher than expected at 39%, boredom slightly lower at 28% and flow normal at 33% (sig. <0.05).

Examining the differences between the Physics cohort and the IS cohort showed that the predominance of the anxiety state was due to the IS students: 47% of their recorded states were anxiety compared to only 22% for the Physics students (Figure 5-9). Consequently the flow and boredom states for the IS students were both low at 27% and for the Physics students they were 46% and 32% respectively. These data tell us that the Physics students were by far the most frequent at experiencing flow overall.

![Flow states for each cohort](image)

**Figure 5-9 Distribution across the 3 states for both cohorts**

Not only did Physics students flow more often, they also showed greater sensitivity to the mode of interactivity, with the Physics movie students’ flow events outnumbering the Physics simulation students’ flow events 59% to 35% (sig. <0.01). Figure 5-10 shows this distribution of states for the IS and Physics students respectively. Bearing in mind that the number of Physics students was much lower than IS students (17 compared to 42), the first plot shows the IS students having a similar pattern for the ‘simulation’ and the ‘movie’ modes, whilst the second plot shows that Physics students exhibiting a significant difference between the two modes. It is interesting to note that, for the Physics students, it was the movie mode that recorded many more flow states than expected and the simulation mode group more bored states, even though it was the simulation that offered more interactive engagement. This is discussed further in the discussion section of this chapter.
Summary

In summary, when flow was measured using the end-of-task survey, no difference in flow was found between the two different courses of study (Physics and IS), nor between the two different learning conditions (movie and simulation). In answer to the research question, Physics students perceived greater control than IS students, but no such difference in control or enjoyment could be found between the learning conditions. When flow was measured by challenge-skill ratios, the IS students recorded greater anxiety than the Physics students, but showed no distinction between the learning conditions across the three flow states. The Physics students, on the other hand, had low recordings of anxiety, but showed a distinction between learning conditions: the movie mode recorded greater occurrences of flow while the simulation mode recorded greater instances of boredom.

5.3.3 Results 2: the process perspective on flow (RQ2.2 and RQ2.4)

The second and fourth research questions ask:

*RQ2.2: What is the changing nature of students’ challenge-skill perceptions through an online learning task?*

*RQ2.3: How does flow measured using challenge-skill ratios compare to flow measured from post-survey data?*

To answer these I have created the concept of ‘flow-paths’, which are used to visualise the changing challenge-skill perceptions. Later these are compared to post-survey data.

Flow-paths for individual participants

Data from the seven challenge-skill probes were used to plot each individual’s flow-path through the learning exercise. These plots give a record of how an individual’s flow state changed regardless of the number of channels in the flow model used to label those states.

Plots for two participants are shown in Figure 5-11 and Figure 5-12. Each square represents one of the 25 possible states defined by the two five-point Likert scales as represented in Figure 5-6. A filled diamond represents the participant’s challenge-skill perception on the first activity of the learning exercise; a smaller filled circle represents the final activity. Each point has had a small random value added to
separate overlapping points on the plot. The dotted ‘flow-line’ represents the ideal flow condition of challenge = skill. The hollow circle represents the ‘centre-of-gravity’ of that participant’s plot.

The first plot, Figure 5-11, shows the challenge-skill path of a participant who performed very well on the exercise in terms of learning outcomes. It shows us that this participant began the exercise with relatively low skills and perceived the first activity to be relatively challenging. By the second activity she found the activity more challenging but also rated her skills as having increased to meet the challenge. The third activity presented less of a challenge and she still perceived her skills as increasing. The final two activities presented more challenge and this participant felt her skills were becoming increasingly less adequate for what the task required.

Some of this plot is consistent with a flow model of learning: the participant’s perceived challenges and skills grew together through the first part of the learning exercise. However, for this participant the final activities were difficult and she ended up in a state of anxiety.

The second plot, Figure 5-12, shows the path for a participant who scored a near perfect score on the pre-test but showed a degree of boredom during the process. This participant actually obtained a lower score for his post-test than his pre-test. The plot shows the participant beginning and ending well into the boredom region, with an excursion closer to the flow line for four pages.

Inspecting such plots for the cohort of 59 participants does not show any clear pattern linking these flow-paths to any of the post-survey flow measures. For example, using a flow rating value that is calculated from summing the percentage values of the enjoyment and control factors (Flow-final), the participant in Figure 5-11 had a flow value of 71% and the participant in Figure 5-12 a value of 57%. Examples can be found of participants who did spend most of their time on the flow line, yet still returned overall flow scores that were relatively low. Similarly some participants who scored highly on this flow measure spent significant time in the anxiety or boredom regions of the flow-plot. It is an interesting feature of these plots generally that participants showed considerable movement throughout the challenge-skill space. Rarely did a participant stay in one cell of the space or stay on the flow-line. This movement in and out of flow contrasts with Experience Sampling Method studies that identify instances of flow during several days of probing (Csikszentmihalyi & Larson, 1984; Massimini & Carli, 1988) or studies that gather reflections of flow after the event (Ghani, 1995; Trevino & Webster, 1992). The outcomes here suggest
that a single flow measure recorded at the end of the session cannot relate well to the overall experience when viewed as a process. In Section 5.3.4 a new alternative measure is present which captures better the flow experiences during the session.

**Flow-paths for groups of students**

Two other visualisations have been found useful in helping to interpret these flow patterns. After identifying specific groups of participants, an average group flow-path point was calculated for each of the seven activities and displayed these in two ways: (i) plots of average flow-paths in challenge-skill space, and (ii) plots of challenges and skills versus page (screen) number (Figure 5-13 and Figure 5-14, respectively). Both visualisations present the same information, but each offers a slightly different perspective.

The groups used for this exercise were three groups of ten ‘extreme’ students based on their pre- and post-test scores. They were chosen to see how their patterns of behaviour shed light on interpreting flow patterns in relation to learning:

1. ‘Learners’: those who learnt most by changing the greatest number of incorrect answers to correct answers
2. ‘Changers’: those who changed their thinking most, but by changing incorrect answers to different incorrect answers
3. ‘Unlearners’: those who ‘unlearnt’ most by changing correct answers to incorrect answers.

These groups of ten were chosen since, recording extreme values for each of the categories, they offered possible alternative insights into the flow process. Examining some of these plots gave a useful perspective to the flow process.

Figure 5-13 shows the average challenge and skill data for the ten ‘Learners’. Note that both challenge and skills at first rise in a similar fashion, then skills tend to fall away from challenge in the final activities. The same information is presented as a flow-path in Figure 5-14, the participants moving up the path from bottom to top.

![Figure 5-13 Challenge and skills for ‘Learners’](image1)
![Figure 5-14 Flow-path for ‘Learners’](image2)

The first section of these plots presents what one might ideally expect from participants who are engaged in the tasks and finding them well suited to their skills. For three consecutive activity pages their skills
improved to match the challenges presented. On the fourth page (p5 on the plots), although they did not report the task as being any more challenging, they rated their skills as being less adequate. This moves them towards the ‘anxiety’ region. From then on the tasks appear to be increasing in challenge and their perceived skills appear to decline. The characteristics of flow that they had in the beginning shift towards anxiety.

What caused the change to skill perception on the fourth page (p5)? The task on that page introduced a physics situation that many of the participants found confronting, namely, that the cart was moving in one direction while it was accelerating in the opposite direction. This page produced the highest average challenge score for all participants. This physics situation is a counter-intuitive one that often causes physics students difficulty. It appears that it disrupted the movement up the flow line and the participants, on average, moved towards a state of anxiety. I will discuss the effects from this particular activity again in the next section.

Figure 5-15 and Figure 5-16 show representations of the ten ‘Changers’ – those who changed many answers between pre-test and post-test but were still answered them wrongly. This group perceived consistently high challenges and relatively low skills (Figure 5-15) resulting in their flow-path being in the ‘anxiety’ region (Figure 5-16). Neither the challenge nor skill averages changed by very much. This is echoed in their individual flow-paths that show the majority spending most of their time in the same space on the plot.

These participants were clearly challenged beyond their ability. They did not report experiencing increasing challenge nor did they report changes in skill. As a group they had very low pre-test scores and generally performed worse after the exercise than before it. It is likely that they had trouble coping with the exercise and were either confused or guessing when it came to answering the post-test questions.

Figure 5-17 and Figure 5-18 represent the ten ‘Unlearners’. When they started they perceived their skills to be a little higher than the task challenge, a slightly bored pattern. However, as the activities progressed they reported challenge increasing but little change in their skills. By page 5 (p5) their challenge and skills ratio was well balanced. In spite of spending much time in what we label the flow region, they changed many of their correct pre-test responses to incorrect in the post-test. Again, their challenge-skill ratings don’t change significantly, unlike that of the ‘Learners’. Their pre-test scores were relatively high, two of them outstanding at 17 and 18 out of 19, respectively. Yet even these highly competent students
reduced their score during the post-test. They were slightly bored early on in the activity, and gained no benefit from it.

![Average Challenge and Skills](image1.png)  ![Average Challenge and Skills](image2.png)

**Figure 5-17 Challenge and skills for 'Unlearners'**  **Figure 5-18 Flow-path for 'Unlearners'**

It is important to note here that each of these plots is an average for a group of ten participants. Although they show steady behaviour, the individuals moved around the space significantly. For example, the individual flow-paths that contribute to Figure 5-18 show three participants who spend significant time on the ‘anxiety’ side of the flow-line, even though the group average shows boredom. These are, of course, balanced by other participants spending more time in the boredom area. These average plots are, however, useful in helping identify trends and suggesting hypotheses to be investigated further.

**Summary**

This analysis has shown that students exhibit much movement through the challenge-skill space suggesting different reactions to the challenges presented by the learning materials. Evidence has been found of learning being associated with gradually increasing and balanced challenges and skills, until the task provided a particularly difficult challenge. Similarly, groups who did not experience learning gains were seen to have perceived challenges too high for their skills, or challenge-skills ratios suggesting boredom or lack of interest.

**5.3.4 Quantifying challenge-skill mappings (RQ2.3)**

Challenge-skill plots give a 2-dimensional view of the flow state in contrast to the 1-dimensional view calculated from the analysis of survey data and most published models. Research question RQ2.3 aimed to compare this 2-dimensional ‘flow-path’ view with that derived from the survey administered after the activity:

*RQ2.3: How does flow measured using challenge-skill ratios compare to flow measured from post-survey data?*

In order to make statistical comparisons between these two measures, the challenge-skill plots had to be quantified. This was achieved by defining ‘from-flow-distance’ as a measure of how far an individual challenge-skill ratio is from the flow-line (challenge/skill = 1). The resulting from-flow-distance measure has been explored in two ways. Firstly, it was used as an *unsigned* quantity where a value of 0 represents maximum flow and a value of 1 represents the furthest distance from flow, that is, either maximum
anxiety (challenge = 5 and skill = 1), or maximum boredom (challenge = 1 and skill = 5). The second form of from-flow-distance involved using signed values such that maximum anxiety is presented by −1 and maximum boredom by +1. Both representations of from-flow-distance gave similar results in the analysis described below. This is due to the fact that much of the data in these plots is attributed to the IS students who were generally in the anxiety region. The rest of the analyses reported here use the signed from-flow-distance quantity.

The expression for this quantity was derived from the geometry of the 5x5 challenge-skill space by observing that each difference of one between challenge and skill values moves a point 0.25 units away from the flow line. This is represented as follows:

\[
\text{from-flow-distance} = 0.25 \times (\text{skill} - \text{challenge})
\]

![Figure 5-19 Calculation of from-flow-distance](image)

A value of from-flow-distance was calculated for each participant for each of their seven activities as well an average value which was calculated for an individual’s whole experience. The seven individual activity values for each participant were correlated with an overall-state flow value in order to check for evidence of a recency effect influencing this flow value. The flow value used was the flow-final value so as to help understand its relation to the whole task. A correlation value was calculated between the from-flow-distance and the final-flow scores for both cohorts of students for each of the seven pages of the exercise; these values are displayed in Figure 5-20. Correlation values for pages 2, 5, 7 and 8 were above the critical value (\(r_{\text{crit}} = 0.322, p<0.02\)).
The graph shows strong primacy and recency effects on pages 2 and 8 respectively (page 2 contained the first learning activity, page 8 the last activity). This suggests that flow-final (the overall-state) as measured by the survey may be influenced by participants’ experiences on the final page of the task. The spike on page 5 is interesting. This is the confronting task discussed in the last section that caused the ‘learners’ to have difficulty and move out of flow. This particular challenging activity appears to have a disproportionate influence on participants’ survey item judgements.

It is interesting to compare this analysis with the definition of flow used by Novak and Hoffman (1997). They define a flow-aphathy dimension as ‘skill + challenge’ and a boredom-anxiety dimension as ‘skill – challenge’. Hence their boredom-anxiety dimension is equivalent to the signed from-flow-distance defined above and appears to suggest that the correlations in the above analysis actually relate to boredom rather than flow. A check on the distribution of flow-states suggests that this is not the case. Most of the data points are in the anxiety quadrant of the challenge-skill plots, hence the correlations are telling us how far each point is away from anxiety along the line towards flow, but rarely crossing over into the boredom region.

Recalculating these correlations for just those who rate low on the flow-final score (omitting those whose flow-final value is above the mean) gives even stronger correlations. This is the group who show greater anxiety on the boredom-anxiety dimension. That this sub-group has a stronger correlation is consistent with the more anxious participants being the ones who contribute most to the correlation, rather than those few participants in the boredom state. The fact that the signed and unsigned values of flow-final give similar correlations also supports this. A check on using Novak’s flow definition of ‘challenge + skill’ showed no significant correlation between page flow values and the flow-final value. Clearly there are many subtle nuances to these measures that warrant further investigation.

**Summary**

Challenge-skills measures and post-survey measures were approaching flow from two different angles: challenge-skill measures represented an ongoing process that varied significantly with the learning tasks; the post-survey represented a reflective view over the whole activity. The latter was shown to be significantly influenced by the most recent task and any significant events along the way.
5.4 Discussion

For this investigation an online physics learning exercise dealing with issues of velocity and acceleration was presented to Physics and IS students. Two versions of the software were used, a movie mode and an interactive mode. All students worked through seven pages of learning activities designed to develop their understanding of the physics principles. Two separate measurement techniques were used to record students’ perceptions of the learning exercise in terms of their experience of flow. A survey administered at the end of the learning exercise followed traditional methods of measuring students’ overall-state of flow.

The special contribution of this study has been to examine measurement of flow from a process perspective, a sequence of states that potentially might change during the course of any learning exercise. The overall-state measure of flow involved students’ reflective judgements after the learning exercise had been completed. This new process form of measurement focused on students’ judgements at different points in the learning sequence. By comparing the flow results generated by each of these measurement forms I have identified important issues that, with further investigation, will expand our understanding of the role of flow experiences in students’ learning. Three major issues raised by the comparisons of these complementary forms of measurement will be discussed below: the role played by ‘control’ in this research, the consistency of results derived from overall-state and process approaches to the measurement of flow, and individual flow patterns for different learners.

5.4.1 The role of control in this experiment

I have interpreted ‘control’ to refer to both the choices that learners can make in choosing the path they follow through the learning materials, and also to the number of choices that they have whilst manipulating a simulation. Using this interpretation, the control aspects of this research can be described as having two components.

Firstly, the learners had a free choice as to the order in which they progressed through the pages of the activity. There were seven pairs of pages (introductory movie + simulation page) relating to the learning activities. The learner moved through these pages using ‘next’ and ‘previous’ buttons, and could use a navigation bar at the top of the screen to jump to any other page. In practice this choice was fairly constricted since the design of the activities strongly suggested that the best way to proceed was to progress from beginning to end. However, there was the option to jump back and revise an earlier page or to skip through and see what was coming up.

Secondly, the learner had a degree of control in relation to the use of the interactive simulation that appeared on the second of each pair of pages. Clearly the nature of this control was different depending on whether the learner was allocated to the ‘simulation group’ or the ‘movie group’. The simulation group could interact with the full range of options in the program. Typically this might mean giving the carts several ‘pushes’ at different speeds, attaching one, two or three fans on the cart to accelerate it, varying the slope of the track, or changing the graph scales in order to produce a better display of the plots. There were no restrictions on the extent of their exploration, nor any restrictions as to whether what they explored was relevant to the particular activity at hand. The movie group, on the other hand, were presented at each screen with several movie clips taken from the simulation. The movies were chosen to
present variations in the motion of the cart that were most likely to be helpful in exploring the activity. They could be run repeatedly, but, of course, they could not change parameters except by finding a movie that happened to offer that choice.

Clearly each group had been presented with a different degree of control that they could exercise over the simulation/movie. However, within the limits of the particular simulation/movie object, each group had full control over what was presented to them. Their perceived control was determined by how they reacted to this presentation rather than by what was designed into it. The analysis showed clearly that the Physics students perceived greater control than the IS students. This was not a surprising result – both the physics content and the physical context were more familiar to them. This is consistent with views that control depends on learner characteristics and complexity of the task (Dillon & Gabbard, 1998; M. J. Hannafin, 1984; Weller, 1988). Their control reflected how comfortable they felt with the material as well as their interaction with it. These students also achieved greater learning gains. This supports Schnackenberg and Sullivan’s (2000) experiment in which students in a learner control condition with higher ability scored better than others. However, in Schnackenberg and Sullivan’s experiment this was attributed in part to coverage of additional materials by the higher ability students; in the experiment described here, it was the additional interactions with the simulation that distinguished the students.

What was less expected was that the simulation mode students did not experience significantly more control than the movie mode students. To explain this we need to distinguish between the potential for control and the perception of control. Whilst the simulation gave the students complete control over how the simulation could be run, it did not necessarily give them a sense of actually being in control of this environment. They had choices to make – decisions as to whether what they were doing was right and whether the simulation was showing what was intended to be seen for the activity. In contrast, the movie mode students had far less control as to what motion they could run, but they had complete and simple control over how to run it. They could be sure that what they saw was the correct motion for the activity. This appeared to narrow the gap between these modes to the extent that the perception of control was very similar for both – the reduced control of the movie being largely offset by its simplicity of use.

Since it is perception of control that is an important parameter in determining the likelihood of flow, this suggests that when designing activities we need to carefully match the amount of control to the skills and experiences of the students. This applies both to the features being offered by the interactive object, as well as to the complexity of the material being offered to the student.

### 5.4.2 Distinguishing between Physics and IS students

There was a clear difference between the Physics and the IS students in that the IS students tended to be anxious, while the Physics students were in more control and more often reached a state of flow. This was not an unexpected result given that the IS students were outside their discipline area and often felt challenged beyond their abilities. What was unexpected, however, was that there was no difference between frequency of flow for the two different modes (simulation and movie) for the IS students, yet there was a clear and significant difference for the Physics students. It was the Physics students in the movie mode who recorded the most flow. The Physics students in the simulation mode were more likely to be bored, but still with more occurrences of flow than the IS cohort. One might have expected that the greater opportunity for interaction offered by the simulation would have supported greater control,
engagement and hence flow. Control was marginally greater for this group, but not significantly so. It is clear that the movie students had sufficient control over their tasks to become deeply involved and enjoy them; they possibly had even greater confidence in what they were doing since the movie clips they viewed had been pre-selected for them and hence were presumably ‘correct’ and ‘appropriate’. The simulation students were possibly less engaged in their learning tasks since they had to drive the simulation as well as focus on the physics; their minds might have been divided between dragging the cart, changing the settings or changing the scales of axes, as well as thinking about the physics they had to learn.

The simulation students were more interactive in the sense that they performed more mouse clicks to carry out these tasks, but we have no measure of their cognitive engagement in grappling with the physics concepts. This is an area for further study.

The motivations of the Physics and IS students were quite different. Both groups were paid to carry out the exercise, but the Physics groups had the added motivation of being self-selected into studying a first-year physics subject and had an end of semester exam coming up in a few weeks time. An informal interview with a group of six of the Physics students after the session showed the importance of this. During an informal interview after the learning session, several made comments such as ‘the activity reminded me of what I didn’t know’ and ‘it was useful revision for the exams’. This different motivation, as well as different physics background, might have contributed to the differences between these two groups.

5.4.3 Consistency of overall-state and process measures of flow

The process measure of flow used in the current study involved students’ ratings of their experience seven times during the learning exercise. Following the dominant practice in flow research, I defined flow in terms of balanced challenge and skill ratings. Approximately one-third of all the rating pairs indicated balanced challenge-skill ratings, i.e. flow. Independently, the responses to the survey questionnaires often indicated high levels of enjoyment and control, also interpreted as an indication that students did experience flow during this learning exercise. Just under one-half of the students reported in the survey that they were unaware of time passing at some stage during the activity.

However, while both forms of measurement point to students experiencing flow, at the individual level, there was no clear link between these two different methods for representing flow. The flow-paths suggest ‘turbulent flow’ experiences as students progressed through the activity, often moving between the three regions of flow, boredom and anxiety. This was true even for students whose post-survey data indicated an extremely high level of flow. Clearly these two measures of flow are measuring different aspects of students’ experience.

Although inconsistent with each other, both forms of measurement have the potential for providing insight into students’ learning experiences due to their different focus. There are two considerations to help understand these findings. Firstly, one would not necessarily expect students to flow consistently throughout a learning activity, especially one from outside their discipline area, as was the case for the Information Systems students. Although the learning exercise comprised seven related activities, the activities were sufficiently varied that some might engender a deep fascination and engagement, flow,
whilst others might allow attention to wander. The physics teachers’ holy grail of a student flowing throughout a physics learning activity and achieving deep understanding has not been observed in this study!

Secondly, we should consider whether overall-state measures of flow might reflect specific ‘high’ points in a learning exercise rather than being an average across the task. Specific points that may have undue influence on overall flow include the first (primacy effect) and the last activities (recency effect). Participants were asked to reflect on their experience and to respond retrospectively to questions about affective aspects of that experience. The results indicated that such reflection was not a considered average of their experience, but was significantly associated with specific points in the learning activities. The flow-distance measure gave evidence that recency and possibly primacy effects influenced the students’ responses. Although we have good knowledge about the operation of primacy and recency effects on recall of information, we know little about its operation on recall of affect. There was also some indication that a change in the difficulty level (challenge) of the activities may have influenced overall flow ratings. On page 5 of the learning activity the challenge-skill flow value correlated with the overall flow value. The particular physics concepts on this page might explain why students found this page challenging, but more significant is that it appeared to influence their final flow value. This suggests that retrospective measures of flow may also be influenced by one particular activity, a ‘challenging event’ effect, even though several others activities may not encourage flow. Further research is required here to help understand the meaning of an overall reflective judgement of flow and its relationship with experiences localised within the learning task.

The apparent operation of a recency effect, a primacy effect, or even the effect of a particularly distinctive activity within a learning exercise, is an important result for those measuring flow in an HCI context. If flow is a useful concept to assist with the design and evaluation of a task, be it a learning task or a general computing task, then the granularity of the flow measurement is an important criterion to consider. Too fine a granularity may interrupt the flow process itself, whilst too coarse a granularity may be heavily biased by the most recent experience or by a particularly challenging one.

Finally, I agree with Ellis et al. (1994) that the label ‘boredom’ is not a good descriptor for the high-skill/low-challenge state, as boredom is not usually regarded as a pleasant experience. Students showed no negative reactions to the experience and generally showed positive enjoyment, in both formal and informal feedback, even when being shown to be in the ‘boredom’ region. The term ‘relaxation’ more recently used by Shernoff, Csikszentmihalyi, Schneider and Shernoff (2003) is more appropriate.

5.4.4 Different flow patterns for different learners

By categorising students by their different learning outcomes, different patterns of flow behaviour have been identified. The plots of the ‘learners’ gave evidence that learning can progress in the manner postulated by Csikszentmihalyi (1988); this was quite distinct from the plots of the other groups. The plots of the ‘learners’ helped identify a point in the learning materials (page 5) where most students experienced a higher level of difficulty than was in keeping with the activities of the previous pages. This suggests that to maximize the likelihood of students, such as the ‘learners’ group, remaining ‘in flow’, we need to tailor activities to match the ongoing development of their understanding of the concepts being taught. Situations like this are likely to be the point at which many students ‘breakdown’ and either fail to
benefit further from the activities or look to their browser button to head off to another Web site altogether.

Other groups of students showed no such progression in their flow behaviour and no beneficial learning from the whole exercise. The flow patterns here helped identify students for whom this particular task was not well suited at all. They either maintained a state of mismatch between challenges and skills and hence made no progress in learning physics, or they progressed from a bored state to one closer to flow, but regressed in their post-test scores.

These flow patterns highlight that the relation between flow and learning is not a simple one. But then nor is the nature of learning a simple process. If we broaden the meaning of ‘learning’ to include knowledge beyond the desired physics outcomes of the activity, then the instances of flow identified in this paper might relate to incidental moments of learning. This type of learning would not show up in the tests but might include skills such as: new vocabulary, relating cart motions to graphs, impact of changing graph scales, etc. From the perspective of constructivist learning, some learning is likely to be taking place whenever students are in a state of engagement with appropriately balanced challenges and skills. This is supported by comments of Salomon (1996) who argued that constructivist learning environments should be accompanied by the assessment of the cognitive learning goals.

Some limitations
A significant difficulty in measuring flow using challenge-skill ratios is to have adequate knowledge of the referent for the ratings made by each student. Do they use the same standards in judging challenge as when judging skill? The issue is one of the validity of measurement. Similarly, do students use the same rating scales consistently across measurement points (reliability)? In other settings an alternative approach is to use the average from all students so that each student is effectively compared to every other one (Kronradt et al., 2003). However, this is problematic for the measurement of flow since the flow state is very much a personal perception of how challenging the task is and how adequate the learner’s skills are. Particularly in learning environments, the background expertise of each individual can be very different. I have not chosen to pursue these issues further in this thesis. Rather, I have chosen to probe flow more deeply by interviewing students, whilst retaining challenge-skill flow-plots as a useful visualisation of a student’s interactions.

A further issue not addressed in this experiment was to what extent the environment in which the students worked produced a state in the students that was conducive to flow. Finneran and Zhang (2003) point out the importance of state and postulates that a person is more likely to experience flow if his or her current state is conducive to absorption, time distortion and loss of self-consciousness. In this experiment there was no time limit set for the students. Whilst this was deliberate so that students would feel no pressure to hurry through the tasks, it might have had a negative effect on some who may have had a time constraint later in the day. If such a person were to check a clock frequently to be sure that they are not experiencing a time distortion, if would be difficult to experience flow. This issue will be addressed in the design of the next experiment by attempting to remove any feeling of time constraint from the students.
5.5 Summary and conclusion

The main research question for this experiment asked:

\[ RQ2: \text{ Of those influences on learner interactions, how do the flow concepts of control, challenge and skill describe learner interaction?} \]

The analysis has shown that flow is a very dynamic process. In a learning activity, students do not necessarily settle into a flow experience for an extended period, but are buffeted around by the varying challenges presented to them. By comparing recordings of challenge and skill throughout a learning task with measures of flow made at the end of a task, we have gained valuable insights into this experience. Flow was better described as a dynamic process rather than simply as a destination. The value in viewing flow from challenge-skill measures was illustrated by the detail revealed of the twists and turns that students underwent as they tackled the complex learning tasks. This was in contrast to the single reflective measure of flow that lost much of the rich information about their various experiences.

Mapping flow-paths was a novel way of exploring this process. It gave insight into the different patterns of learner behaviour leading to the following three conclusions:

- flow can be usefully regarded as a process rather than simply as a destination;
- there are both consistencies and inconsistencies between process and outcome measures of flow;
- the flow-path visualisation is a valuable tool in the analysis of the flow process.

Dividing the students into two different learning modes – movie and simulation – showed that increasing the number of degrees of freedom presented to the students did not result in an increased perception of control. Perceived control, it appears, relates more to the students’ perception of their ability than the features of the software presented.

The research, however, leaves some questions unanswered. Differences between the experiences reported by the Physics movie students and the Physics simulation students suggest that the students’ perception of challenge and skills was affected by the nature of the interactive task. The challenge-skill plots helped track students’ progress through a learning task, but they did not confirm, or elucidate, the nature of their experiences. We need a better understanding of what the challenge-skill measures were telling us, what characterised flow experiences during online learning, and what we can do to support flow.

To answer these questions we need to examine students more closely during a learning session. We need to engender in them a strong motivation to learn, and then explore their learning behaviour in terms of flow constructs. This is the aim for the next experiment.

Summary and findings of Research Question 2

\[ RQ2.1: \text{ How is the perception of control affected by features of a learning task?} \]

\[ F2.1: \text{ Physics students perceived greater control than IS students, but no significant difference in the perception of control could be found between the learning conditions.} \]

\[ RQ2.2: \text{ What is the changing nature of students’ challenge-skill perceptions through an online learning task?} \]
F2.2: Students exhibit much movement through the challenge-skill space suggesting different reactions to the challenges presented by the learning materials.

RQ2.3: How does flow measured using challenge-skill ratios compare to flow measured from post-survey data?

F2.3: Challenge-skills measures can be used to describe a process of flow that varies greatly during a sequence of tasks. Post-survey measures can provide a reflective view over an entire activity that may be significantly influenced by a recent task or significant events along the way.

RQ2.4: How do patterns of flow relate to the learning outcomes of the students?

F2.4: Learning is associated with gradually increasing and balanced challenges and skills. But a particularly challenging task can disrupt this movement ‘up the flow channel’. Similarly, lack of learning can be associated with perceived challenges too high for the perceived skills, or balanced challenge-skills suggesting boredom or lack of interest.
Chapter 6

Experiment Three:
The Flow Experience

“Being completely involved in an activity for its own sake. The ego falls away. Time flies. Every action, movement, and thought follows inevitably from the previous one, like playing jazz. Your whole being is involved, and you're using your skills to the utmost.”

(Csikszentmihalyi, 1996b)
6.1 Introduction: obtaining a rich picture of flow as a process

In the previous chapter flow measurements were based on two established techniques: challenge-skill measures and a survey of affective measures. Although these have not been used extensively by others in an online learning context, the assumption was made that, between the two of them, they would provide a clearer picture of students’ flow and relate it to their learning outcomes. The experiment provided many insights into flow in this context and showed that flow is a complex process that can be explored in various ways. However, the measurements did not clearly identify flow in an unambiguous manner. I needed to examine the challenge-skill measures more closely and to gather richer, qualitative data of the students’ experiences.

Hence, the final research question to be addressed was:

*RQ3: How does flow manifest itself in an online learning task?*

This was examined through three sub-questions:

*RQ3.1: How does the flow process in a learning context, as measured by challenges and skills, relate to the experience of flow identified by Csikszentmihalyi?*

*RQ3.2: What are the features of an online interactive learning activity that maximise the potential for flow?*

*RQ3.3: What are the characteristics of flow as experienced by students during an online interactive learning activity?*

From answering these questions, a descriptive model of flow was constructed that represents students’ interactions in an online learning environment.

Despite their limitations, the flow-paths developed in Experiment Two provided a tool with which to view the process of flow and to observe changes in flow states of students as they worked through a complex learning sequence. However, they did not give a picture of how students felt about the other elements of flow: goals, feedback, control, engagement, self-consciousness, merging of action and awareness, time distortion and enjoyment. It has been suggested by some that the relative importance of the antecedents to flow might differ in a task which has a well-defined goal compared to an exploratory activity (Novak et al., 2003). Although challenge-skill ratios have been shown to be a valid measure of flow in a general Web context (Novak & Hoffman, 1997), questions still remain about what the challenge-skill measures were telling us about flow in online learning.

This final experiment presented a richer picture of the nature of flow by providing an analysis of qualitative data. It explored the notion that ‘challenge’ and ‘skills’ might have ambiguous meanings: did the challenge relate to the use of the simulation or to the physics concepts? It also addressed questions concerning students’ experience of flow. What were the important elements? What were students focusing on as they worked on the task? The resulting analysis was used to construct a model of flow as it applies in an online learning environment.

The exploration of these issues required a modified learning task providing significant intrinsic motivation that would maximise students’ chance of experiencing flow and achieving significant
learning. The new task was based on the materials developed for Experiment Two, but modified to give
the students greater control over how they explored the physics content. The motivation for their
exploration was provided by requiring them to teach aspects of the physics to another person after the
learning session was finished. Eight students were monitored individually throughout the task, their
learning outcomes were explored and they were interviewed about their flow experiences.

One of the aims of the interviews was to gain insights into what features of the task or artefact supported
flow. Whilst challenge-skill measures might indicate that the student was experiencing flow, they do not
tell what aspects of their activities were challenging, nor what they were referring to by a low or high
perception of skills. Similarly, other elements of flow needed to be examined more closely to help
develop an understanding of how they contributed to the experience in this learning context.

From these data a new model has been proposed describing the nature of a student’s flow interaction
during an activity and how it focused on either the given task, the artefact used to explore the task, or
both. This model helps us to appreciate how an artefact can either support students’ learning or,
unintentionally, distract from it. This is particularly important when the artefact is a highly interactive
multimedia object that may attract students’ attention irrespective of their learning goals. If the reason for
exploring flow in this context is to help design better learning experiences online, then we are not looking
just for engaging experiences, but ones that attract students to engage with new concepts and then, having
had a positive and enjoyable experience, to want to return for more.

In summary, two clear results have emerged. The first relates to the flow experience itself, how various
measures reflect it and how students perceive it. The second presents a new model of the flow interaction
supporting the proposition that the task (to learn physics, in this case) and the artefact (a Web-based
learning environment) need to be separated when assessing the incidence of flow.

This chapter is organised as follows. Section 6.2 describes the design of the learning materials and test
instruments, and presents the methods used to analyse the data. Section 6.3 describes the analysis of the
teaching and interview video sessions resulting in a table summarising the experiences of the eight
students. This table is discussed in Section 6.4 providing a synthesis of all the data. Section 6.5 describes
the analysis of the data in detail, presenting the qualitative data derived from the interviews. Section 6.6
discusses flow specifically in a learning context considering which features are important and what is
likely to be observed when someone experiences flow in a learning activity. A new model for flow is
presented in Section 6.7. Finally, the discussion in Section 6.8 shows how this model sheds new light on
the interpretation of data from Experiment Two.

6.2 Experimental design and method

This section describes the experimental design of this final experiment that used a qualitative research
approach to gain a richer understanding of students’ flow experiences. The first sub-section (6.2.2)
describes how the learning materials from Experiment Two were modified to produce a more highly
motivating student experience. The next two sub-sections (6.2.3 and 6.2.4) describe the design of the data
collection instruments and interview questions that related specifically to the elements of flow and to
probing the affective nature of the students’ experience. The next three sub-sections (6.2.5 to 6.2.7)
describe the participants and outline how the actual experiment was run and how the learning sessions and interviews were conducted, and data collated.

The final three sub-sections describe how the qualitative data were analysed. The data comprised a mix of formats: challenge-skill probes, Web interactivity logs, online survey responses, teaching video data, learning video data, test scores and interview data. The survey, interview, and test data were synthesised into a table (sub-section 6.3) in order to describe the flow experience of each individual participant. In the final section, 6.4, the process of identifying the emerging themes relating to tasks and artefacts is described as well as a process for internally validating these findings through triangulating the various sources of data. Finally I describe how these data were synthesised into a format from which conclusions could be drawn.

6.2.1 Approach taken

The data required to provide deeper insights into students’ flow experiences suggested that a qualitative research approach with a smaller number of participants was appropriate. Hence, in this experiment, extensive use was made of interview data in addition to the data types recorded in Experiment Two.

This experiment used an interpretive approach to gain rich and deep insights into the experiences that students had during the learning activities (Shanks, Rouse, & Arnott, 1993). Data relating to flow were collected using the same challenge-skill measures as were used in Experiment Two, but also by using interviews with students in which they were questioned about the elements of flow experiences as well as recollection of any particular flow events. The whole process for each student was video-recorded.

A novel aspect of this experiment was the technique used to motivate the students to work through the learning material in a studious fashion. Direct observation of students participating in the activity of Experiment Two suggested that some were not highly motivated by the learning task but had a clear aim to work though the activity, collect their payment, and leave. To minimise this, each student in Experiment Three was told that, after the learning exercise, they would be required to teach concepts that they had learnt to another student. This not only provided motivation for them to take the learning session seriously, but it also aimed to motivate them to learn the concepts required for the teaching session.

6.2.2 Design of learning materials

The aim of the learning materials was to provide a rich environment in which students could become engaged, explore and achieve some learning. In Experiment Two this was effected by a series of Web pages that led the students through a learning sequence. Pre- and post- physics tests were used to measure learning (Appendix C-1). These tests were similar to the ones used in Experiment Two, but modified slightly to be more relevant to the particular aspects of physics to be addressed in this exercise. The first eight questions used in Experiment Two were removed as they related to force and the current experiment dealt with acceleration only. The next three questions on tossing a coin were retained. The following eight questions were reduced and modified to produce five questions on acceleration rather than eight on force (they were the same questions, and same answers, but involved choosing an acceleration-time graph rather than a force-time graph). The final six questions related to velocity-time relationships, two of them coming from the well-established test known as the Force Concept Inventory (Hestenes & Halloun, 1995; Hestenes et al., 1992).
In this third experiment the aim was to take students beyond the reward of earning a few dollars, to give them greater scope to determine their own approach to the learning by providing more opportunity to explore and become fully engaged in the material. To achieve these goals the learning Web pages were modified and the extra exercise of teaching physics was added to increase motivation.

The new learning materials, using the same simulation object as in Experiment Two (iMotion), presented the students with four questions to explore (the Web pages are reproduced in Appendix C-2). Rather than direct the students as to what to learn, these questions simply stated a question that another (fictitious) participant wanted to understand, and asked the students to explore the simulation sufficiently that they could teach the required information to the other participant at a later time.

For example, the first question in the learning materials was:

‘I want to understand the idea of velocity - what it means and what a steady (constant) velocity would look like on a velocity-time and on an acceleration-time graph. Also the idea that velocity has direction - what do positive and negative mean in relation to velocity?’

Some initial guiding approach was offered to get students going:

‘Drag cart around, or give it a push and let go, to produce positive and negative velocity-time graphs.’

Then it was left up to them to direct their own exploration and to decide when to move on to the next question. Figure 6-1 shows how the four pages of physics questions, teaching session and interview, fit into the complete experimental session for a student. Note that the other components of the session were identical to those in Experiment two.

The motivation for the students to learn was provided by requiring them to teach another participant the physics ideas learnt in response to the four questions. The aim was to provide motivation through the students wanting to avoid the negative consequences of not being able to explain the ideas adequately (Morgan, 1993). The outcomes of the teaching sessions themselves – implemented by having a research assistant with physics background play the role of the other participant – provided a check on assessing students’ learning, which was useful to triangulate with the post-tests.
6.2.3 Design of post-survey and online data collection

This experiment had the same requirements as Experiment Two in relation to logging online data. The challenge-skill measures and interactivity data would provide a useful and rich reference should a student, during an interview, refer to a specific instance in their learning session. The post-session survey supplemented the interviews by providing an overview of the affective nature of their experiences. In summary, all these data were collected using the same techniques as for Experiment Two.

6.2.4 Design of interview questions

The aim of the post-session interviews was to obtain information about the students’ experiences while working through the task. A detailed description of the questions is given at the end of this sub-section; the questions themselves are presented in Appendix C-3.

In interviews of this kind, it is important that the questions be designed to address the specific research issues being investigated (Anfara, Brown, & Mangione, 2002). One of the aims of the research was to establish whether and when flow occurred so that comparisons could be made with the challenge-skill measures. The most direct way to do this was to semi-structure the interviews based on the elements of flow. Students were asked to comment on each of these in turn.

A second aim of this experiment was to gain a deeper understanding of the students’ experience of flow and to add internal validity to the data gathered in the earlier questions. ‘Internal validity’ describes the degree to which a research design ‘operationalises what it purports to study in a way that prevents alternative explanations for the results’ (Cook & Campbell, 1979). This was carried towards the end of the interview. Two descriptions of flow taken from the literature (Csikszentmihalyi, 1982) which have been used for various other studies on flow (Rettie, 2001) were read to the student. They were asked to talk about any experiences they had that might have been similar to the ones described.

To help explore the limitations of the challenge-skill measure of flow, I was interested to know whether the students’ reflections tended to focus on the learning task they had just completed, or the artefact that they used whilst learning. One possible approach would have been to probe students frequently during the interview as to whether they were thinking about the task or artefact, and to try to have them distinguish task from artefact in their comments. An alternative approach was to leave the interviews neutral on this issue and observe how it emerged from the data. The latter approach was chosen for two reasons.

First, it was desirable to avoid directing students’ thinking one way or the other. If, for example, they had had a strong flow experience by engaging with the simulation (the artefact), then I wanted them to recall that and focus on those feelings right through to the end of the interview. Questions directing them to think about the task would disrupt and distort their report.

The second reason was more of a pragmatic one. Each student had just spent about one hour working on a computer, including working through two tests. They had also spent about 30 minutes teaching aspects of physics in a one-on-one session with a stranger. To have extended the interview asking them to comment on both task and artefact at each question would place an unreasonable time burden on these (paid) volunteers.
**Description of interview questions**

The interview questions comprised four sections (antecedents, experiences, effects and flow; see Appendix C-3) and, whilst the entire interview explored elements of flow, I did not specifically mention ‘flow’ until the final section. The first section addressed the antecedents of flow: goals, feedback, balance of challenge and skills. It was designed to find out whether the required conditions for flow were perceived as being present by each student. Theses questions also allowed me to explore students’ interpretation of ‘challenge’ and hear how they perceived these challenges in relation to the activities presented.

The second section of the interviews addressed the students’ experience of flow: concentration and control. This gave an indication of their degree of engagement with the task. Many flow studies also try to gauge to what extent the participant experienced a merging of action and awareness. This can be a strong indicator of flow in activities with a strong physical component (skiing, rock climbing, surgery, etc.). However, in this exercise I decided not to pursue that particular concept, as it did not seem to fit, or be easy to express, in an activity where most of the action was of a cognitive nature and was conveyed by perceptions of concentration.

The third section probed the effects of flow: loss of self-consciousness, loss of a sense of time, and enjoyment. These affective elements are a crucial aspect of the flow experience. The questions allowed some discussion about distractions, how long they thought they had been working, and to express what aspects of the experience gave them enjoyment.

Finally, students were introduced to the concept of flow and probed as to whether they had any similar experiences during their session. If a student recalled having a flow experience, they were asked to try to recall when it occurred, and what they were doing at the time. This was also an opportunity to ask whether the student was aware of any learning taking place and whether they could articulate any new concepts learnt. These questions addressed the extent of the links between learning and flow.

### 6.2.5 Profile of the participants

The eight participants in the experiment were student volunteers who responded to an advertisement promising payment of $30. Four were male and four female (referred to initially in this chapter as students S1 to S8). They were all studying an Information Systems course at the University of Melbourne. Seven were in the first year of their course, and under 21 years of age; one (S1) was in his third year and was aged between 21 and 25 years. Six had completed and passed a physics subject in their final year of high school; two had done no physics prior to this experiment (S7 and S8).

Eight participants were chosen order to provide a variety of experiences yet a manageable number to cope with in terms of time and resources. It was not intended to form generalisations from the data hence a larger number was unnecessary. The interview data were analysed in an interpretive fashion to help describe the nature of participants’ flow experiences.

### 6.2.6 Conducting learning sessions and interviews

The students’ learning sessions, teaching sessions and post-interviews were all conducted in a usability laboratory. Each student was given a quick tour of the lab facilities to show them the control room and monitoring equipment. The student then sat alone in the lab and worked through the Web materials whilst
being monitored by three fixed cameras in the room. I observed the session from a control room through a two-way mirror and made notes on the proceedings. Each student was provided with a booklet containing the four questions (which were also on the Web site). They could write in the booklet if they wished. Students were told this booklet would not be available for the later teaching session.

After each learning session the students were introduced to a research assistant, who was actually a physics student studying for a Masters of Science by research. She was playing the role of ‘another participant’ who wanted answers to the four questions that the student had been learning about. This person was chosen for her strong understanding of physics and good teaching skills. It was important that she be able to play a role of not understanding the physics yet wanting to learn, and also of questioning the students to gain a measure of their understanding of what they had learnt.

The teaching session was conducted in an open-ended style. One video camera was used to record the research assistant, the student, and the whiteboard that the students were encouraged to use to aid their explanations. This provided a record of what the students said as well as their explanatory diagrams. The proceedings were observed from the control room and impressions of the degree to which the students understood each aspect of physics were recorded. These notes were to be used later in conjunction with the research assistant’s rating of the students’ understanding.

The post-interview session was conducted with the student in the same usability lab. This was also recorded by digital video camera.

6.2.7 Collation of learning session quantitative data

To provide quick access to the various data collected from each student during the learning session, a summary ‘Subject Profiles’ booklet was prepared that had some summary information on the group of eight students, followed by two pages on each student recording their demographic information, challenge-skill scores, survey and test scores, times on each section of the task, a further breakdown of test scores, flow-path, interactivity information and interactivity pattern. The front page of this document and one sample student’s page (S1) is presented in Appendix C-4.

6.3 Analysis of videos

6.3.1 Teaching sessions

The purpose of the teaching sessions, apart from motivating the students to work through the learning material in an engaged manner, was to provide a record of their understanding of the physics concepts presented. These tapes were not transcribed but were referred to as required to clarify students’ understanding of various aspects of the physics involved in the task.

After the teaching session, the research assistant examined each student’s understanding of the physics presented in the four questions of the learning exercise. This was done by first identifying the essential physics concepts associated with each question. This resulted in a list of 18 concepts – four or five for each question (Appendix C-5). By viewing the videos, each student was rated on their understanding of these concepts using the following zero-to-five scale:
0 – no knowledge
1 – very poor
2 – poor
3 – satisfactory
4 – good
5 – excellent

Appendix C-5 also shows the 18 scores for each student and summary scores that indicate their understanding of each of the four questions.

Ratings were checked against the observer notes and compared with students’ pre-test and post-test scores. The three measures of students’ physics knowledge, (pre-test, post-test and teaching session ratings) are shown in Figure 6-2, ordered from higher to lower demonstrated understanding of physics (based on the average of the post-test and teaching session rating scores). The teaching session ratings have been converted to a percentage (maximum raw score possible was 90), as have the test scores (maximum raw score possible was 14). This comparison is only a rough guide since the teaching questions do not have exactly the same coverage of the material as the test questions. There was consistency in the different measures of knowledge for students S1, S2 and S6: they each showed a thorough understanding in their teaching sessions that was supported by their test scores. S5 also showed a thorough understanding during her teaching session, but this was reflected in a significant improvement in her test score rather than a high absolute score – she started the session from a very low base in terms of physics knowledge (pre-test score of 2 out of 14 improving to 7 out of 14). S4 also showed a significant increase in physics knowledge but, together with the other three students, showed relatively low understanding during the teaching session and this was reflected in the relatively low post-test scores. Overall, this analysis showed good agreement between the two methods of measuring students’ physics knowledge.

![Figure 6-2 Students' physics knowledge as derived from pre-test, post-test and teaching session](image-url)
These ratings of physics knowledge also provided a view of the increasing difficulty of the physics concepts as the teaching session progressed. A summary of the average score that each student received for each of the four questions is shown in Figure 6-3. This figure charts the students’ understanding of the issues that were explored sequentially through the four questions of the learning session and shows that most students found the last two questions more challenging to explain than the earlier two. The three students showing good physics knowledge in Figure 6-2 (S1, S2 and S6) are shown near the top of Figure 6-3 with solid lines, one of them (S6) performing significantly worse on Question 3 than the other two. The two who showed significant learning gains (S5 and S4) are shown with dotted lines; they displayed a poor understanding of the latter questions. Of the remaining three, S3 and S8 (lowest two lines) showed relatively poor performance throughout the exercise. S7 declines significantly towards the end, and, although his performance looks similar to S6 in Figure 6-3, his post-test score (Figure 6-2) suggests that he is more similar to S3 and S8.

![Progress in Learning](image)

**Figure 6-3 Students’ understanding of the four physics questions**

To make future discussion of these eight students easier to follow, the students have been re-named to capture the essence of their physics understanding or learning (following the order of students in Figure 6-2). Three of the students (S1, S2 and S6) showed competent physics knowledge and have been named ‘Physicist_A’, ‘Physicist_B’ and ‘Physicist_C’. Two students (S5 and S4) showed weaker knowledge but displayed significant learning during the exercise; they have been named ‘Learner_A’ and ‘Learner_B’. The remaining three (S7, S3 and S8) showed weak physics knowledge and little learning; they are named ‘Nonlearner_A’, ‘Nonlearner_B’ and ‘Nonlearner_C’. These mappings, together with the average of their post-test and teaching session rating scores, are shown in Table 6-1.
Table 6-1  Renaming of students

<table>
<thead>
<tr>
<th>Name</th>
<th>Code</th>
<th>Average of post-test and teaching session rating scores</th>
</tr>
</thead>
<tbody>
<tr>
<td>Physicist_A</td>
<td>S1</td>
<td>100%</td>
</tr>
<tr>
<td>Physicist_B</td>
<td>S2</td>
<td>92%</td>
</tr>
<tr>
<td>Physicist_C</td>
<td>S6</td>
<td>85%</td>
</tr>
<tr>
<td>Learner_A</td>
<td>S5</td>
<td>67%</td>
</tr>
<tr>
<td>Learner_B</td>
<td>S4</td>
<td>52%</td>
</tr>
<tr>
<td>Nonlearner_A</td>
<td>S7</td>
<td>38%</td>
</tr>
<tr>
<td>Nonlearner_B</td>
<td>S3</td>
<td>33%</td>
</tr>
<tr>
<td>Nonlearner_C</td>
<td>S8</td>
<td>22%</td>
</tr>
</tbody>
</table>

6.3.2  Interview sessions

Technical aspects

The videos of the interview sessions were recorded in digital format and transferred to computer to be stored as *QuickTime* movies. The audio tracks from the interview were transcribed and annotated with headings related to the questions asked. Computer scripts were written to allow ‘*QuickTime* chapter tracks’ to be easily added to the *QuickTime* files so that different sections could be accessed quickly in order to view the context of the spoken words. This quick access to video segments proved extremely helpful when trying to gauge meaning of particular expressions that students made. In particular, responses to questions on enjoyment gave more meaning when synchronised with the student’s facial expression and their vocal intonation. The programming code written to achieve this is listed and explained in Appendix C-6.

Analysis of flow experiences

Interview data were analysed in six stages leading up to the compilation of an Interview Summary Document for each student’s experience (see sample document in Appendix C-7). The analysis was used to address three issues:

- to establish if and when each participant experienced flow and what they were doing at the time;
- to establish the degree to which each element of flow was present for each student during the learning session;
- to examine the degree to which students separated the ‘task’ from the ‘artefact’ in their reflections on their activity.

Stage 1: transcription. The eight interviews were transcribed from the audio track of the videotape and stored as separate word processor documents. The eight subjects were indicated in the transcriptions by their coded names.

Stage 2: coding flow experiences. The structure of each interview was based on the nine elements of flow (Csikszentmihalyi, 1975; 1993). Some comments related to an overall impression of the whole
activity (e.g. Learner_A’s comment on lack of self-consciousness: ‘It was the whole time’) while others were more specific to a particular task (e.g. Learner_A’s comment on time passing quickly: ‘with the simulation towards the end’).

Any comment that referred to a particular flow element was coded by that element (using the software ‘TAMS Analyser’). Passages of text with the same coding were collated and read and a judgement made as to the extent that the students experienced each element. Due to the fact that some students made little or no comment in some areas, the ratings were categorised simply as ‘low’, ‘medium’ or ‘high’. A sample page of marked-up interview transcription is given in Appendix C-8 together with a sample of the analysis process.

For example, in discussing control, Nonlearner_A comments ‘I think the computer had an upper hand’ and ‘It was presenting things and it tells you “this is what you can do” and use it to do this and press, and when you’re through go here, go here’. This was coded as ‘low’ for control. When Physicist_C was asked whether he felt that the computer was controlling him at any stage, his reply was ‘No I just use the computer to study what I want’. This was coded as ‘high’ control.

The only exception to this coding system was for comments relating to the challenge-skill ratio that were rated ‘bit low’, ‘good’ and ‘bit high’. This was in recognition that the optimum ratio for flow was in the middle of the scale (‘good’) rather than at one extreme.

**Stage 3: initial compilation of Interview Summary Document.** The beginning of a document was compiled comprising a summary comment of each participant’s experience written under each topic heading of the interview (a sample student entry from this document is given in Appendix C-7). By examining this material, in conjunction with the full transcripts and the video records, each student’s experience was rated in terms of how well they conformed to likely flow experiences. Those participants who had an appropriate challenge-skill balance (‘good’ or ‘bit high’) were classed as ‘flow’, and generally had ‘medium’ or ‘high’ for all other ratings. The exception was Nonlearner_B who had two ‘low’ ratings, but whose comments on those items were vague and low, rather than emphatically so. Those participants with a low challenge-skill ratio, or more than two ‘low’ ratings, were classed as ‘no flow’. The comments from one participant (Learner_A) suggested that she moved from not flowing early on to flowing later in the activity.

These data were entered into the summary table (Table 6-2, p. 145), which is discussed in more detail in Section 6.4.

**Stage 4: participant perception of flow.** At the end of each interview students were asked a direct question about flow to discover to what extent each student thought that they had experienced flow, and to be able to list the terms they used to describe flow. These assessments of flow were added to Table 6-2 and could then be compared with codings of flow derived from the rest of the interview. This comparison can be seen in the row labelled ‘Flow?’ in the table. A summary of the flow elements and emotions that they mentioned, together with what they were doing at the time, is recorded in a separate table in Appendix C-9. Although only two students made a significant contribution here (Learner_B and Nonlearner_A), the matrix provided me with a richer picture of the way in which they described their experiences, any emotions they mentioned and a check as to what they were doing at the time.
Table 6-2  Factors that appear to contribute to flow

<table>
<thead>
<tr>
<th></th>
<th>In flow</th>
<th>Flow w/o excitement</th>
<th>Mixed</th>
<th>No flow</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Physicist_A</strong></td>
<td>11(\rightarrow) 14</td>
<td>12(\rightarrow) 12</td>
<td>5(\rightarrow) 6</td>
<td>2(\rightarrow) 2</td>
</tr>
<tr>
<td><strong>Physicist_B</strong></td>
<td>Good</td>
<td>Good</td>
<td>Bit high</td>
<td>Bit high</td>
</tr>
<tr>
<td><strong>Physicist_C</strong></td>
<td>Good</td>
<td>Good</td>
<td>Bit high</td>
<td>Bit high</td>
</tr>
<tr>
<td><strong>Nonlearner_B</strong></td>
<td>M</td>
<td>H</td>
<td>H</td>
<td>M</td>
</tr>
<tr>
<td><strong>Nonlearner_A</strong></td>
<td>M</td>
<td>M</td>
<td>M</td>
<td>L</td>
</tr>
<tr>
<td><strong>Nonlearner_C</strong></td>
<td>M</td>
<td>M</td>
<td>M</td>
<td>mixed</td>
</tr>
<tr>
<td><strong>Experience</strong></td>
<td>Concentrate</td>
<td>H</td>
<td>M</td>
<td>M</td>
</tr>
<tr>
<td></td>
<td>Lack of self-conc.</td>
<td>H</td>
<td>L</td>
<td>H (sim)</td>
</tr>
<tr>
<td></td>
<td>Loss of time</td>
<td>H (real)</td>
<td>L</td>
<td>H (real)</td>
</tr>
<tr>
<td><strong>Effect</strong></td>
<td>Enjoy</td>
<td>M</td>
<td>H</td>
<td>H</td>
</tr>
<tr>
<td></td>
<td>Autotelic</td>
<td>Low</td>
<td>High</td>
<td>Med</td>
</tr>
<tr>
<td><strong>Flow</strong></td>
<td>Flow by above elements?</td>
<td>Yes - high</td>
<td>Yes - med</td>
<td>Yes - fairly high</td>
</tr>
<tr>
<td></td>
<td>Flow by specific flow question?</td>
<td>Yes - high</td>
<td>Yes - med</td>
<td>Yes - high</td>
</tr>
<tr>
<td><strong>Survey</strong></td>
<td>(\Sigma) survey flow data (1 – 5; Av 3.6)</td>
<td>3.4</td>
<td>3.8</td>
<td>3.8</td>
</tr>
<tr>
<td><strong>Interactivity</strong></td>
<td>Clicks (Av 198)</td>
<td>118</td>
<td>145</td>
<td>145</td>
</tr>
<tr>
<td></td>
<td>% interaction</td>
<td>2.4%</td>
<td>2.3%</td>
<td>0.8%</td>
</tr>
</tbody>
</table>

Key:

\(\rightarrow\) => Change through session
L => Low
M => Medium
H => High
* => student had no prior physics background beyond Year 10 at high school.

lang => student Physicist C mentioned having to concentrate due to language difficulties.

Loss of time ‘real’ => student estimated time and was significantly less than the actual time period.

Loss of time ‘not real’ => student estimated time and was quite accurate.

Sim => relates to simulation
**Stage 5: task-artefact focus.** Interviews were inspected to determine whether ‘task’ and ‘artefact’ references were the focus for instances of flow. A comment was coded as ‘task focus’ if it mentioned: physics terms; learning strategies or goals; learning difficulties; concepts; what the student was doing to accomplish the learning task; or comments suggesting thoughts about pedagogy. A comment was coded ‘artefact focus’ if it mentioned: specific aspects relating to control; design or features of the simulation not directly related to physics; instructions; or other aspects or limitations of the computer or its software.

**Stage 6: completion of Interview Summary Document.** Using the preceding data, the Interview Summary Document summarising each student’s experience was completed and used as a reference in the writing of this chapter. It presents student background information, survey scores, interactivity data, reflections on issues from the interviews, as well as data from the Stage 5 analysis relating to task-artefact issues.

### 6.4 Synthesis of data

In bringing all the various types of information together, it was useful to tabulate features from the interviews in order to look for similarities and differences and to make judgements as to the degree of flow for each student.

One important aim was to ascertain what students’ flow experiences looked like judging from their responses to the questions about flow elements, and to compare these with other measures of flow. Hence the summary matrix (Table 6-2) was used to compare and contrast different information from each student. The table is organised into five sections as follows. Section A shows the students’ pre and post-test scores. Section B shows how well student comments fit flow conditions for each of the elements mentioned in the interviews (this process was described in Section 6.3.2). Section C shows two ratings of flow: the first based on the flow elements in Section B and the other based on students’ responses to the specific interview question about flow. These were not always consistent. Section D contains the average Likert scores (1 to 5) from the survey questions on control, engagement and enjoyment (negative items appropriately reversed). As in Experiment Two, this gives some indication of flow based on models which use those factors (such as the models used by (Ghani & Deshpande, 1994; Webster et al., 1993). Finally, Section E presents interactivity data for reference, comprising the number of clicks performed by each student and the percentage of time they spent dragging the cart in the simulation.

The autotelic condition (in section B) was determined from observing students during the interview and also examining the videos afterwards. This was gauged by the responsiveness of each student when asked about their enjoyment of the session. Some students responded positively to questions about enjoyment but showed no particular signs of pleasure or excitement. It is this aspect of flow that distinguishes it from other models of engagement in learning situations – it is desirable for students to have an experience that is so enjoyable that they would want to do it again, voluntarily. To gauge the strength of this factor the video sequences were examined taking note of the student’s manner and expression, looking for simple facial expressions indicating enjoyment (smile, raised eyebrows) or other body language and these were used to help interpret their response to the question about enjoyment. Since flow should be a highly positive, or optimal, experience, this requires a stronger response than a calm statement of ‘yes, I enjoyed it’.
The autotelic nature of the students’ flow experience is also reflected in their responses to the online survey questions at the end of the session. Whilst the average response to the 5-point Likert scales for all the survey questions is presented in Section D of Table 6-2, only four of these questions related to enjoyment. They were:

*I found the activities enjoyable;*
*I found the activities interesting;*
*the activities bored me;*
*the activities excited my curiosity.*

The three different measures for each student’s enjoyment response are shown in Table 6-3.

<table>
<thead>
<tr>
<th>Table 6-3 Enjoyment measures from post-survey and interview</th>
</tr>
</thead>
<tbody>
<tr>
<td>Enjoyment</td>
</tr>
<tr>
<td>interview</td>
</tr>
<tr>
<td>------------</td>
</tr>
<tr>
<td>Physicist_A</td>
</tr>
<tr>
<td>Physicist_B</td>
</tr>
<tr>
<td>Physicist_C</td>
</tr>
<tr>
<td>Learner_A</td>
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<tr>
<td>Learner_B</td>
</tr>
<tr>
<td>Nonlearner_A</td>
</tr>
<tr>
<td>Nonlearner_B</td>
</tr>
<tr>
<td>Nonlearner_C</td>
</tr>
<tr>
<td>Group average:</td>
</tr>
</tbody>
</table>

The responses to the question about enjoyment during the interview; the observations of students’ autotelic response as described earlier; and the average scores from the 4 survey questions. The autotelic assessment tends to be consistently lower than the assessment of enjoyment based on the interview comments. That is, the students verbalised a stronger enjoyment than was apparent from interpreting their physical expressions. There was also consistency between the survey scores and the interview comments in that those scoring above 4 also commented ‘high’ enjoyment, and three of the four scoring below 4 indicated medium enjoyment by their comments.

The order in which the students are presented in Table 6-2 was based on a synthesis of the complete set of data in the table. This categorised the students loosely into four groups:

1. Four students who were highly engaged and showed best evidence of flow experience (Physicist_A, Physicist_B, Nonlearner_B, Nonlearner_C).
2. Two who were not highly engaged, but gave evidence of some flow experience (Learner_B, Nonlearner_A).
3. One who was ‘mixed’ – gave evidence of flow, but with contradictions (Learner_A).
4. One who gave no evidence of flow experience (Physicist_C).
In summary, the collation of these data into a single table provides a useful view of an extensive amount of qualitative and quantitative information. Given the nature of flow, it is not an easy task to establish whether or when someone had this experience – or with what intensity they experienced it. Section C of Table 6-2 shows two independent assessments of flow derived from different aspects of the interviews. These are in reasonable agreement giving more confidence to the categorisation of who achieved flow and who did not. Attempts to triangulate these two assessments of flow with the survey data (Section D) was not successful, confirming the conclusion from the previous chapter that a retrospective measure of flow at the end of a learning session is not an appropriate as a single index of the experience.

6.5 Deeper analysis of flow experiences

The previous section produced a description of each of the eight students in terms of their physics knowledge and learning, as well as their flow experiences. The eight students were categorised into three groupings: those having good content knowledge; those achieving significant learning; or those having poor knowledge without much improvement after the exercise. Their flow experiences have been described as being either in-flow, showing signs of flow but without the autotelic experience, having mixed flow experiences, or not in flow at all. This section uses these descriptions to help construct more detailed interpretations of the interview data and flow experiences.

Sub-section 6.5.2 presents a general overview of the students based on their flow experience as a group. Sub-section 6.5.3 discusses how we need to distinguish between students’ engagement with the learning objective from their engagement with software object they used to explore this objective. The former is referred to as the ‘task’, the latter the ‘artefact’. Sub-section 6.5.4 discusses the deficiencies of the challenge-skill ratio as a measure of flow. Finally, in sub-section 6.5.5, the nature of the flow experience as described explicitly by the students towards the end of the interview is discussed.

However, to begin, here is a vignette describing the learning session of one student who had limited flow experiences but who articulated very clearly the nature of these experiences.

6.5.1 A vignette: capturing the experience of Ann (S4: Learner_B)

(I have given Learner_B the pseudonym ‘Ann’ for this section to add to its readability.)

About Ann

Ann is less than 21 years old; her first language is a European language other than English. She studied her final year of high school physics the year before she took part in this experiment and scored a reasonably good score of about 75%. Her overall final year high school grade put her in the top 5% of the state. Her pre-test on the physics for this experiment was, however, only 4 out of 14, slightly below the average of 6.3 out of 14. In her post-test she scored 6 out of 14, a slight increase but again below the average of 7.9 out of 14.

Her responses to the post-survey questions tell us about her reflections on the experience that she had just completed before her teaching session began. She reported enjoying the experience. She found it interesting, rarely boring and it stimulated her curiosity. She felt very much in control, usually knowing what was the right thing to do, only occasionally being frustrated. However, she perceived her level of engagement as being very low. She was often distracted and thought about other things. She didn’t think
that she needed to put in much effort to complete the tasks; that is, her perceived skills were high compared to her perceived challenges.

Ann’s experience makes an interesting study because she reported her level of engagement as being so low. Twice in response to the interview questions she articulated clear flow experiences and related them to moments of learning. Ann’s experience of flow will be presented by describing it in relation to each of the nine flow components.

**Challenge and skills**

One unusual feature of the learning task was that it was not highly prescriptive as to what each student should learn. As such, it was up to each student to decide when they had learnt enough about one question and were ready to go onto the next one. How did Ann make that decision? She appeared to make a sensible judgement about her learning:

Just when I got sort of bored with it and felt like I could answer the questions without the simulation.

This ‘boredom’ refers to the fact that the simulation was the same for each of the four questions; she would have liked it to have changed. It is interesting that, whilst most of her focus so far appeared to be on the learning task, it was the artefact (simulation) that became boring. Her skills with the artefact developed quickly, while she still found the tasks challenging. The boredom became progressively worse as she went though the four questions:

Yes. That’s why I spent the longest on the first one, like to have a play with this, and then the second one’s like – same thing, same thing, same thing.

Ann was correct in her estimate of time here. Her interactivity pattern (Figure 6-4 on the next page) shows that she spent about half the time on pages 3 and 4 as she did on pages 1 and 2, respectively. (She actually explored question 1 while still working with the ‘Introduction to the simulation’ – this shows up as a long time spent on the very first page – page 0 – and virtually none on page 1.)

She emphasised this increasingly boring aspect of the simulation when asked about the challenge-skill probes. Whilst the simulation was not challenging for her, she kept her focus on the learning task that clearly was challenging and it was this that dominated her challenge-skill responses and kept her interest. In response to being asked whether the challenge-skill probes reflected her boredom, she replied:

Not really because I learnt different things along the way, like, I realised different things as I saw it from a different perspective. And then I kind of lost my concentration as I went down and I think that’s how I reflected the boredom rather than not finding it challenging because the simulation wasn’t challenging but the concept that I got from the simulation was challenging.

In that last comment she clearly distinguishes between the simulation (artefact) being of low challenge, and causing her boredom, even though the task was of high challenge. Ann goes on to report her skills as becoming inadequate as the task progressed:

For the first two parts, I thought they were okay. And then I really felt like I need to know more to appreciate the simulation.
Figure 6-4 Interactivity pattern for Ann
This decrease in her perceived skills was reflected in her responses to the challenge-skill probes as shown in Figure 6-5. Her skills are shown as being adequate for the first two questions (represented at the bottom of the plot) then decreased for the last two. In contrast, her perception of the challenge of the activities increases from very low to quite high. Clearly, from her last comment, it was not her skills with the simulation that were challenging her, but her ability to ‘appreciate the simulation’ – that is, to interpret and make use of what it was conveying to her.

![Figure 6-5 Flow-path for Ann](image)

This discussion with Ann about boredom provides strong support for the need to separate task and artefact measures in challenge-skill probes. In a simple challenge-skill measure of flow, Ann’s increasing boredom should be reflected by a movement towards the lower right of the challenge-skill plot; the ‘boredom’ zone. But her movement is upwards and to the left – the anxiety zone. Although her skills with the simulation are most likely improving, she is finding the learning task more challenging, which is moving her up into the ‘anxiety’ zone. On one hand she is feeling bored, but on the other hand she is feeling challenged. This is a clear indication of Ann making separate judgements about task and artefact.

The final question Ann worked on (Q4) related to tossing a ball in the air and describing its acceleration. The simulation still portrayed a cart on a slope, with an explanation given that the slope behaved like ‘diluted gravity’. Ann found this particularly challenging and couldn’t make the analogy work for her:

> Well it was a different situation. They were asking like for a ball and a coin – sorry … like a free object whereas the other one was on something, on a slope, and I felt like maybe something that…I don’t exactly remember the problem that I had but there was this problem in my thinking that couldn’t reconcile the two…

Her solution to this inability to reconcile the ball and slope was not to persist with the simulation but to leave it and just think instead:

> Yeah, so I left the simulation there and kind of tried to think about it and more of a realistic, practical…

The artefact ceased to engage her, but the task still did.
This illustrates another mismatch, for her, between the artefact and the task. It was not that the simulation became hard *per se*; it was the same one as for all other activities. However, it no longer fitted the task as well as it had. Figure 6-5 shows her perception of her skills as decreasing for the last two questions. Whilst her skills to drive the simulation would not have changed, the skills required to deal with the new (harder) learning content had changed. Her response was to abandon the simulation and rely on her *thinking* skills to explore the task. When she responded to the challenge-skill probes, she focused on thinking how to solve a physics problem. From her comments earlier, it would appear that her low skill measures for the first two pages reflected, in part, her early simulation skills when the match of simulation to task was more in balance. Even during her frustrations from making the computer crash on questions 1 and 2 (by searching for a curved graph, discussed later) she still reported her skills to be adequate (3 out of 5) and the challenge increasing from low to medium (1 out of 5 to 3 out of 5). But, as we have seen, by the end of the exercise her challenges and skills were well out of balance and related strongly to the learning task rather than driving the simulation. She had progressively shifted her attention as she moved through the exercise.

Ann claimed that she readily abandoned the artefact during the last question when it appeared not to be directly helping her with the task, even when it was clearly designed to do this. However, she did not give up easily. She actually used it more for this question than for the other three questions. Her interactivity pattern shows that she had begun the third question with a period of 2.5 minutes of non-interaction (as seen annotated in Figure 6-4) – the video shows that she was thinking and making notes. She then makes two changes of angle of the slope of the track (labelled ‘A’ in the interactivity pattern), seven changes of fans on the cart (labelled with *fan*) and four actual runs of the simulation (small triangles, red on the computer screen, labelled in the figure; other triangles represent resetting the simulation). She also had begun her previous two questions with three minutes of thinking and note-taking but followed up with less use of the simulation. In fact, for those two pages she only made one run of the simulation each time. Ann’s recollection was one of ignoring the simulation, however, in fact, she was still interacting with it.

Ann’s pattern of use of the simulation was strikingly different from the other seven students. Each of them tended to spend about one minute reading and thinking and then made extensive use of the simulation to explore the question. Ann was true to her comment of ‘*I work better with words than pictures*’ by spending more time thinking and less time doing. To both questions two and three she spent more time thinking about the question *before* moving the cart than she spent after moving it. This suggests that her lack of engagement reported in the post-survey may relate more to the simulation than the learning task.

**Goals**

A condition for flow is clear goals and timely and appropriate feedback. Ann appreciated the clarity of the four learning questions presented to her in dot-point form. However, sometimes the supporting explanatory text was distracting to her:

> Then you’re trying to figure out two questions like, what they wanted me to see here, and then how does that relate to the actual question.

These guiding questions confused her a little as if she were answering ‘*two questions instead of one*’. She would have preferred not to have had them. She was showing a preference to focus on the learning task at
hand and did not want distractions to get in her way. A simple model of flow does not accommodate this
split in attention. Ann’s initial perception of her learning goals were clear, but the natural expression of
the instructions to guide the achievement of these goals introduced a confounding factor – how to
approach a solution using the simulation.

Feedback
The feedback Ann obtained from the simulation was ‘pretty clear’, but with one exception. That
exception was that at one time she wanted to produce a curved graph but couldn’t achieve it. This ‘curved
graph incident’ caused Ann considerable grief. It began with her preconceived notion of what she
expected to be able to see:

Because I kind of remember somewhere having curved acceleration graphs with straight velocity graphs.
This is where her prior physics learning misled her. She was remembering the curved position graphs that
accompany constant velocity graphs, not curved acceleration graphs. She was never going to find curved
acceleration graphs because they can’t exist for this kind of motion, yet she was confident that they
existed. She persisted, repeatedly magnifying the scale of the position-time graphs hoping to discover a
curved line hidden in there somewhere:

I tried to change the scales to make them bigger so… (laughs)
The consequence was that the simulation crashed three times. It is interesting that she persisted with the
hunt for these curved graphs. They were not asked for or even suggested by the questions on-screen.
There was not even any mention of position-time graphs at all. Yet her belief that they existed, and would
be helpful to her, dominated her work for quite a while and represents Ann setting a different goal from
the main goal. She never managed to get the simulation to behave as she wanted. Her response to this
frustrating experience was a desire to turn away from the computer:

I felt like getting a text book out and reading (laughs) the theories so I could answer the question better… Like
I couldn’t get what I wanted from that program so I was going to go somewhere where I could.
This illustrates the close link between goals and feedback and their roles in producing flow or frustration.
Ann’s readiness to abandon the computer reflects her preferred learning style. She later comments:

I work better with words than pictures.
This is also reflected in the amount of interaction she made with the simulation. Observing her in the
video recording of the session, she spent much of her time sitting and thinking with no physical activity.
Ann’s interactivity pattern illustrates this (shown again in Figure 6-6). It shows many instances of
interaction (represented by letters above the main horizontal bars, connected to them with vertical lines).
However, it also shows long periods at the start of pages 2 and 4 before she even clicked the mouse (clear
horizontal areas), followed by periods of very sparse interactions. These are periods of deep thought for
her.
For contrast with other students, Figure 6-7 and Figure 6-8 show the very intense interactions in the interactivity patterns of Learner_A and Nonlearner_C, respectively.
Ann was very confident that it was the simulation that was in error, not her thinking, and it was only in the interview that she reflected that her ideas might have been wrong:

Maybe there was something wrong with my idea of them but I just wanted to see what it was…because obviously it was probably a major part of my thinking, now that I think back at the last bit, so it would have been good to see exactly what that was.

Apart from that frustrating experience Ann found the environment gave her good feedback. She didn’t find the introduction to how to use the simulation useful: she would have rather skipped that and relied on help files when needed. But she read them because she ‘thought they were important’.

What Ann had encountered here was a distinction between ‘artefact feedback’ and ‘task feedback’. The simulation was displaying to her correct information in response to her actions. However, what she observed did not fit with what she expected or wanted. The simulation could not ‘know’ this, not even advise her that her actions were inappropriate – it was providing precise and timely artefact feedback for her actions, yet it was leading to frustration in Ann’s mind as it was not providing appropriate task feedback for her learning.

**Control**

Ann always felt that she had more control over the computer than it had over her, except for specific aspects of the simulation that she wanted to change:

I felt that the program was quite limiting. There were only like two, three things that you could really do with it.

So after you master that… I don’t know if that kind of relates to control but I felt in control except for changing the fields. And I wanted it to do more than it was doing.

‘Changing fields’ refers to the scales on the axes of the graphs. When these did not give the results she wanted, Ann felt less in control. This mixed feeling of control – being in control generally but less control with simulation – is consistent with her mixed feelings of challenge: the task was challenging but the simulation was not. The simulation appeared to play a minor role in both her actions and her thinking. It
was a stepping off point, but not always used to its maximum effect. For example, in question four, the one run of the simulation that she did make was not the best for the ball-toss problem; she let the cart run down the slope and never ran the appropriate motion of the cart being pushed up the slope and allowed to return under gravity.

Her response to this lack of control of the simulation was one of frustration – not with the computer, but more with the program or programmer:

I never really feel like the computer has more control. I get frustrated. I don’t get frustrated with the computer. It’s more the program or the programmer because I’ve programmed a few things and it gets tedious. You can imagine how hard it would be like doing spaces and changing different things all the time.

Ann’s overall sense of control was mixed. This was largely due to the differences she experienced between control over the task and control over the artefact.

**Concentration**
Some of Ann’s sparse use of the simulation can be attributed partly to her view that it was rather limited in its scope. She found that she didn’t have to concentrate very hard and that the default time duration for the cart’s motion (10 seconds) was a bit too long to hold her attention. She appeared not to appreciate the rich combinations of motions that were possible:

So your concentration goes by the end of it because you know what’s happening after you try two scenarios. You kind of can get all the scenarios because of the program wouldn’t allow you to explore more scenarios.

Ann’s concentration focused on the task, with less interest in the artefact.

**Time**
Ann didn’t report any sense of feeling a loss of self-consciousness, but she thought that time might have passed more quickly than normal. This was particularly while she was using the simulation and also teaching the research assistant later on:

Well during the computer simulation it was passing more quickly. Actually, no, during even the talk. I felt like the talk lasted 5 minutes and I was aware that the person, I don’t remember her name… was looking at me and thinking – ‘this is wrong’ because obviously she has much more physics knowledge that she’s… I wasn’t sure what her background was but I kind of assumed that. The time felt that it went really really quickly there but mainly it was because of nervousness.

She states that the 25 minutes she spent teaching the research assistant felt like 5 minutes. The period when time went ‘really slowly’ was when she was trying to obtain the curve graphs that were never to be. This was a period of computer crashes that forced her to relate back to her prior knowledge rather than rely on the computer:

Just like booting up the computer again and doing that was really frustrating and I tried to focus more on what I knew from last year. Try to answer the questions when that happened.

Although Ann appeared to experience a loss of a sense of time during the teaching session, during the learning session time appeared to drag.
Enjoyment
Ann enjoyed the session, especially at times when she learnt something. Interestingly she relates this to the simulation and her interaction with it:

I found some of it stimulating especially when I had an idea and then when I tried it on the graphs it was different and I tried to explain that. I’d try to find explanations for the difference and account for them. That part was interesting.

This is a mix of her using the simulation and then thinking hard to resolve differences. In spite of her sparse use of the simulation, she still attributes its role to her learning. The only parts that she didn’t enjoy were when she was not learning anything new. Overall, she found the experience enjoyable, but not to the extent of being excited by it.

Learning
Although Ann’s test score only improved from 4 out of 14 to 6 out of 14, she was aware of, and could articulate, two instances of learning that are substantiated by her test. These ‘moments of learning’ she also relates to moments of flow.

Ann began with confidence in her physics knowledge, but this waned somewhat by the time she had completed the post-test:

At the start I felt like I knew the answers to all the questions. But then when I did the post-test I realised that I had missed a few subtleties.

The learning session reminded her of several things that she had previously learnt and forgotten. Two in particular she focused on. The first was that negative acceleration could refer to a car speeding up, but in negative direction (towards the left):

There are lots of things that I’d forgotten. Mainly negative acceleration. I thought that was always deceleration and then I realised it was just the change in the direction of velocity that cause negative acceleration. That could be deceleration, but doesn’t have to be deceleration.

She says that she realised this principle during the third question. It was a surprising result while running the simulation that made her realise that her idea of negative acceleration was not correct:

Probably the third question. I was just changing the um…no just running simulation on the cart and the graph wasn’t what I expected.

…The acceleration was negative while the velocity time graph was going up and I thought – what’s wrong here? And then I ran it again and I realised it was just because it was to the left.

This learning event she later describes as:

I think that was probably, like, the main, sort of, epiphany.

The other moment of learning related to the conventional physics use of the word ‘constant’. She previously interpreted this word to mean ‘zero acceleration’ (as is the case with ‘constant velocity’) but learnt that another situation could be that the acceleration was constant, yet non-zero, leading to a steadily changing velocity:

Because the ‘constant velocity’ meant to me that acceleration was zero and I think I reflected that probably in my answers for the first test - every time I saw the word ‘constant’ I was like zero acceleration, zero
acceleration. I definitely remember that from last year, but then I saw that the constant acceleration could also be related to velocities that were going up or down constantly, on slopes. So that was another moment when my thinking was changed. And that was again through the simulation…

Again she had recalled a moment while using the simulation during which her thinking changed. The fact that she relates these moments to simulation use is interesting given that the number of times she ran the simulation was relatively low. The first moment she states she was ‘running the simulation’; the second one she uses the phrase ‘through the simulation’. It is unclear whether she was actually engaged in running the simulation when she realised her learning or whether she was thinking about the outcome of a run – the unexpected result. In either case, she attributes the simulation as the trigger for her learning, rather than any other cause.

In spite of her awareness of her learning, she was still confused about aspects of acceleration. Her post-test shows that she corrected misconceptions about what acceleration-time graphs look like for cars speeding up, in a positive or negative direction (questions 4 and 7 on the test). However, in both the teaching session and the interview she still showed some confusion between the concepts of velocity and acceleration. In particular, the progress plot of her understanding through the learning session (the line labelled ‘S4’ in Figure 6-3 on page 142) shows a marked decline after teaching material relating to the first two questions (Appendix C-5). Nevertheless, she remained confident and gave the appearance that she believed that she had made specific learning gains.

Flow
Ann responded quickly to a description of flow, and a question as to whether she flowed, by saying:

Probably the two moments when my thinking was changed.

Earlier she had commented that at those moments time went ‘probably quickly’. Flow to her might have been associated with use of the simulation, but her thinking was clearly an important component:

But I think that flow for me would depend on how much I knew about the situation or about the topic beforehand or how much I was learning because I really didn’t feel like I learnt as efficiently as I could have learnt. Like if I had an hour with a book I could have learnt that – well I could have learnt the whole chapter in an hour. An hour was kind of struggling with two concepts.

She certainly was struggling with the concepts, but she saw this struggle as an unnecessary one that could be avoided by referring to a book. She is contrasting a clear textbook exposition with an interactive object that presents her with a situation in which she can explore, struggle and learn. However, in her view, the simulation was a tool to confirm her thinking rather than a tool to help create new knowledge:

The simulation kind of confirms your thoughts on the theory rather than creates a theory.

It is possible that the simulation became confusing to her, but it is also likely that any confusion is due to her confronting misconceptions for the first time. Physics education research suggests that textbook learning has difficulty changing concepts that are firmly established and that the struggle of confronting challenging situations is what is required to assist learning (Halloun & Hestenes, 1985b; McDermott, 1991).

Even during her frustrating times Ann considered herself to have been in a state of flow. The evidence she offered for this was being focused to achieve an aim, lack of awareness and being absorbed:
Ann: It was a bit…it was frustrating, so…no I guess I had flow then as well because I was kind of focused on that trying to achieve that aim and…

Interviewer: But also some frustration?

Ann: Hmmm. But I was absorbed in it – I guess that would probably be one of the moments too when I wasn’t aware of what was happening around, and just...

Interviewer: You just said you were absorbed.

Ann: Yeah because I was trying to fix that problem.

Ann also described her time teaching the research assistant also as one of flow. This experience she mentioned when asked about ‘enjoyment’. She did not mention enjoyment when she was talking about her other flow experience. She attributed this flow experience to having a problem to solve and having to concentrate on it do it:

Well, I felt like there was a problem and my aim was to solve the problem as best that I could. The problem was her and in her understanding. I was just trying to relay a message. So I guess when there is a problem, there was more flow because you want to solve it.

Ann rated the whole experience as highly enjoyable on the survey (Likert scale 4 out for 5 for each of enjoyment, interest and curiosity) yet in the interview she only mentioned enjoyment in relation to the teaching exercise. She clearly did enjoy what she did, but didn’t show any visible signs of pleasure.

Watching the video of her learning, and the long pauses during which she sat motionless looking at the screen, suggests she experienced deep engagement for most of the session. Yet her survey scores suggest that she was not very absorbed (2 out of 5) was distracted (4 out of 5) and often thought about other things (4 out of 5 each). Some of these distractions could be attributed to the three computer crashes that certainly impacted on the smooth running of the session, but it is still puzzling why she rated her engagement so low.

During the interview Ann did not respond positively when asked about most of the nine elements of flow (Table 6-2 on page 145), yet she expressed clearly that she experienced two episodes of flow. Her case has illustrated that an individual can experience flow on occasions during learning, yet responded to general questions about the session as if flow were not present.

**Summary of Ann’s experience**

Ann’s experience has many interesting features. She was a student who preferred to learn from text and was driven very much by the learning task, rather than by exploring the simulation. The simulation seemed to play a minor part in her experience and her use of it was limited somewhat by her lack of adequate physics skills. She never really felt mastery over the simulation and it appeared to hold little interest or fascination to her. Yet, even so, she indicates that the simulation did trigger her thinking and initiated some episodes of learning.

Ann’s experience of flow was associated with thinking or learning about the physics content. Talking with Ann confirms the idea that flow is a state that can be associated with learning. She made this connection herself by identifying the moments when she thought that she had learnt something and describing these moments as ones when time went quickly. This was in contrast to the time when she was frustrated in looking for non-existent curved graphs and time went slowly. She was very highly focused.
during these times of flow. However, there is no clear evidence that these times were especially enjoyable. Whilst she made no comment to the contrary, she was working hard, struggling and engaged, but not necessarily having an autotelic experience. This raises the question of just how much fun can one expect a student to have while engaged in a learning activity. Should we be satisfied that they report high scores on a set of ‘enjoyment’ survey questions? Or should we be looking for deeper or different affective signs of enjoyment? This issue will be addressed at the conclusion of this thesis.

### 6.5.2 Measuring flow: consistency of survey and qualitative results

Before discussing in detail the information gathered from the interviews with the eight students (next subsection), it is useful to consider the information that the post-session survey (control, engagement and enjoyment) gave of the group as a whole and compare it with other data where appropriate. The survey used was a modified version of one used and verified by others (Ghani et al., 1991). Such surveys have been used to produce a global rating of flow. Yet the discussion below illustrates the deficiency of this measure of flow in its inability to focus specifically on task or artefact, respectively, in this situation.

Flow is a very personal experience and we can expect this experience to sit on a continuum from no flow to maximum flow (Hoffman & Novak, 1996). The experiments in this research have investigated flow using several measures (challenge-skill, post-survey, interviews) and hence it is not unexpected that these indicators point in different directions at times and that there are contradictions as well as convergences.

The grouping of students in Table 6-2 (p. 145) into the four categories of in-flow, flow-without-excitement, mixed and no-flow is different from that suggested by the online global post-survey alone. The survey was scored on a 5-point Likert scale and the data were grouped into responses about control (3 items), engagement (4 items) and enjoyment (4 items). Table 6-4 shows each student’s average score for each category, together with their overall averages (5-point scale). Appendix C-10 presents the eleven question items and Appendix C-11 the detailed responses.

<table>
<thead>
<tr>
<th>Table 6-4</th>
<th>Summary scores from post-survey questions</th>
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<tbody>
<tr>
<td></td>
<td>Control</td>
</tr>
<tr>
<td>Physicist_A</td>
<td>3.3</td>
</tr>
<tr>
<td>Physicist_B</td>
<td>3.3</td>
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<tr>
<td>Physicist_C</td>
<td>4</td>
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<tr>
<td>Learner_A</td>
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<td>Learner_B</td>
<td>3.7</td>
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<tr>
<td>Nonlearner_A</td>
<td>2.3</td>
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<tr>
<td>Nonlearner_B</td>
<td>3</td>
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<tr>
<td>Nonlearner_C</td>
<td>3</td>
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<tr>
<td>Average</td>
<td>3.2</td>
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The three questions on control related to:

control (specifically),
frustration, and
knowing the right thing to do.

The four questions on engagement related to:

absorption,
thinking about other things,
distractions, and
effort.

The four questions on enjoyment related to:

enjoyment (specifically),
interest,
boredom, and
curiosity.

Students’ responses to each of these three questions are addressed briefly below.

Control (3 items, av. = 3.2 out of 5): Students’ responses showed that all but one had a middling degree of control (3 or above). There was a moderate level of frustration but most students felt they knew what was the right thing to do, with just three of them being slightly unsure.

Engagement (4 items, av. = 3.5/5): The levels of engagement were moderate to high for all but two students. Those two students were not absorbed and did not feel that they had to put in much effort to satisfy the tasks. There were mixed responses as to whether students thought about other things, or were distracted, during the session.

Enjoyment (4 items, av. = 4.0/5): The overall enjoyment was reported as being high, with only one having a Likert-scale score below 3.8 (Nonlearner A rated enjoyment as 3 out of 5). Boredom was low for all except one student and curiosity was 3 or higher for all students.

These survey results are interesting in that nearly all the responses are at a moderate to high level (in a positive sense). Since these are all indicators of flow, one would expect that many of the students experienced flow at some stage during the exercise. An anomaly here is Physicist C. He reports being highly in control, with very high enjoyment and reasonably high engagement. However, other factors suggested that he did not experience flow. His highly competent physics background was such that he did not feel challenged; he felt neither loss of self-consciousness nor any loss of time. He did not respond positively to the description of flow. Yet he was not bored. This is an example of a highly competent student who enjoyed working through the exercise but was not sufficiently challenged to experience flow.

However, in spite of the high survey scores, taking all measures of flow into account did not lead me to rate all students as being in flow. This illustrates a difference between what students reported in their surveys compared with what was deduced from interview and observation. There was often an affective aspect missing that made it hard to label them as ‘flow’ in the accepted meaning of the term. High scores set the appropriate global scene for flow to take place, but the missing affect might mean that a student,
rather than having a flow experience, simply has an enjoyable, challenging and engaging experience. In short, for the students engaged in this exercise, high scores on the affective measures was a necessary, but not sufficient, indicator of flow.

An example of an affective response that this survey could not measure well was the strong feeling of excitement or autotelic behaviour that should accompany a flow experience. Whilst high excitement might not be expected for a learning task of this nature, it was noticed from the interview video clips that there were differences in the ways the students talked about their enjoyment of the activity. Each video clip was examined to look for visual signs of excitement while the student talked about enjoyment (onset of a smile, raised eyebrows, body movements). Whilst not a reliable measure, it gave a hint as to whether the student became excited by the experience. Some students expressed enjoyment of the experience, but did so with a rather cold, analytical expression, whilst others offered a smile and indicated that it really was quite fun. Students in this latter case were Nonlearner_B and Nonlearner_A. Nonlearner_B was rated as one of the ‘in-flow’ students, but Nonlearner_A showed some contradictory responses and is discussed later.

Others were rated as not flowing because they showed no sense of time loss or did not become sufficiently engaged to experience a sense of loss of self-consciousness.

In summary, the survey measured the parameters necessary for a flow experience to take place, but more specific information was required to detect actual flow instances. Further information was required to identify the highs and lows of the experience, to indicate a sense of excitement. The interview sessions provided such reflective confirmation of flow experiences and are discussed in detail in the following sub-sections.

6.5.3 Focusing on task and artefact

Much research into flow asks participants to reflect on recent experiences and rate their perceived challenges and skills for the task. It has been suggested that there is some ambiguity in interpreting ‘challenge’: does it refer to something which is difficult or something that is stimulating (Novak & Hoffman, 1997)? Students in this experiment interpreted the word ‘challenge’ to have a meaning closer to ‘stimulating’ than difficult. Although ‘difficult’ sometimes was mentioned together with ‘challenge’, there was frequent use of phrases such as ‘made me think’, ‘interesting’ and ‘enjoyable’ in association with it. In the context of this study, a more appropriate concern has been whether challenge was interpreted with respect to the computing environment (the artefact) or the physics learning (the task) that the participant was trying to master. The discussion below presents those aspects of the students’ experience that showed that flow might be experienced in relation to either one of these.

Figure 6-9 to Figure 6-16 present each of the eight students’ flow-paths. They are included here for reference. Some features of them are immediately obvious and contrasting. For example, the location of Physicist_C’s recordings in the high-skill/low-challenge region of the space (Figure 6-11) suggests that he found exercise much less stressful than Nonlearner_B, whose recordings are all in the ‘anxious’ region of low-skill/high challenge (Figure 6-15).

Some of thee flow-paths also appear later where they are discussed in context with interview comments.
Challenges and skills

Early in the interviews, students were asked to comment on the challenge of the task and the skills that they had to cope with that challenge:

Interviewer: How challenging did you find the session? Can you illustrate with particular instances? What about your skills to meet these challenges? And your meaning of challenge?

Their interpretation of the word ‘challenge’ related to stimulating activities, interest, issues to do with learning and thinking rather than simply ‘difficult’. For example:

Learner_A: How well I can actually grasp… in terms of the simulation… how well I can grasp the concepts.

Challenge was usually a positive feeling, often associated with interest:

Nonlearner_C: I think it was very challenging, very interesting. It wasn’t as hard as I thought so I enjoyed it.

However, challenge, even as something stimulating, was not always enjoyable. For Nonlearner_A, the negative aspects of challenge were offset by the interest it generated:

Nonlearner_A: It made me think a lot. It wasn’t straightforward… was not that enjoyable because it was challenging. On the other hand it was pretty interesting, a different kind of thing. That kept me going.

Almost always these responses to the word ‘challenge’ related to the learning objectives of the task. For example:

Learner_A: Finding it in terms of being able to accomplish the task. How well I clarify it to someone else what I learnt.

For Learner_A the challenge related to her ability to complete the given task and understand it well enough to explain to someone else. Even when the challenge presented itself directly in terms of the artefact, the task would sometimes show through. In the dialogue below a confusing outcome from the artefact led to a greater challenge to obtain meaningful output in order to answer her queries:

Learner_A: When I mentioned the simulation, how to start the carts, I thought it first of all a drag but depending on how much you drag it and how great the velocity is…
Interviewer: To drag and let go?

Learner_A: Yes. The result was the velocity was very, very jagged and everything just got really mixed up and it wasn’t what I expected it to be.

Interviewer: That was more challenging when you got that unexpected result. Is that what you’re saying?

Learner_A: I mean more challenging to retrieve the results I wanted to answer the queries I had in mind. However, a couple of comments gave insight into an interesting distinction between the challenge of the artefact and the challenge of the task:

Learner_B: …the simulation wasn’t challenging but the concept that I got from the simulation was challenging. and

Nonlearner_C: It was challenging in terms of having no Physics background but with my knowledge I think I can do these (points to worksheet) but those ones (refers to test) I think I need a bit more Physics background.

Both of these comments draw attention to a task-artefact distinction, but in different ways. The comment by Learner_B (‘Ann’ in the previous subsection) clearly states that she was not challenged by the actual simulation but was challenged by the concepts she was trying to learn from it. Nonlearner_C was comfortable working through the learning task, but did not feel comfortable with the test. She reflected this in her very high levels of engagement and enjoyment yet very poor scores on the post-test (2 out of 14) and the commensurate low ratings of her understanding made by the research assistant. The plot of learning progress in Figure 6-3 (student S8) on p. 142 illustrates this poor performance. Unlike Learner_B, she was unaware of the difficulty she was having interpreting the correct meaning of the physics and this was not off-putting to her while she tried to learn. She made an inordinately large number of interactions with the simulation compared to most others yet her learning often reflected low-level recall rather than conceptual understanding (her interactivity pattern is shown in Figure 6-17). The interaction with the artefact was strong and enjoyable, but her interaction with the physics was poor.
An understanding of this notion of the focus of challenge and skills moving from artefact to task helps us to interpret some of the puzzling data from Experiment Two relating to differences between movie mode and simulation mode students in their classification as ‘anxious’, ‘flow’ or ‘bored’. As is discussed further in sub-section 6.8.2, the movie mode students appeared to move their focus from the artefact to the task and became challenged by a specific and difficult aspect of the physics. The simulation mode students, on the other hand, appeared to be more pre-occupied with the artefact and less aware of that particular challenging event.

The significance of this task-artefact distinction lies in the way challenge-skill measures are used to indicate flow experiences. In the context of interactive learning objects, it is necessary to understand which aspects of their work students are focusing on when they record a challenge-skill measure: the conceptual understanding or the artefact used to present it. This is discussed again in more detail in section 6.5.4.

Control

Asking students to comment on degree of control they felt they had while exploring the four questions suggested that there was a spectrum of perceived control from controlling the artefact through to feeling in control of the physics task. The examples from the six students described below show increasing recognition that both the artefact and task play a role in perceptions of control.

For Nonlearner_A, who was a student with no physics background, ‘the computer’ – meaning the computing environment in a general sense – had firm control. It told him what to do, when to do it and why:

Nonlearner_A: I think the computer had an upper hand. Yeah. It was presenting things and it tells you ‘this is what you can do’ and use it to do this and press, and when you’re through go here, go here.

He became ‘accustomed’ to this and, by the end, felt he had greater control. However, in the early stages of the task he was also very unsure of how to interpret what he saw:

Nonlearner_A: I was really unsure of what was happening. I didn’t know what the graphs meant, when you see it change this and…but after a while, doing it for a couple of times it became manageable.

‘Manageable’ was an interesting choice of word. It suggests that he gained control over the artefact, but was not yet in control of the task. He reinforced this interpretation by saying that his problem was not how to get the cart to produce the graphs that he wanted, but rather it was the interpretation of what was produced on the screen that was hard. He illustrated this by describing the following event:

Nonlearner_A: …like if you drag them, the cart…and it went like a heart beat machine.

‘Heart beat machine’ refers to the ragged graphs one can sometimes get while dragging the cart. Had he understood what the graphs were telling him he would have realised that this was just an idiosyncrasy of the software (any erratic dragging of the cart is exaggerated in an acceleration graph since acceleration is a measure of ‘rate of change’ and is hence very sensitive to non-uniform motions). These ragged graphs did not require any interpretation and should have been ignored. This student perceived some control of the artefact in the end, but did not appear to gain, or be aware of, any sense of control relating to the task.

In contrast, Learner_A also felt low control of the simulation early on:
Learner_A: At the start I felt that I didn’t have a lot of control and then later on when I understood what I was doing I could say that I had absolute control.

She related her low control period specifically to learning about the simulation. Her perception of control moved from mastering and knowing what she wanted to do with the simulation towards her feelings of understanding the task, although it is unclear precisely what was included in ‘absolute control’. However she did state that towards the end she felt confident working though the questions, suggesting that she was feeling more in control of the task towards the end of the exercise. She made significant learning gains during her learning session as shown by her test score improvement from 2 out of 14 to 7 out of 14.

Physicist_A mastered the artefact quickly, and was in control of it, but slightly out of control in terms of what he was doing with it:

Physicist_A: Yeah. I felt I could control the cart but I felt like I didn’t know exactly what I was doing.

He later referred in some detail to various features of the software. He clearly controlled the software well, but hints that there was another level of control that he felt was lacking;

Physicist_A: Yeah – I felt…apart from that initial let go stage, as I was saying, I still felt I was in control but maybe just not as accurately as potentially it might have need to have been. No, but I felt I was in control of the cart obviously, the fan, acceleration was relatively straightforward, the way you didn’t have any control over the speed or did you I’m not sure…

His control with the simulation was good, yet he was aware of needing greater control in relating this to the task.

Learner_B (Ann) had an issue with control in that she wanted more control over the simulation than it offered. She wanted to change graph scales to an extent that the software would not allow (and crashed). She didn’t actually need these scale changes (as discussed previously in Section 6.5.1). She was chasing curved graphs that didn’t exist for this motion. What was interesting with her responses was that she did not blame the computer, but rather the program or programmer:

Learner_B: I never really feel like the computer has more control. I get frustrated. I don’t get frustrated with the computer. It’s more the program or the programmer because I’ve programmed a few things and it gets tedious.

She was clearly looking through the artefact to the task. Control over the artefact was not really an issue in the sense that it might be controlling her, but there was an issue that she wanted more control over it than she apparently had.

Nonlearner_C, the other student with no prior physics background, made a strong connection between control and the learning task. In reference to two of the test questions about the motion of blocks, there was a strong sense of uncertainly about her perception of control:

Nonlearner_C: Again it varied with the questions. Like if I think I know this question. This question seems to make sense to me but I was in control. Like with the block ones…no I think they were in control.

But when she was working with the simulation she felt in control except where her understanding of a specific concept became an issue:

Nonlearner_C: I think I was pretty much in control except I just couldn’t understand the acceleration graph.
This is another example of the level of understanding of the task influencing the perception of control.

One of the students with strong prior knowledge, Physicist_C, felt that he always had good control and never felt that the computer was controlling him:

Physicist_C: No I just use the computer to study what I want.

He was very confident and his comments were the clearest concerning seeing through the computing environment to focus on the task.

The role control plays, as an antecedent to flow, is one of perception: the student needs to perceive that they are in control in order to achieve flow. This could be achieved simply by mastery over the artefact. On the other hand any perception of control decreased, even with artefact mastery, if the task was providing significant challenge. The perception of control was very strong for Learner_A, ‘absolute control’, which is reflected in her well-balanced challenge-skill flow-path (repeated in Figure 6-18). In contrast, the perception of control by Physicist_A, Learner_B and Nonlearner_C were lower as they acknowledged the challenges of the task. Physicist_C, whose flow-path never reported him as being challenged, felt he had good control all the time, over the artefact as well as the task.

![Figure 6-18 Flow path for Learner_A](image)

**Goals and Feedback**

An important aspect of both flow and learning is to receive adequate feedback on what one is doing and how well one is achieving one’s goals. For a learning task involving Web-based interactive multimedia, feedback can be related to the navigational tasks pertaining to the students’ movement through the environment, their knowledge of where they are and where they want to go, their perception of what to do next and how to do it. These are clearly linked to the students’ goals. The navigation tasks for this experiment were minimal, requiring only that students work through four Web pages during the actual learning sequence. It was, however, important that the goals be clearly set.

For most students the goals were clear and related to the learning task:

Learner_A: It’s the concept of motion and what exactly velocity is and how if a body is moving in a particular direction at a particular gradient, what the results are. And the relationships between velocity, acceleration and distance.
The generality of this reflects the fact that the learning materials expressed general goals in a fairly non-specific manner (e.g. ‘I want to understand velocity’ and ‘What is acceleration?’) but added some suggested approaches to finding out the answers (e.g. ‘Drag the cart around to produce…’ and ‘To get steady acceleration, use the fans’). It was a deliberate design decision not to give clear instructions so that students would have to think and make up their own minds about how to approach the task. But even these guiding suggestions were sometimes a distraction:

Learner_B: I think they were pretty clear because the questions were really easy to understand. They were in dot points so there were guides there to help you. But when there’s a guide sometimes it’s not obvious to get at the answer that way so maybe, like, if there wasn’t a guide you could kind of see your path more clearly...

Feedback relates to the learning task itself: how well is the system informing students about the concepts they are trying to learn? This is reflected in comments like:

Physicist_B: The graphs actually helped in understanding the direction of the motion and the constant acceleration, constant velocity.

However, for some of the students the feedback was confusing:

Nonlearner_C: It was quite useful and I sort of got what I wanted to know but somehow it’s just a bit confusing.

The reason for this was that this kind of feedback required interpretation by the student in order to be useful. The student needed to observe a motion or graph, interpret what it meant and then relate it to the learning goals pertinent at that moment. This is a task that someone with reasonable physics knowledge might succeed at:

Physicist_B: It was there on the screen but I think I just looked a bit and then using my own understanding tried to interpret the thing. The graphs were helpful though.

(Physicist_B gained a high score of 12 out of 14 on the pre-test)

But for others the feedback was less useful:

Nonlearner_A: …for a time I was just pressing things and seeing carts moving up and down and wondering what’s going on. So it took a while for the feedback to finally get back.

(Nonlearner_A scored only 2 out of 14 on the pre-test)

And again:

Nonlearner_C: There’s not much that’s bad about it except you just don’t know what the model is trying to convey to you or you don’t understand what it’s doing

Interviewer: So you did have some thoughts of not quite knowing whether you were doing the right thing or not knowing the right answer.

Nonlearner_C: Yeah I just took a logical guess based on what I saw.

(Nonlearner_C scored only 2 out of 14 on the pre-test).

Hence feedback cannot be gauged simply by what the software is doing but we need to take into consideration how well the student can interpret the information presented. Generally the three students who performed well on the pre-test (Physicist_A, Physicist_B and Physicist_C) all reported the feedback
was useful and articulated it in terms of the artefact informing them about the concepts. A fourth student, who scored a middling pre-test score of 5 out of 14, also indicated that she could reflect on the helpfulness of the feedback by relating it to her prior knowledge: ‘Quite a lot. It’s like remind me of the things I learnt back in school.’ The other four, with very low pre-test scores, indicated that the feedback, whilst generally useful, was often a little confusing. This reflected their difficulties in interpreting the physics presented due to their lack of important prior knowledge.

In summary, the task-artefact distinction as applied to feedback allowed one group of students to benefit from the artefact while another group struggled. The value of the feedback depends upon an appropriate fit with the student’s existing knowledge schema.

These comments so far relate to feedback that helps develop conceptual understanding. But little has been said to indicate whether the students felt they were learning sound physics principles. Physics as a discipline has long recognised the burden of misconceptions learnt from early childhood that do not agree with the ‘scientist’s view’ of the world (Clement, 1982; Halloun & Hestenes, 1985a). These early childhood views come about by observing the world and drawing invalid conclusions about the underlying principles at work. Such misconceptions are often robust and hard to shift. For example, a common misconception is that the acceleration of a ball at the top of its flight is zero, whereas it actually has the same non-zero value as for the rest of its flight. Only one of the eight students correctly answered this concept on the pre-test; three subsequently got it correct on the post-test. For the cohort in Experiment Two, 23% of the IS students had it correct on the pre-test and that percentage did not change for the post-test; 24% of the Physics students had it correct on the pre-test rising to 35% on the post-test. This misconception was not an easy one to change!

Not only are these misconceptions hard to change, but there is a risk that additional ‘incorrect’ concept formation can take place in a loosely structured learning exercise such as this one. Although the simulation always presents a situation that is ‘correct’, that is, its obeys the laws of physics, it is up to the student to be confident that they have seen the appropriate motion and can then interpreted the graphs correctly. One student,Physicist_A, recognised the inadequacy of the task in this respect and articulated it well. He recognised the value of the feedback from the point of view of knowing what was going on:

Physicist_A: I just tried many different times to move it which way and having the feedback was quite good.

Interviewer: By feedback what do you mean?

Physicist_A: The acceleration and velocity graph.

But later, when asked to comment specifically on feedback, he refers to his preference for feedback that would tell him whether his learning is on the right track:

Physicist_A: There wasn’t a lot of feedback, wasn’t a lot of things where you type in the question and they say ‘that’s wrong’ or ‘try again’ or they’ll try and explain why you got it wrong.

He goes on to distinguish between feedback from the simulation, per se, and feedback on his learning:

Physicist_A: …so obviously you’re getting feedback, so you’re doing something and the graphs are all there. Easy to interpret – to know what’s happening to the cart. But as far as you actually learning the questions here, there’s not much feedback on whether you’re…it’s just sort of intuitive knowledge.
You can be sitting there thinking ‘I’m understanding it and knowing all this’ but then afterwards you’ll get asked a question and you’ll go – ‘I don’t know’.

Interestingly, this student, whilst recognising that the software wasn’t telling him whether he was right or wrong, did not feel that adding that extra level of feedback would necessarily be useful. He found that the relatively uninterrupted nature of the learning session to be more conducive:

Physicist_A: I was…probably a fair bit of contrast between the learning session and the explanation session. I felt a fair bit more absorbed and at one with the program and it was flowing…because you weren’t being probed so much.

whereas frequent responses by the computer might have broken that flow:

Physicist_A: For instance if the computer had been asking those questions and then saying – no you’re wrong or yes you’re right, then you can go back into it and go and look at it a different way whereas…when your sort of not…yeah.

Interviewer: So if the computer asked those questions, you think that would have interrupted your feeling of flow?

Physicist_A: Yeah.

The question being raised here is what role does feedback play in establishing a rich flow experience with the learner? Flow theory states that one quality of the flow experience is that it usually provides ‘clear, unambiguous feedback to a person’s actions’ (Csikszentmihalyi, 1975, p. 46). The feedback in this experiment was adequate for those with reasonable physics knowledge and it helped them achieve their learning goals. For the others, it was sufficient to enable them to play with and enjoy the simulation, but it didn’t provide good access to learning. For some of these it supported a flow experience with the artefact but not a flow experience with the learning content; for the latter they needed better feedback on their cognition.

Concentration

The experience of flow is one of deep engagement or concentration, losing track of time and losing any sense of self-consciousness. As one would expect, ‘concentration’ was a topic in which both artefact and learning task were referred to by students. Most students found that they had to concentrate moderately hard. When talking about the concentration required for the exercise, students frequently referred to the simulation. It appeared to be the focus even when the aim of the overall task was clearly to teach unfamiliar physics to a stranger at a later time:

Physicist_A: Most of my concentration was going onto the computer. Into moving the things and reading the responses.

Concentration was often reported as being higher at the start when both the simulation and the learning task were being assimilated:

Learner_A: I concentrated more at the beginning to understand what I had to do but then later on once everything sunk in I found the concentration requirement less.

This was in spite of the fact that the learning tasks were getting harder towards the end.
Learner_A: I found it at the start more challenging when I was taking everything from the start and all the concepts and theories from the start and thinking how everything worked with the model.

If the artefact generated confusion or a surprising result, this generally put the focus onto the task – not onto the artefact itself. This is, of course, the aim of interactive software: to challenge students’ ideas and hope that they will reflect on the concept rather than the artefact that presented the challenge. The following comment is from a student being asked when he had to concentrate hard. He indicated that he did not have to concentrate very hard except where there was some cognitive conflict:

Physicist_B: When I was thinking about acceleration and thinking about constant acceleration and constant velocity during one of the tests. And I was thinking how the graph should look like. I was getting confused – it should be at a 45 degree angle or should it just be a horizontal line. So that kind of thinking, I tried to relate to what it does in the graphs and apply it…concentrate a bit more.

Another student showed how focus on the artefact switched to increased concentration on the task when the challenge increased:

Learner_A: Then when I saw the graphs and I wasn’t getting exactly what I want it took some time and I had to concentrate and think how everything worked.

Even though much of the students’ discussion frequently mentioned being engaged with the simulation, there was little evidence that their minds focused on this simply as an object per se rather than as a way of representing the physics. A few mentioned minor problems either in controlling the cart or in learning the environment initially, but when they talked about ‘confusion’ or having to concentrate harder, the emphasis was on the task as accessed through the simulation, rather than the simulation itself. As with challenge, concentration was an element of flow that commonly related to the artefact but quickly moved to the task when the challenge increased.

An interesting exception was Learner_A. As her perception of control improved through the session, her level of concentration decreased. She grappled early on to get the simulation to give her the results she wanted, but then became more confident and concentrated less towards the end. She made good learning gains and enjoyed the exercise very much. The suggestion here is that, for her, she got ‘in the flow’ as she took control and settled into a state that did not require too high a level of concentration.

**Loss of self-consciousness**

Four of the students did not report any loss of self-consciousness. But three of the others, Physicist_A, Nonlearner_B and Learner_A, offered clear statements that they experienced a feeling of loss of self-consciousness or lack of awareness for all or part of the session. One of them, Physicist_A, reported ‘Most of my concentration was going onto the computer, into moving the things and reading the responses.’ He felt ‘relatively absorbed’ but not to the extent that he would not have noticed someone enter the room. When Nonlearner_B was questioned about lack of awareness she reported a distinction between when she was working with the simulation and when reading the text:

Interviewer: ...did you have that feeling where you just so focused on the task that you weren’t thinking about other things?

Nonlearner_B: Quite some part of it.

Interviewer: Can you recall any part in particular?
Nonlearner_B: Those part with the graph on it.

Interviewer: When you were looking at the graphs.

Nonlearner_B: The cart and graph those things.

Interviewer: So when were you being… not feeling unaware?

Nonlearner_B: When all the written part. (Referring to the text on screen)

In spite of this apparent moving in and out of awareness determined by what she was doing at the time, she reported a strong sense of time-loss and enjoyment throughout the whole exercise. Both Physicist_A and Nonlearner_B were classified a having strong flow experiences.

Learner_A, on the other hand, was ambivalent as to whether she flowed, although she showed many of the characteristics. She felt out of control early on when she was grappling with the simulation and was having to concentrate hard. Later she commented ‘I could say that I had absolute control’ while exploring the simulation. It was at this later time that she reported ‘I found the concentration requirement less’. This is an example of the challenge decreasing to an appropriate level and hence the concentration demands reducing, resulting in the appropriate conditions to support flow for her. She begins her comments on self-awareness by linking the timing of her lack of awareness to her first use of the simulation:

Learner_A: It was once I started to think about the simulation, then I just forgot about things.

She later reports that she was initially confused, but as she took control over the simulation, she was able to move from confusion into a state of less awareness and ‘indulgence’:

Learner_A: First of all I thought with the model it’s a bit confusing and I had no control over how to use it or not enough idea on how to use it. Then after I understood and grasped the concepts I enjoyed it a lot.

Interviewer: And is that when you think you got into this state of being less aware of things, once you were out of that confusion?

Learner_A: Yeah and become indulged in the simulation.

For this student, the artefact was an impediment to flow until she gained mastery over it. Whilst she did not give a clear response to the direct questions about flow, her ‘indulgence’ in the simulation can be described as a flow experience. She improved her score on the test more than any other student (from 2 out of 14 to 7 out of 14) and showed very good comprehension of the physics concepts during her teaching session (student S5 in Figure 6-3, p. 142). This suggests that during this time of reduced awareness she was engaging in the physics concepts in a fruitful manner. Her control was moving from artefact to task. Her mind was not just enjoying the motions on the screen, but actually learning and making sense of what she was seeing.

Clearly, loss of awareness was a hard notion to pin down. This probably reflects the notion itself – it is difficult, retrospectively, to be aware of not being aware. References to it tended to refer to the artefact, although awareness of the learning task was often behind the absorption with the artefact. The task was clearly in the background and no doubt contributed to the level of engagement that brought on this effect.
Summary
In this sub-section we have seen that students made an important distinction between task and artefact in the way they reported, and hence thought about, their learning experience. Whilst the same feedback was present for all students, those with better domain knowledge were able to interpret it more effectively than those with less knowledge. This is critical information for the design of engaging learning systems: the feedback essential for flow must take into account the individual’s prior learning or domain knowledge. Whilst students could focus their minds on the artefact, the task, or both, when the concepts were demanding it was the task that tended to dominate this concentration. There was no guarantee that concentration on either the artefact, the task, or both, would alone be adequate to ensure that students would engage sufficiently to produce effective learning.

6.5.4 Challenge-skill as a measure of flow: contrasting examples
A simple application of flow theory suggests that flow can be measured from a student’s balance of challenge and skill (Csikszentmihalyi, 1997; Massimini & Carli, 1988; Novak & Hoffman, 1997). This ratio should enable us to predict a student as being in a state of flow, boredom or anxiety by whether their perceived challenge is balanced with their perceived skills, less than their perceived skills or greater than their perceived skills, respectively. However, such measures, made at the end of an activity, can only offer a global measure of flow. This is, of course, complicated in the present case by the extended duration of the activity that might see students moving in and out of flow during the course of the exercise. Hence the flow-path plot is a more useful instrument than a one-off measure for observing this movement. (All eight flow-plots for these students can be seen starting on p. 163.) As a starting point for this discussion I have chosen two students with extreme flow-paths: one (Physicist_C) firmly fixed in the ‘boredom’ region and the other (Nonlearner_B) in the ‘anxiety’ region. Both students had weak language skills and English was not their first language. Their flow-paths are repeated here in Figure 6-19 and Figure 6-20 respectively.

![Figure 6-19 Flow-path for Nonlearner_B](image1)

![Figure 6-20 Flow-path for Physicist_C](image2)

It is not hard to understand why one of these students appeared anxious and the other bored. Both had done physics in their final year of school in the previous year but Nonlearner_B achieved significantly lower scores in both physics and her final year school studies generally than Physicist_C. Nonlearner_B scored 5 out of 14 on the pre-test; Physicist_C scored 11 out of 14 – an excellent score as this test was not
What is inconsistent with theory is that one of these (Nonlearner_B) reported during her interview a fairly strong flow experience and the other (Physicist_C) did not – one would expect neither to have experienced flow based on these plots. The evidence for their experience of flow, or lack of it, comes mainly from their interview responses regarding the experience and effects of flow (lack of self-consciousness, loss of time and enjoyment) together with the direct comments that they made about whether they experienced flow-like feelings.

The evidence of flow for student Nonlearner_B was quite strong. She experienced lack of self-consciousness for ‘quite some part of it’ especially when looking at the cart and graphs. She reported feeling that time was passing quickly ‘all the time’ and when she was asked to estimate in the interview for how long she had been involved in the exercise she replied ‘It’s like half an hour or 45 minutes’. In fact, 80 minutes had passed and she was clearly surprised to hear this. Added to this was her feeling of enjoyment. She expressed strong enjoyment for all aspects of the activity even though she had not enjoyed physics at school. Her post-survey score on enjoyment supports this (4.3 out of 5).

Particularly interesting is the way she responded to a direct question about flow. Flow was described to her in the interview using the following two descriptions from the literature (Csikszentmihalyi, 1982):

My mind isn’t wandering. I am not thinking of something else. I am totally involved in what I am doing. My body feels good. I don’t seem to hear anything. The world seems to be cut off from me. I am less aware of myself and my problems.

and

I am so involved I what I am doing. I don’t see myself as separate from what I am doing.

Asked to comment on whether she had any similar feelings she replied:

I know what I’m doing and sometimes I lost my conscious of the environment, what happen outside.

She went on to comment ‘My mind just on the computer’, ‘I’m in control’ and in commenting on feelings said ‘enjoy and comfortable with the thing’.

In comparing her responses to those of others, they indicate that she experienced the strongest flow of the group. She was a quiet student whose English was not strong, and consequently did not bubble over with visual signs of excitement, yet she quietly showed that she really enjoyed what she was doing, was deeply engaged, in control, lost track of time, and was not distracted.

In contrast, Physicist_C showed little sign of the effects of flow. He reported no sense of loss of self-consciousness. He estimated the time for his learning session reasonably accurately to be 40 minutes (it was 50 minutes). His comments about whether he thought time was passing quickly were a little ambiguous and followed by:

Physicist_C: I didn’t notice the time actually. I just working on the task and just get it right.

In responding to a question about whether he had any flow feelings he commented:

Physicist_C: Yes but, you know, I did think about others as well, doing on the computer.

The ‘other things’ he thought about were ‘just the motion in the normal world, in the real world, not just of the simulation on the computer’. This thinking was triggered when he read each question and then
played with the simulation. The simulation, it seems, was a means of confirming his already well-formed ideas. He was distracted, but by thoughts that were associated with the learning task rather than by extraneous thoughts. It seems that the task itself was not particularly challenging, but he was deeply engaged with the ideas embedded in it and had sufficient domain knowledge to see beyond the task and reflect on the real-world physics.

However, Physicist_C did enjoy the activity, giving it the same rating as Nonlearner_B in the survey. He was also very engaged with it. This engagement was illustrated by his comments on thinking about ‘the motion in the real world’. But he also had to concentrate hard on interpreting the text while still having fun:

Physicist_C: …Well reading the words is quite hard. By the way you know we are playing with models. When dragging things around I find it’s not hard, it’s just fun.

He goes on to comment that he had to concentrate hard on the language since his native language was not English. The flow experience leaves no room for other thoughts hence it is likely that concentration on language was what prevented flow for this student.

These two students clearly had very different experiences during their learning session. Nonlearner_B was highly challenged for the whole time yet she gave no indication in the interview of having been stressed or anxious. She got quite excited by the task. In contrast, flow theory would classify Physicist_C as being bored, but he gave no indication of this in the interview and rated boredom as a low 2 out of 5 in the survey. He was enjoying himself, thinking about the physics and his prior knowledge of it, and struggling a little with the language. He didn’t indicate the same excitement that Nonlearner_B did, but nevertheless had a much more positive experience than one would expect if someone were bored with the task.

What were the main features that help us to distinguish between these two students? Clearly Nonlearner_B was much more challenged than Physicist_C. She described the session as ‘quite challenging’ and it made her think. She acknowledged her low skills in physics yet, in spite of this, she reported that she had adequate skills to do the thinking that was required (and also gave a low estimation of her skills in the survey). She reports her concentration as ‘just all right’, ‘not that tension’ (her word for ‘tense’) and ‘maybe it take more concentration than study at home’. Physicist_C, although getting confused in some parts, did not find the work particularly challenging ‘because I’ve got some background about Physics’. The survey shows both having high enjoyment, being very interested, and not bored. Physicist_C felt slightly more in control and Nonlearner_B indicated a moderate level of frustration.

In summary, the challenge-skill plots for these two students did not prove a valid description of their experiences in terms of flow. Whether Physicist_C flowed or not is a little uncertain, but even while sitting firmly in the ‘boredom’ region he was still interested and highly engaged in the task. This suggests that although he recognised that he was in good control of his physics, this task that he perceived as ‘easy’ still provided him with sufficient positive aspects of flow to keep him interested and engaged. This makes an interesting contrast to, yet is still consistent with, the cohort of Physics students discussed later in 6.8.2 and illustrated in Figure 6-26 (p. 194). Many of those Physics students were over-represented in the high-skill/low-challenge (‘boredom’) area of their flow-paths, and I suggest in 6.8.2 that this is because they focused on the simulation artefact and not so much on the task. This student, Physicist_C,
sees through the simulation to the task as the focus of his attention and even this task is not a great challenge to him. The result is that he too suggests ‘boredom’ judging by the mappings of his flow-path.

It is interesting to compare Physicist_C with Physicist_A due to their similarities in background. They each scored 11 out of 14 for the pre-test and improved by two and three marks respectively. Physicist_C had the second highest Likert scale score for the group on control, engagement and enjoyment, 4.0 out of 5, whilst Physicist_A had a significantly lower score of 3.4 out of 5. Physicist_A was about 3 years older than Physicist_C. They clearly both came into the exercise with a solid knowledge of the underlying physics. Both initially got the same pre-test questions wrong relating to the acceleration of a ball tossed into the air; this was the topic of the final page of the learning task. The flow-path for Physicist_A is compared side-by-side with Physicist_C in Figure 6-21 and Figure 6-22 respectively.

![Figure 6-21 Flow-path for Physicist_A](image1)

![Figure 6-22 Flow-path for Physicist_C](image2)

Physicist_A began with a high perception of his skills and saw the initial challenge as being low. However he quickly re-assessed his skills and also his perception of the challenge of the task.

The antecedent conditions of Physicist_A were well set up for a flow experience as is illustrated by the following passages. He found the goals for the activities fairly clear even though some parts were hard for him to explain:

Physicist_A: I understood what we were meant to ask in (question) one. Perhaps I’d actually thought it might have been one of the ones that were more difficult to understand but when it gets to that… when it’s that simple… it’s sort of more re-intuitive understanding habit. So with (questions) two and three it was more substantial. The question they were trying to ask though was a bit more… maybe even easier to answer it because there were some definite things you were trying to find out, the first one, you know, ‘what’s the idea of velocity’ whereas the second two and three was more specific questions. I think the first bit of two I understood it, what I was meant to be asked and how you were meant to go about it. Number three I understood what I was meant to be asked but I couldn’t quite explain it as well.

He perceived there to be reasonable feedback from the simulation:

Physicist_A: Yeah, that’s good, so obviously you’re getting feedback, so you’re doing something and the graphs are all there. Easy to interpret - to know what’s happening to the cart.

but not so much to help his learning:
Physicist_A: But as far as you actually learning what you’re meant… the questions here, there’s not much feedback.

The challenge was increasing for him. It began fairly easily:

Physicist_A: I thought the first two were relatively easy. They were straightforward things and I could grasp what I thought that was trying to tell me. Those few questions using the simulation.

but became more challenging towards the end, maybe pushing him to the limits of his comfort zone:

Physicist_A: Question three and four I think they were a bit more difficult. Just wrapping your head around positive and negative effects of acceleration, positive and negative velocity. Maybe just got a bit muddled.

He was clearly struggling a little at the end to understand aspects of acceleration. This was the area of the pre-test that he got wrong and that he later corrected in the post-test.

His flow experience was quite strong. He was quite absorbed in the task and focused:

Physicist_A: I didn’t really find myself distracted at all.

Physicist_A: Yeah I’d say to a certain degree I felt relatively absorbed in it.

Physicist_A: Most of my concentration was going onto the computer. Into moving the things and reading the responses.

His estimate of the time was 45 minutes when in fact it was 100 minutes. When questioned about flow he distinguished between the learning session and the teaching session. About the learning session he comments:

Physicist_A: I felt a fair bit more absorbed and at one with the program and it was flowing…because you weren’t being probed so much, I was able just to work out things and try and find the answer to them.

He goes on to comment on how, during the teaching session, his flow was broken when it came to explaining things that he did not understand fully. This is consistent with the notion that achieving flow whilst in a stressful situation, or anxious, is unlikely to be successful. Generally Physicist_A rates the survey scores lower than Physicist_C – even though he appeared to be experiencing stronger flow, he did not indicate as strong control, engagement nor enjoyment. There was little indication of excitement through his interview, whereas Physicist_C showed a few more signs of becoming excited by the exercise.

The flow-path for Physicist_A (Figure 6-21) reflects much of the above discussion. He started off with a low challenge-skill ratio even though his comments indicated that this first question might have been harder, or less well defined, than subsequent ones. For the following three questions he perceived that the challenge became greater compared to his skills and his flow-path moved into what, for him, was an area of flow: challenges appropriately higher than skills. This reflects his comment mentioned earlier ‘with (questions) two and three it was more substantial’. However, in spite of his concerns over question three (‘Number three I understood what I was meant to be asked but I couldn’t quite explain it as well’) that point on the flow-path is lower than questions 2 and 4. This is a reminder that several factors could determine how he responded to that probe during the task. In this case he was possibly responding to his understanding of the task rather than considering the complexity of understanding the concepts behind it.
Summary

These three students, Nonlearner_B, Physicist_A and Physicist_C, paint a complex picture of what constitutes flow. It is clear that an appropriate challenge is an important element, but, as Nonlearner_B showed, that challenge can be of a very high level and yet not prevent flow. The challenge-skill ratio alone is not an adequate indicator of flow in a learning context. Loss of awareness of time gave a good indication as to who experienced flow, yet even with a very real time loss (Physicist_A) flow need not be accompanied by an exuberant demonstration of pleasure. As one would expect, this suggests that flow in a learning situation might not produce the same strength of pleasure that you might expect in an activity such as rock climbing, where the activity is both mentally and physically challenging and intrinsically motivated. It is feasible that some learning situations might produce this excitement, but it was not generally observed amongst these students. Of all the students Nonlearner_B was the one who came closest.

Challenge-skill flow-paths, whilst being too simplistic to be the total measure of flow in this context, still provide a useful description of a student’s experience. Looking at Physicist_A’s path, for example, we can see that the challenging part of the exercise for him was after the first page. It was unlikely that the experience was going to be very valuable to him while he was experiencing relatively low challenge at the start. Indeed, for him it was in the latter pages that he refined his concept of acceleration that was reflected in his improved test score.

No attempt has been made here to normalise the challenge-skill data to either the individual or the group. As discussed in Chapter 4, this is something more easily done for a week long flow study that for a short, one-off exercise. The consequence of this it that we know nothing about the calibration of the Likert scales that each student must (unconsciously) make. For example, Physicist_C used the maximum scale rating for his skills and minimum rating for his challenge. This left him no space to locate vastly simpler material, should it have been present. If the session had ended with some trivial exercises, he would have had no way to distinguish them on his plot from the other, harder, exercises. The point here is that a student must carry out some self-normalisation or a calibration procedure for the expectations of the task at hand, and we have no knowledge of how this is done. This reinforces the inadequacy of challenge-skill plots, on their own, to reflect flow.

6.5.5 Students’ description of the flow experience

Towards the end of each interview, students were read a standard description of flow and were asked whether at any time they had similar feelings during the session.

No student gave a response indicating that he or she flowed with extreme pleasure – a strong autotelic experience. However, seven of the eight indicated that they had moments of flow, or that they had experiences of deep engagement that were often associated with enjoyment, even if not a high degree of excitement.

The most surprising response to the question was from Nonlearner_A, one of the two students with no prior physics background. His survey scores (code S7 in Appendix C-11) suggested that he did not feel a strong sense of control (2 out of 5), was not deeply engaged (2 out of 5), had only moderate enjoyment (3
out of 5), frequently thought about other things and was distracted (4 out of 5 each). He did not find the goals of the task particularly clear:

Nonlearner A: You had to try it for yourself and then after a while you would realise – Oh this is what they wanted me to do then.

He didn’t find the feedback particularly helpful or immediate:

Nonlearner A: It took a time to build up to that point but for a time I was just pressing things and seeing carts moving up and down and wondering what’s going on. So it took a while for the feedback to finally get back.

He found the tasks ‘a bit challenging’ but he thought his skills adequate (presumably he was thinking about his skills with the simulation here; his physics skills were very poor and he probably realised that). His flow-path reflected his assessment of challenge-skills as being balanced most of the time (Figure 6-23). He did not feel in control of the computer, especially at the start, commenting:

Nonlearner A: I think the computer had an upper hand.

![Figure 6-23 Flow-path for student Nonlearner A](image)

He did not experience any distortion of time and he found it hard to concentrate due to the distractions of the room’s monitoring facilities. He refers to it being ‘like you’re being watched’. Interestingly, he used the term ‘flow’ before hearing it in the questions:

Nonlearner A: No, it’s like when you move to touch the mouse or something, or when you look at the screen suddenly the Physics goes again and you think – Ahh okay. When you actually move to do things. But when you’re thinking about the questions it’s okay, when you’re in that flow, but as soon as you move your head, or notice that it’s a different kind of environment, that’s when it gets to you.

This last quotation appears to be a reference to a sense of deep engagement that lasts for a short while, but is very fragile. The task holds his attention for a while, but it is easily lost again. He reports this happening in particular as he moves from one question to another, but not during periods while he is using the simulation.

Out of all of the above traditional flow elements, only his challenge-skill balance appeared to indicate a flow experience. Yet when asked specifically about flow he gave this surprising response:
Nonlearner_A: It’s like I wasn’t here, somewhere alone with this machine doing something. Like separate from everything else because…we’re just there for like time and then now you’re out of it. It’s like you entered a little place that’s not normal for you.

The experience he described, possibly similar in kind to ‘telepresence’ (Steuer, 1992), stayed with him continuously for the duration of the learning session:

Nonlearner_A: The whole time basically when I started answering the questions I was not really here. I was like inside a place the computer had made for me to go.

This slightly contradicts his earlier comments about being distracted as he moved from question to question. It was as if he took the distractions in his stride and saw them as part of the world that he was immersed in. These distractions could be viewed as punctuations in his experience as he moved in and out of flow. In a complementary manner, we earlier saw that Learner_B (Ann) experienced no flow for most of her session, but moved into flow a couple of times during moments of learning. Both of these students’ experiences support the notion that flow can turn on and off during a period of activity.

In contrast to Nonlearner_A, many of the others often described flow experiences more specifically in relation to the learning task they were focusing on. Physicist_A reported being ‘absorbed and at one with the program’. He related this to being able to ‘work things out and try to find answers to them’. He was thankful that there was not too much feedback to interrupt him. His seemed to have a more robust experience than Nonlearner_A. Physicist_B reported being ‘with the tasks’ and not distracted while answering the questions and the test. Apart from the instructions, which he did find distracting, he commented that the best aspect was ‘working the simulation and understanding, interpreting…’.

Nonlearner_B also reported a disconnection from the outside world:

Nonlearner_B: I know what I’m doing and sometimes I lost my conscious of the environment, what happen outside.

She reported being in control with her ‘mind on the computer’. Her feelings were enjoyment and being ‘comfortable with the thing’. She was the only one to mention enjoyment while talking about flow. Nonlearner_A had reported that he felt no negative emotions but just a feeling of ‘curiosity’.

A more common emotion was frustration, mentioned by Learner_B and Nonlearner_C. Learner_B’s (Ann) frustration was when she was trying to display her curved graph. She reports:

Learner_B: I guess I had flow then as well because I was kind of focused on that trying to achieve that aim.

She related her flow to focus on her task rather than the simulation.

Nonlearner_C also related her flow to being focused and interested. This happened while she was using the simulation, rather than just reading or thinking, and her mind was clearly on the learning task:

Nonlearner_C: I think when I was trying to work out these graphs, work out what was going, why it’s back to the start, why is that positive, why is that negative…

Her frustration was only slight and happened while trying to understand the task and, in particular, the acceleration graphs.

The one student who appeared not to flow was Physicist_C. He was one who had a strong physics background and hence was not very challenged by the exercise at all. Most other conditions for flow were

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present: he found the goals ‘pretty clear’; found he had sufficient feedback; he felt in control; he didn’t have to concentrate hard on the task, he found it ‘not hard, it’s just fun’. He did, however, have to concentrate on the English, as it was not his first language. He enjoyed the exercise – especially dragging the cart and watching the graphs. However, he felt no loss of self-consciousness and felt distracted by other thoughts:

Physicist_C: …just the motion in the normal world, in the real world, not just of the simulation on the computer.

His distractions were relevant to the task, but nevertheless he saw them as distractions from the task at hand.

Some valuable, yet slightly different, insights into flow experiences were offered by Learner_A, the student who made the most significant learning gains of the group (test results from 2 out of 14 to 7 out of 14). Although she did not provide useful specific comments on flow – preferring to talk about experiences in other learning situations instead – other aspects of her interview suggest that she did flow and gained benefits from it. As described earlier, this student stated that she found the exercise more challenging at the start as she grappled to apply the ‘concepts and theories’. Part of this was her gaining mastery over the simulation. This was a time when she felt in low control and had high concentration. Later, as she gained ‘absolute control’ she found she had to concentrate less. Some of her comments suggest that she was having a flow-like experience for most of the time. For example, when asked about whether she felt a sense of a loss of self-consciousness, she replied

Learner_A:  Yep. It was once I started to think about the simulation, then I just forgot about things.

She goes on to say that this occurred from the first question until the very end. It appears that, for her, her concentration reduced somewhat while in flow to a ‘steady-state’ level that sustained her until the end.

She thought that time went faster ‘probably at the start when I wasn’t too sure how to use the simulation’ but also comments that it went slower during some of the harder explanations during the teaching session: ‘When it got more tough time passed more slowly’. This suggests that perceptions of time might vary through the duration of a flow experience, but such perceptions are hard to think back on and report reliably.

This student was also interesting in that she was the only student who volunteered information about engaging in some free exploration with the simulation. When asked about whether there was something that she learnt and for which she could remember her activities at the time, she replied:

Learner_A:  I wouldn’t really say there’s anything else apart from just using the fans to try and maintain a constant velocity.

Maintaining a constant velocity was not something that was suggested or alluded to in the exercise. This was a ‘playful’ activity on her part as she tried to make the cart run up a slope at a steady speed. She was partially successful:

Learner_A:  At some point I pretty much maintained it and then it just lost itself and I didn’t have enough fans.

This notion of exploratory behaviour, or play, is one that others have noted as being a consequence of flow (Ghani & Deshpande, 1994; Ghani et al., 1991; Novak et al., 2000; Webster et al., 1993). This suggests that, certainly at the end of the exercise, Learner_A was experiencing flow. Her challenge-skill
balance has evened out and time was passing more quickly, she was not having to concentrate too hard, she felt in good control, was enjoying herself and not being distracted, she was motivated to explore and play with her environment.

**Summary**

These comments from the students in response to flow tell us several things. Firstly the challenge-skill balance is an important one, but not, in itself, a reliable indicator of flow. Most of the students recognised that the task was a demanding one and that it was taxing on their skills. This helped them to maintain their engagement with it. It was a deep engagement with the task that students focused on; the artefact itself was a minor player getting some mention but always in the context of the associated understanding or interpretation of the physics. The notion of losing self-consciousness, or being unaware of distractions, was one that students appeared to relate to readily and could describe in terms of their engagement with the task.

As for the emotions associated with flow, surprisingly frustration did not deter the two students who reported it. To some degree, their frustration drove them to deeper engagement to sort out their thinking. We don’t know how enjoyable this was, but then again, enjoyment played a less significant role with these students. The students enjoyed the overall experience generally, although Learner_B might not have enjoyed her moments of frustration if asked at the time. Certainly enjoying the activity alone was not sufficient for flow. Physicist_C enjoyed particularly playing with the simulation but never became very engaged. The one element that Physicist_C appeared to have lacking was adequate challenge; the task was too easy for him and never developed the level of engagement that the others experienced.

The contribution from Nonlearner_A in an interesting one to reflect on in respect to flow theory. He appeared to reach a state of complete engagement based on moderate enjoyment of the task and a perception of moderate challenge for his skills, but few others of the traditional flow elements. It is likely that he did not engage with the task as fully as others, but engaged with the simulation to quite some degree. Something about what he was doing dragged him into the world of the computer and he stayed there. Was this flow? It is likely that it was not. He was certainly deeply engaged but is unlikely to describe the experience as one he would be keen to repeat just for the enjoyment of it.

The place of extreme enjoyment, in the autotelic sense, is interesting in the context of flow and learning, but this aspect of flow was not explored significantly in these interviews. Several students reported high levels of enjoyment, but I could not say whether they would opt to work though such a learning exercise again purely for the pleasure of it. That is surely an ambitious, yet highly desirable, aim for learning environments.
6.6 Flow in a learning context

The previous section of this chapter explored many facets of flow as observed through surveys, probes, data-logging and interviews. These are now interpreted in terms of the three research sub-questions of this experiment.

6.6.1 Flow as measured by challenge-skills (RQ3.1)

RQ3.1 How does the flow process in a learning context, as measured by challenges and skills, relate to the experience of flow identified by Csikszentmihalyi? (RQ3.1)

Experiment Two of this thesis made the assumption that a simple measure of perceived challenge and skills would provide a measure of flow in a manner established by other researchers (Massimini & Carli, 1988; Novak & Hoffman, 1997). An appropriate balance of these two factors was expected to be an indication of a perception of clear goals, appropriate and timely feedback, a good sense of control, a merging of action and awareness leading to a state of high concentration, enjoyment, lack of self-consciousness and possible a distortion of time. This third experiment has shown that, for students engaged in learning, challenge and skills are not as clearly defined in their minds as was assumed. Although others have expressed concerns about the interpretation of ‘challenge’ in terms of cognitive stimulation or difficulty (H. Chen et al., 1999), a more problematic concern turns out to be the interpretation of ‘what is challenging?’ and ‘skills for what?’.

It is clear that, depending on the ability of the student, they might focus on the simulation presented to them or the learning task that was designed around it. Either of these might result in a flow experience, be it flow with the artefact or flow with the task. However, should the interpretation be mixed, for example reflecting on their perceived challenge of the learning task but their skills in the use of the simulation to cope with it, then the interpretation is less clear. A balanced challenge-skill ratio in this case might still be an indicator of flow. For example, if one student is concentrating on understanding an aspect of physics, and seamlessly using the simulation to explore it, then they might record a mid-level rating for both a challenge and skill suggesting flow. However, another student in the same situation might give a mid-level rating for challenge but reflect on how straightforward the simulation is and hence record a higher level of skill that would not suggest flow. Not knowing how students interpreted their challenge-skill ratings adds an uncertainty to this as a method for measuring flow.

6.6.2 Design features of a flow activity for learning (RQ3.2)

RQ3.2: What are the features of an online interactive learning activity that maximise the potential for flow?

In this sub-section I explore what these findings tell us about the design features of a learning activity that are important to optimise the chance of students experiencing flow. There were two important features of the activity presented to students. First, the learning task was of sufficient complexity and was delivered through a specific medium (the artefact). The task required the students to grapple with the complexities of difficult concepts in physics and so is not the equivalent of tasks requiring simple acquisition of knowledge, for example, tasks relying on recall of information. Complex concepts require significant
construction in students’ minds and hence rely on their ability to interpret complex information. This can provide a considerable challenge, depending on the prior knowledge of the student.

Second, the nature of the artefact is also important. In this research it was a simulation requiring a level of domain knowledge to operate in addition to the interpretation of the physics concepts being presented. For example, understanding how graphs represent velocity and acceleration was a necessary precursor to exploring how the acceleration behaved in a given situation.

These two task parameters defined the specific context within which interpretations concerning the occurrence of flow were made. The findings have clear implications concerning dimensions of goals, feedback and the ratio of challenge to skills.

The discussion below will assume a similar nature of task and artefact to those described above. I will assume that the artefact is an interactive object of some kind. I will draw on the experience from the experiments and note, where necessary, improvements that might be desirable to the learning task and artefact that was used.

**Goals**

The findings suggest that flow is more likely to occur when students perceive clear goals for what they are going to be doing. Some of these goals will be *task goals* that relate primarily to the learning task and help motivate them to proceed and to continue as the difficulty level increases. Other goals will be *artefact goals* that relate to manipulating the artefact to give students access to appropriate information. On both counts students need to come to the learning activity with certain levels of task and artefact knowledge. To determine these goals a student will need to know the capabilities of the artefact. This might be provided in the form of instructions, or a simple exercises not complicated by needing to interpret the learning task. The danger is that often such activities become tedious. Many students might prefer a guide, or appropriate context-sensitive help system, rather than reading instructions, but this can be difficult to implement. A balance is required here.

**Feedback**

Requirements for feedback also involve both task and artefact. The artefact demands seamless, prompt feedback that confirms to the students that they are performing an appropriate interaction with it. When the students are using the artefact they need to ‘be absorbed and at one’ with it. This suggests a direct engagement-style of interaction (Hutchins, Hollan, & Norman, 1986) rather than one where the feedback is via simply clicking a button and waiting for a response. The aim here is that the artefact itself becomes a transparent conduit to the learning task concepts.

However, an artefact that intrinsically gives feedback (as was the case with the graphs within the simulation in this experiment) might not, on its own, be good at supporting learning. It needs to mesh closely enough with the task so that the feedback can inform the student’s knowledge state. The risk of an attractive interactive object is that it can present to the student feedback that has an appearance of providing knowledge about the task, but if that feedback cannot be easily understood it distracts the student from engaging with the goals of the task.

Task feedback is more difficult to define than artefact feedback. Task feedback confirms to the student that what they are doing is appropriate and that the learning they are deriving from it is correct. This is a
common interpretation of feedback in a computer-based learning context (Kihine, 1996). However, with complex tasks this will present different challenges according to the knowledge state of the student. Hence, the feedback needs to match carefully the current conceptual understanding of the students to provide appropriate information about responses they have made. It needs to connect with their current thinking, while at the same time keeping them focused on the task itself; to engage their minds with the task, seamlessly manipulated through the artefact.

This was achieved to varying degrees for students participating in this study. The feedback presented students with the graphs that they needed to understand the physics. However, if they did not immediately know how to interpret the graphs, the feedback gave no indication as to the reasoning behind the graphs or whether students were focusing on appropriate aspects of them. A better way to complete the feedback cycle here, after viewing a graph, might have been to let students draw a graph on the screen for a particular situation and have the computer give an appropriate response to their input. On the other hand, too many probes or requests from the system might interrupt a more expert student’s flow. The challenge for the artefact designer is to provide ways that the feedback can adjust itself to the learner’s needs.

To achieve a high intensity flow experience relevant to learning one should aim for feedback of two types – feedback to satisfy the manipulation of the simulation object to achieve a short-term goal, and feedback to provide the excitement of knowing that you have got something right or learnt a new idea correctly. Although students reported a high level of enjoyment after the task in this experiment, there was limited evidence of high excitement.

**Control**

Closely related to feedback is a perception of adequate control that is important in any learning environment. Perceived control will be determined by the task, the artefact, but also by the knowledge state of students as they strive to interpret the feedback provided by the system. If the task is too challenging or difficult, then it is likely that the student will not feel a sense of control over it and may become frustrated and confused. They may nevertheless engage with the artefact, master it and achieve a sense of control over it, resulting in a flow experience, but not one that is likely to encourage learning.

For an effective learning environment involving flow, the locus of control should be firmly with the students so that they feel ‘in control’ of what they are doing, but the environment must support this control in two ways. Firstly, the artefact must respond quickly, accurately and appropriately to the students’ inputs. The interpretation required to make sense of the outputs should be aligned with the students’ skills so that they do not have a sense of struggling to understand what is being portrayed. Secondly, feedback from the task must also give a feeling of being in control, although students may sense a lower degree of control of the task as they struggle to comprehend it. This is part of the delicate balance to provide a sufficient increase in challenges to encourage skill development, but not so great as to lose flow due to a lack of control.

**Challenge-skills**

An appropriate level of challenge is essential to differentiate flow from an engaging experience that is simply fun. The challenge must be such that the students are striving to learn, not just confirming what they already know. The reason for this is not just to maintain their interest, which will often be done by
the interactive object itself, but it is because their interpretation of their actions with the artefact will depend on their abilities with the learning task at hand.

The challenge of the artefact should be not too demanding and remain reasonably consistent so that its operation becomes seamless and intuitive. The level of challenge of the task, however, needs to attract the attention of the students and increase as their skills develop. This increasing challenge-skill coupling needs to maintain the students’ focus on the task, while the artefact plays a motivating role in the background. If the challenge with the task becomes too great for their skills, they may stay engaged with the artefact but lose interest in the task and not learn the concepts desired. It is quite likely that, under these conditions, they will have no way of knowing whether their learning is correct or not.

Students will have different learning styles and some may not want to become engaged with the artefact at all. The artefact can act simply as a trigger to motivate their learning, and flow can result if the task itself provides appropriate challenges and feedback to keep them engaged.

**Summary**

It will always be hard to produce a particular task-artefact combination that offers a high chance of flow for all students due the different domain knowledge, artefact knowledge, and learning styles that students bring to an activity. However we have seen that by taking these factors into consideration we can enhance the potential for students to experience flow. In particular, these findings highlight the need to be very aware of how students move focus between task and artefact during a learning session. Such awareness is important to develop better ways of encouraging flow, measuring flow, and using it to produce more effective learning.

### 6.6.3 A view of flow for learning (RQ3.3)

*RQ3.3: What are the characteristics of flow as experienced by students during an online interactive learning activity?*

This study has explored on-line learning materials of the kind likely to be needed for a conventional course. In this context it is unlikely that flow will take on the highly intensive form observed in rock climbers, chess players, or computer game players. Such activities are usually self-initiated and, as such, self-motivating. For the context explored here – sitting a student in front of a compulsory learning activity – the effects of flow are likely to be far less exuberant. Below are descriptions of the significant flow elements in a learning context deduced from the experiment analysis and the reflections on student interviews.

**High concentration and engagement.** The verbal description of flow presented to the students in this experiment was one of involvement, feeling good, being unaware of surroundings and being ‘at one’ with what one is doing. Each of these elements was found to be present with the students to different degrees. Most notable was the level of engagement and concentration experienced by students. By definition, any student in flow will be highly engaged and report being ‘focused’, ‘in a world of the computer’, or ‘forgetting about other things’. However, their reporting of engagement may differ depending whether they are focusing on their engagement with the task or their engagement with the artefact. A high level of engagement will lead to a lack of awareness of surroundings. But this might be erratic and vary depending on timing and specific aspects of the task.
High affect. A factor that differentiates flow from on-task engagement is that students will report a high level of enjoyment after the event. This might not be as extreme in a learning task as in some other activities (such as game playing) but without it the key autotelic nature of flow is missing. This affective element of flow is likely to be identified by students reporting enjoyment, pleasure or a sense of having fun.

Control of both task and artefact. If the artefact is novel to the students, they might feel a lack of control over it early on in the exercise. There will be a ‘training period’ during which time they will develop sufficient skills with it to understand its capabilities and to then be able to use it to explore the task. Control over the learning task is, however, a different matter. If the task is too challenging for an individual, then he or she may never feel in control of it. That student might still have a flow experience, but this is likely to relate only to the artefact and not the learning task. There is a need for control over both artefact and task to maximise flow in a beneficial sense.

Feedback. Feedback must be supportive of students’ learning and be appropriate for the skills of the student. An interactive object might offer feedback intrinsically (as does a simulation) but the interpretation of the feedback might be beyond the skills of some students rendering it of little value. Frequent, overt feedback might distract the student from engaging with the task. The feedback needs to guide and reassure students that they are progressing with the task, yet not distract. Since this depends so much on the skills and abilities of the student it is one of the most difficult aspects of designing interaction to achieve flow.

Sense of oneness. It is likely that a student will report loss of awareness or loss of self-consciousness while experiencing flow. This is something they might reflect on in terms of a lack of awareness of their surroundings, a sense of loss of time, being absorbed or in a state of high concentration. This experience will be more likely if the manipulation of the artefact is effortless and not an impediment to their working. In such conditions a student may experience a sense of ‘oneness’ that will reflect the good design of the artefact.

For an individual sitting at a computer engaged in a learning task, it is unlikely that there will be signs of flow that are easily visible. This means that to recognise the above elements as being present one needs to monitor the students during the session and to survey, or preferably discuss, their experience after the session is finished.

6.7 A model of the flow process

In this section I propose a model of the flow process in a learning context that draws on the discussions of this chapter to represent a student’s interaction with a task. The model is first discussed then supporting evidence is presented from the interview data.

6.7.1 Describing the model

The preceding sections of this chapter have examined the complications of flow being linked both with the artefact that a student uses and the learning task on which they are working. This model describes three situations: flow with the task, supported by the artefact; flow with the artefact; and flow with the task, despite the artefact.
Flow with the task, supported by the artefact
This describes the flow process that a designer is aiming to achieve when designing an interaction to support learning. Goals are specified in terms of the learning task, but the artefact is presented as the object through which one accesses the task. The artefact is an attractive and motivating object that grabs the attention of the student, but allows the student to move on and engage with the task content. The student will continue to use the artefact during that engagement, hence it must have a degree of ‘transparency’ in that it can be used seamlessly in a direct engagement style and not draw too much attention away from the task. Examples of this behaviour were observed with Physicist_A and Learner_A, both of whom took some time to master the artefact, but, as their skills with it improved, they moved on and used it to focus on and explore the task.

Flow with the artefact
This describes a flow process in which the student’s challenges and skills with the artefact are so well balanced that their flow process is one of engaging with the artefact and not the learning task. In this case the artefact becomes an obstacle between the student and the task and prevents the student from moving on to address the task. This is the often-criticised ‘bells and whistles’ syndrome of multimedia in which the interactive object gets in the way of learning. This was observed with Learner_B (Ann) when she described a flow experience while trying to create a curved graph that was not possible to achieve. During that period the challenge of her self-created task became sufficient to take her mind off the set learning task and apply her skills to achieve her aims. Similarly, Nonlearner_A showed little evidence of engagement with the task, yet became completely absorbed in the computing environment and its artefacts.

Research into learner-interface interaction has suggested that it can distract from learning and that students need to be familiar with the interface in order to learn from it (Hillman et al., 1994). Learner-artefact flow extends this notion by referring not just to a general computing interface but to one designed as a learning object (the artefact) yet still one that can exist as an obstacle to student’s learning.

Flow with the task, despite the artefact
In this situation the student ignores the artefact and experiences flow directly with the learning task. The student reflects on, and learns about, the concepts of the task without interacting with the artefact in any significant way at all. Such a student would be utilising prior knowledge to construct meaning relevant to the goals of the task. This style of interaction was exhibited by Learner_B (Ann) who spent little time using the simulation, and hence spent little time doing the activities associated with learning the concepts. However, she spent much time thinking about the ideas that she needed to understand. She drew heavily on her prior knowledge of physics, but little on the use of the artefact or on the demands of the task specifically.

The balance between task and artefact
The above descriptions of the flow process illustrate that the artefact can be both an asset and a hindrance to encouraging flow. On the one hand the artefact presents a tangible, motivating conduit through which students can engage with the concepts presented by the task. It allows them to access the task in a
practical sense and maintain an interaction with it as their skills develop. On the other hand, it can distract a student and shift attention from engaging with the task to engaging with the artefact.

The descriptions also illustrate the to-and-fro nature of the artefact-task interaction. The students’ attention may frequently change from artefact to task as they struggle to make sense of the concepts presented. The purpose of these representations is to highlight the relative positioning of the artefact and task and how each can capture the students’ focus and hence affect the nature of their flow. They also emphasise the delicate balance between the artefact and the task. The artefact needs to be attractive in the sense of alluring the student to interact with it, but not so alluring that the students’ focus remains on the artefact and not the task. A well-designed artefact will have a degree of ‘transparency’ that allows students to move through and engage with the task; it will not get in their way. A poorly designed artefact will block students’ progress and leave them simply interacting with the artefact.

What makes an artefact well or poorly designed? This depends on factors relating to the student’s background as well as the artefact and the task themselves. A complex and highly interactive artefact, coupled with a highly challenging task, is unlikely to let the task demand sufficient attention from the student – the student may be reluctant to engage with the task at the expense of the artefact. Yet an artefact presenting similar information, but with a more appropriate (maybe lower) degree of interactivity, might let the student move her focus from the artefact and be able to interpret, understand, and flow with the task.

6.7.2 Illustrating the model

An illustration of this representation of flow comes from using it as a lens through which to examine an individual student’s response to her experience in Experiment Three. I have chosen Learner_A as an example as she appeared to struggle initially with mastering the simulation, then showed signs of flowing in relation to the task. Learner_A was the student who made significant learning gains and showed strong signs of flow, but in an erratic manner. The following extracts from her interview illustrate how she moved her focus from artefact to task in response to the questions.

From the start, she had a clear understanding of the goals of the exercise in terms of the task:

Learner_A: It’s the concept of motion and what exactly velocity is and how, if a body is moving in a particular direction at a particular gradient, what the results are. And the relationships between velocity, acceleration and distance.

She also interpreted ‘challenge’ in terms of the task, even though it was conveyed by the artefact:

Learner_A: I mean in that sense understanding what the simulation was trying to teach me …in terms of the simulation, how well I can grasp the concepts.

However, she indicated that the artefact (simulation) presented an early challenge that appeared to keep her from engaging fully with the task:

Learner_A: At first it was challenging when I tried to understand how the cart worked, the cart model.

Her concentration was high at the start:

Learner_A: …when it took me some time to settle down and think how the whole model, the cart model worked…
but reduced as she mastered the simulation:

Learner_A: …later on, once everything sunk in, I found the concentration requirement less.

This early part was a challenge to her as she tried to integrate ideas of the task with the operation of the artefact:

Learner_A: I found it, at the start, more challenging when I was taking everything from the start and all the concepts and theories from the start and thinking how everything worked with the model. Then, when I saw the graphs and I wasn’t getting exactly what I want, it took some time and I had to concentrate and think how everything worked.

Her sense of control was also low at the start and improved as she progressed:

Learner_A: At the start I felt that I didn’t have a lot of control and then later on when I understood what I was doing I could say that I had absolute control.

Her confidence was poor at the start ‘due to the model’ but increased towards the end.

Some elements of flow she reported as being quite constant throughout her experience. She reported feeling a sense of loss of self-consciousness from early on:

Learner_A: It was once I started to think about the simulation, then I just forgot about things.

and she maintained this until the very end. This was in spite of her early perception of confusion:

Learner_A: First of all I thought, with the model, it’s a bit confusing and I had no control over how to use it or not enough idea on how to use it.

which inhibited her enjoyment until she gained control:

Learner_A: Then after I understood and grasped the concepts I enjoyed it a lot.

and she became ‘indulged in the simulation’.

Although her estimation of time was quite accurate for the learning session, she sensed that time passed more quickly for her whilst she was struggling with the simulation early on:

Learner_A: I think it was probably at the start when I wasn’t too sure how to use the simulation… I didn’t know what I was doing and I wasn’t thinking more about the time than I was thinking about how to operate the simulation.

She reports ‘fully’ enjoying the whole session – ‘I enjoyed it a lot’ – and reports learning many aspects of physics from it. Her comments on learning indicate she became quite engaged with thinking about the task once she had overcome her early challenges with the simulation. She reflects on previous learning;

Learner_A: … I was still having confusion because I couldn’t recall back to what I learnt at school.

These comments relate mainly to the latter parts of the session and indicate that she was starting to think quite deeply about the new ideas presented to her as she progressed the end of the session:

Learner_A: I changed the angle of the slope and saw the graphs they were drawn. I never thought about that a lot because I always learnt about the concepts of a ball but never about the slopes, and that was something quite new to me.
Some of her developing concepts were still quite naïve but she was certainly very engaged and was learning. She even began exploring the simulation of her own volition by ‘using the fans to try and maintain a constant velocity’. She didn’t achieve this goal, as the software could not provide enough fans to have the desired effect. This is an example of free exploration, or playfulness, which is also reflected in the extreme number of simulation interactions recorded in her interactivity pattern (Figure 6-7 on p. 154). Exploration and playfulness are indicators of flow taking place (Ghani & Deshpande, 1994; Webster et al., 1993) and how, by the end of the session, Learner_A was deeply engaged with the task.

To summarise the experience of Learner_A in terms of the flow model, she appeared to focus early in the session on mastering the simulation. This could have been a flow experience in itself – she reported a sense of loss of time, but she did not appear to have the degree of control that one usually associates with flow. Later in the session she appeared to have all the characteristics of flow, and reported her perception of learning. She had gained mastery over the simulation and it ceased to be a challenge to her as she focused more determinedly on understanding the physics. Learner_A moved from a challenging near-flow experience with the artefact to finish up experiencing a strong flow experience with the task.

6.8 Discussion

This chapter has re-examined the roles of challenge and skill as a measure of flow in the light of a distinction between task and artefact. It has shown the need to disambiguate these terms when used as a measurement tool as well as when used in discussion about flow experiences. One of the interesting consequences of this enlightened view of flow, focusing on task versus artefact, is a new interpretation of two of the interesting results from Experiment Two.

6.8.1 Interpretation of the ‘challenging event’ effect

A feature of Experiment Two was described in Section 5.4.3 as a ‘challenging event effect’ that happened on page 5 of the learning exercise. This was the page at which the ‘from-flow distance’ measure of flow (based on challenge-skill measures) correlated highly with the ‘overall-state’ measure of flow (based on post-survey data). It was also the page after which the rising perception of challenge and skills by the ‘learners’ ceased to maintain a ratio of 1 and their skill perceptions fell as the challenge perceptions continued to rise. This was presented in Figure 5-13 and is reproduced here as Figure 6-24. The corresponding plot for the ‘unlearners’ is also reproduced, for comparison, as Figure 6-25.

Figure 6-24 Challenge and skills for 'Learners'  
Figure 6-25 Challenge and skills for 'Unlearners'
With hindsight, we can now use the new model for flow to improve the interpretation of these data. The ‘learners’ were progressing well for the first three pages of the exercise with their challenges and skills in good balance and both improving as they learnt. Page 5 saw their perception of their skills decrease. The activity had not demanded a change in their artefact skills: they were required to do very similar things with the simulation that they had been doing all along. Clearly the drop in perceived skills relates to a focus on the task that had suddenly become beyond their abilities. This was the page that presented the confusing issue of the cart’s acceleration being in the opposite direction to that of the motion. The task continued to become more challenging, and their skills to cope with it continued to decrease.

In contrast, the group of ‘unlearners’ maintained a reasonably steady perception of skills that was roughly balanced to their perception of challenges. If we focus on the learning task, it is hard to explain why they did not perceive the increasing challenges to be much higher than their skills, especially considering that they had such trouble learning new ideas, or even holding onto what they already knew. They even appeared oblivious to the conceptual jump required to understand page 5. Clearly they did not engage deeply with the learning task at all. If we conclude they were so out of their depth with the task that they focused on enjoying the artefact, then the plot makes sense. Throughout the exercise they interacted with the simulation and did so for each activity presented. No page presented any more of a challenge to their skills than any other page because they did not develop sufficient cognitive engagement with the learning task itself. The attraction of the artefact, combined with the challenge of the task, has blocked their progress to interact with the task.

This awareness of the task-artefact distinction has enriched our understanding of how learners and non-learners react to flow situations.

6.8.2 Interpretation of flow state distribution

The separation of task perception from artefact also helps to explain the different spread of flow states between IS and Physics students observed in Experiment Two. In that experiment we observed that the Physics movie group experienced more flow instances than the Physics simulation group. However, we saw no such difference between these modes for the IS students. Figure 6-26 shows these differences (these data were presented in the previous chapter as Figure 5-10). The question to ask here is ‘why should Physics students, using the simulation, experience more instances of their perceived skills being higher than their perceived challenges, whilst this is not the case for IS students?’
Using the new flow model, this can now be explained as follows. A group of students found the exercise difficult. These students are represented by the ‘anxious’ recordings within both the IS and Physics cohorts. It made no difference in which mode they worked, simulation or movie mode, the task to them was a challenging one of unfamiliar physics and it was this task that became the focus of their challenge-skill responses. As one would expect, there were more anxious IS recordings than Physics students.

So, why should there be differences between the remaining IS and Physics students who recorded ‘flow’ or ‘boredom’ states?

It is useful first to consider the students’ backgrounds. The IS students were not familiar with the physics topic as they were not currently studying physics; the Physics students, however, were quite familiar with the topic – they had even done a laboratory experiment on it earlier in the year.

There was no differentiation between the frequency of flow states for IS students in the different modes (left-hand plot of Figure 6-26). From their novice background, it made no difference which artefact they used – it is likely that their minds were focused on the (to them, challenging) task and hence the artefact had little differentiating influence.

However, the Physics students showed a very different distribution between the flow and boredom states (right-hand plot of Figure 6-26). To understand this, we need first consider the different nature of the movies and the simulation. The movies were relatively ‘transparent’. By this I mean that little manipulation was required to operate them – just the click of a button – and they were hence less likely to intrude upon students’ thinking; less likely to get in the way of the task. They gave appropriate and immediate feedback by displaying the ‘correct’ motions for the given situation. The locus of control was more often with the system; the degrees of freedom were low. In contrast, the simulation required considerable mental effort to operate: decisions of graph scales had to be made; the cart direction chosen; fans added; appropriate ‘push’ given to the cart; and so on. Importantly, the simulation also gave no explicit feedback as to whether or not the student had run an appropriate motion for the task being explored; the student had to make this judgement. The simulation was a complex object; it had the potential to become an obstruction to a student engaging with the task.
Comparing the Physics students’ flow and boredom distributions with the corresponding IS ones, the notable feature is that there are many more occurrences of Physics movie-mode students indicating the flow state and fewer indicating the boredom state. Those using the movies had a very different experience from those using the simulation. The movies presented few obstacles to the students that might obstruct their focus on the learning task. After all, it was merely a click to play the movie, then all that remained to do was to focus on the learning task at hand; immediate feedback was provided requiring little judgement as to its appropriateness. The task was perceived as challenging and their perception of skills decreased as the task progressed and became more difficult. But the challenge they perceived was appropriate for the task, well balanced with their skills, and led to a greater number of flow recordings for this group than boredom recordings. The nature of this flow I label ‘flow with the task’ since it involved their interaction with the task.

In contrast, many of the Physics students would have found the artefact familiar and not particularly challenging – it was very similar to what they had experienced in their physics laboratory class a few weeks earlier. Although the simulation required mental effort to operate, it was not difficult for students with their physics background. The skills it demanded from them were skills that they were expected to have as students of physics. In this situation they were likely to have had their attention attracted by the (fun) simulation itself, rather than by the learning task. This they could cope with, it was not too demanding to them, but it held their interest sufficiently that they focused on it rather than the underlying physics (the task). The result was a greater tendency to rate their skills more highly resulting in more ‘boredom’ states being recorded.

Note that there are only slightly fewer Physics simulation recordings shown in the flow group in Figure 6-26 compared to the boredom group. Whilst we can’t be sure whether these recordings relate to students focusing on task or artefact, it is likely that some, as with the movie mode students, would have focused on the task and experienced ‘flow with the task’, whilst others may have found the simulation appropriately fun and challenging, experiencing ‘flow with the artefact’ – an indication of how well they were coping with the simulation rather than with the physics.

If the above interpretation is correct, we would expect to see a different progression of skill perceptions through the exercise between the Physics movie and simulation groups. Indeed, looking at the average challenge-skill plots for the movie and simulation groups, respectively, shows a striking difference (Figure 6-27 and Figure 6-28). The plot for the Physics movie-mode students, presented in Figure 6-27, shows the challenge steadily increasing and the skills steadily decreasing, consistent with the students finding their physics skills lacking more and more as the task increased in difficulty. The plot for the Physics simulation-mode students, Figure 6-28, shows a similar increase in challenge, but the students’ perceive their skills to stay relatively high most of the time. This is consistent with them reporting on their skills relating to the simulation, which, once learnt, stayed reasonably steady even as the task became more challenging.
The above explanation is conjecture and the number of students is fairly small; there could be alternative interpretations. But it is consistent with the notion that the two different artefacts, movie and simulation, presented very different levels of challenge to the students and hence affected the way in which they responded to the challenge-skill probes. In one mode, movie, the manipulation of the artefact was simple and the visual results were guaranteed to be ‘correct’ or appropriate. It is unlikely that it would rate as a significant factor in the ‘challenge’ rating of a student. In the other mode, simulation, the manipulation was more complex and, importantly, required interpretation as to whether what was produced was ‘correct’. This task was not hard for someone familiar with the physics environment; it is quite likely that it would have dominated their challenge-skill probe responses with positive feelings of mastery.

In the above discussion, an awareness of students’ focus on task or artefact has improved our understanding of how students react to the different modes, or levels, of interactivity.

6.8.3 Summary

What we have seen in the two examples presented above are the consequences of students relating challenge and skills to both task and artefact, and the impact that the level of challenge provided by the task or artefact can have on their resulting interaction. The ‘learners’ were a group who were focused on the task with which they were making some progress, and they reflected this in both their challenge and skill assessments. The ‘unlearners’ had their minds firmly on the artefact for both their challenge and skill measures. The Physics students, as a group, were swayed in their focus by the nature of the artefact: a simple artefact, such as the movies, allowed them to see through to the task; but a more complex artefact, the simulation, attracted their attention when it came to reporting their level of skills.

The simple challenge-skill measure used in Experiment Two did not provide the measure of flow that I had originally intended. But nevertheless, it has highlighted the important role that a visual representation plays in representing the process of the flow experience. The findings from this experiment emphasised the importance of matching the nature of the interactivity of an object to the skills of a student. In describing an object’s potential to support learning, it is not adequate to describe it as ‘engaging’ or ‘highly interactive’. Nor is it adequate to describe it as ‘likely to encourage flow’. For engagement or flow to be effective in supporting learning it must, eventually, bring the student’s mind onto the learning task. The desired degree of interactivity will depend on the student’s ability to move their focus from the artefact to the task.
6.9 Summary and conclusion

In this chapter I have drawn together a significant amount of qualitative and quantitative data from an experiment with eight students to help refine our understanding of flow in an online learning context. The analysis of these data has moved our thinking a long way from the ideas presented in Chapter 5 that viewed flow as a process that could be monitored using simple measures of challenge and skills. In that chapter, the measures of challenge and skill appeared not to relate to other measures of flow nor did flow, whichever way identified, relate strongly to learning outcomes. From the work presented in this chapter, we have developed an understanding as to why that was so. It was unclear whether students were thinking of the task or the artefact in responding to the probe questions and whether flow experiences related to the materials to be learnt or to the simulation from which they were intended to learn.

We now have a more detailed picture of what flow looks like, what the important factors are in encouraging a student to experience flow, and have gained further insights into the problematic nature of measuring flow in a learning environment.

The main research question for this experiment asked:

RQ3: Why do the flow concepts of challenge and skill present such an apparently inconsistent picture?

The analysis has provided a better understanding of why challenge and skills, used as simple measures, are not appropriate for measuring flow in a learning environment. The situation is far more complex than other situations in which flow has been measured. We need to be mindful of what stimulates the flow and this leads to the idea of flow with the task and flow with the artefact. As has been suggested by Finneran and Zhang (2002; 2003) the interactions with task and artefact are best considered separately in order to understand better the nature of the flow experience.

This experiment has suggested how the design of a learning environment might encourage flow that is beneficial to support learning. It has painted a picture of what flow looks like from the student’s perspective and presented a model that has proved to be a useful lens through which to interpret students’ behaviour. This model can be used as a representation to guide the future design of online learning tasks.

This experiment has also suggested that flow might be detrimental to learning in some situations. If the student remains engaged with the artefact then he or she may not develop a sufficient engagement with the task for learning to occur. There is a hint of this effect in other research. Otera, Rogers and Boulay suggest that the lower than expected learning outcomes they observed in an experiment to explore interactivity might have been due to learners focusing ‘too much on the diagrams and gave inappropriate attention to the important information in the text’ (Otero et al., 2001). Given the highly immersive nature of their 3-d software artefact it is quite possible that their learners engaged with the artefact and not with the concepts that they wanted them to learn.

This chapter has adequately answered the question of why the challenge-skills measures appeared to paint an inconsistent picture of flow. The answer lies with the students’ interpretation of these parameters at the times of being probed. The question of how flow with task or artefact impacted on learning will be discussed further in the next chapter.
Summary of findings for Research Questions 3

RQ3.1: How does the flow process in a learning context, as measured by challenges and skills, relate to the experience of flow identified by Csikszentmihalyi?

F3.1: Challenge-skills measures can give misleading indications of flow if there is more than one interaction that might be the focus of attention. In such cases it is important to ascertain what students are focusing on as they report their challenge-skill ratings.

RQ3.2: What are the features of an online interactive learning activity that maximise the potential for flow?

F3.2: The essential features are to provide adequate goals, feedback, control and challenge-skill balance that are designed with the students’ background knowledge in mind. Each of these requires thought in relation to their application to the task and the artefact in order to maintain the delicate balance that can support flow experiences that engage the student with the learning task.

RQ3.3: What are the characteristics of flow experienced by students during an online interactive learning activity?

F3.3: Flow in a learning context has been seen to be different from flow in many other activities. Whilst all the classic characteristics are present, they occur in different complex configurations in which not all of them are necessarily present at the one time.
Chapter 7

Discussion and Conclusions

“Guided by stronger learning theories and richer instructional models, new research agendas should involve descriptive, qualitative, and developmental as well as experimental approaches.”

(Reeves, 1997)
7.1 Summary

This thesis describes a journey from an initial exploration of the important features of interactivity in online learning environments, through to a detailed examination of the process of flow. On the way I have developed tools for monitoring and visualising interactivity and for gathering data relating to affect during a learning task; identified ‘flow’ as a valuable theoretical model through which to explore online learning; discussed models of flow and made flow measurements using traditional techniques; developed a novel visualisation of the twists and turns of the flow process; and finally, I have shed light on why simple traditional measurement techniques are not appropriate in this particular context of online learning.

The main outcomes from this research represent a shift in the way we view the flow experience. I have shown that flow in a learning context is better represented as a process rather than a discrete state. This process describes a dynamic change of focus by the student between the learning task and the software artefact through which the task is being explored. This has implications for instructional and software designers who need to be aware of how a student’s engagement might move between task and artefact and, in particular, how engagement with the artefact might be an obstacle to the intended learning outcomes.

The main research question asked ‘How can flow theory be used as an explanatory framework for investigating student engagement in an online interactive learning environment?’. This was broken down into three sub-questions:

RQ1: What are the influences on learner interactions in an online interactive learning task?

RQ2: Of those influences on learner interactions, how do the flow concepts of control, challenge and skill describe learner interaction?

RQ3: Why do the flow concepts of challenge and skill present such an apparently inconsistent picture?

Question RQ1, although addressed in Experiment One, was actually answered by the final experiment of the research. Whilst Experiment One showed patterns of students’ behaviour and identified affective aspects that were to be pursued further, it was in the final experiment that the importance came to light of how students engage with either the learning task or with the artefact used to explore the task. The essential factor in their interactions was how the materials attracted them to engage with either of these aspects of the learning environment.

In answering Question RQ2 we have seen that challenge and skill measures provided a useful way to describe students’ interactions during a learning task, but they did not provide an appropriate measure of flow, as they have done in other contexts. The reasons for this, posed in Question RQ3, related to whether the focus of the student was on the learning task, the artefact, or moving between them both. Hence, the answer to Question RQ3 identified the two significant aspects that students might focus on, task and artefact, and how either or both might become the focus of a flow experience. This explained the apparent inadequacy of the challenge-skills measures used in Experiment Two. Task and artefact alone do not necessarily comprise a complete set in terms of what students may interact with. For example,
characteristics of the individual, such as an awareness and engagement in the process of learning itself, could encourage a flow experience. Such behaviour on the part of the students was not observed in the data from these experiments, but would form a valuable focus of future explorations.

Other outcomes from this study relate to learning. It was not the aim of the research to find a causal relation between flow and learning, nevertheless, evidence was found of flow incidents coincident with learning occurrences. A warning was given that flow might distract from learning. The challenge in this regard is to design learning environments that encourage and support flow in a manner supportive to constructive learning.

This research has set the stage for many further exciting investigations into flow and learning. An awareness of the need to disambiguate task and artefact will lead to many experiments that refine flow measurement techniques, follow students’ behaviour through learning tasks, and explore how we can use flow theory to design better, more effective, learning environments.

7.2 Significant contributions

The outcomes of this research contribute to our understanding of the flow process itself, as well as how it applies in learning contexts and how designers might use an awareness of flow when designing interactive online environments.

7.2.1 Primary contributions: flow theory

The primary contributions of this thesis are to our understanding of the flow process, the roles of task and artefact, and the description of a model of flow that suits the learning environment.

Flow as a process

A significant contribution of this research has been to recognise that flow in a learning context is a process that students move in and out of as they progress through a set of activities. This recognition of flow as a process differs from the outcomes of research that seeks to identify times when participants are ‘in a state of flow’ (Massimini & Carli, 1988; Webster et al., 1993). Research that uses the Experience Sampling Method, or Web-based surveys, to establish the frequency of such states do not show the richer picture of what happens during a short time activity such as a learning session. In such an activity flow experiences come and go as the skills of the students are brought to bear on the challenges of the activity. This is not captured by flow measurement techniques that have too coarse a focus to follow this process.

The 3-channel model of flow has been shown to be an appropriate one to use in interpreting the movements of students during their learning sessions. Although it is a simpler one than is often used in other contexts, it caters for novices with very low initial skills and their increasing level of skills as the challenges increase, as well as for more advanced learners. This is particularly apt for learning situations as it highlights the need for an effective learning environment to match challenges to individuals’ skills. It portrays the learner’s progress up the flow channel as originally suggested by Csikszentmihalyi (1975).

The roles of challenge, skill, task and artefact in measuring flow

A second contribution has been to show that challenge-skills measures are not a complete technique for measuring flow in learning contexts. An interactive online learning environment presents students with
two significant conceptual challenges: the interactive object (the artefact) and the concepts to be learnt (the task). The second experiment, presented in Chapter 5, showed that attempting to identify flow by using challenge and skill measures without acknowledging these two conceptual challenges led to confusing results. It was hard to see a clear picture of how flow related to other aspects of the students’ experience: there was a piece of the puzzle missing. This missing piece was to recognise the dual nature of both challenge and skills, as perceived by the students. Future measures of flow need to take this concept into account.

**A visual representation of the flow process**

A novel method for visualising students’ progress during a learning activity was developed. These ‘flow-path’ plots charted students’ progress by presenting their changing challenge-skill perceptions as they progressed through the activity. This visualisation of the flow process presented a valuable picture of students’ movement through the activity and the twists and turns that they experienced during such a task. It presented a unique view, for individuals and groups, of their experience with the activity.

**A model of flow for learning**

An explanatory model has been presented that describes the flow experiences that students had during a learning task and suggests an explanation as to how these experiences related to the learning exercise. In this model, an interactive artefact is presented as both a motivating attraction to a learning task, but also as an obstacle through which some students do not penetrate. Any exploration of the experiences that students have should be cognisant of the way such an artefact can support learning or detract from it.

**7.2.2 Secondary contributions: learning and design**

**Learning**

A secondary contribution of this research relates to how students experience flow during a learning activity. This research cautiously supports the notion that flow can be a desirable experience in a learning context. The rationale behind this notion is clear: the sense of control and the deep engagement aspects of flow are also important aspects of learning. The resulting enjoyment of a flow activity should leave students with a desire to come back for more. This research has confirmed that students do experience flow while engaged in a learning activity.

However, it has also shown that, when the learning task is complex, the application of flow theory is also complex. For many students, flow can be an experience that binds them to an artefact, resulting in no substantial learning. For others, it can represent an engagement with both task and artefact giving the potential for learning to occur.

This research supports the idea, and helps us understand, that the ‘bells and whistles’ of multimedia learning materials are not necessarily beneficial in a learning environment. Whereas they might provide a valuable and attractive motivational attribute, a strategy must be incorporated to move the students’ thinking beyond a superficial engagement with that artefact.

**Contribution to design**

A further contribution of this research has been to identify an important question for designers of on-line materials: how to ensure that the flow experiences that students have engage them with the task and not
just the artefact. Whilst doing this, the materials must let the attraction and enjoyment of a motivating interactive object lure students back for more. The challenge here is to design an environment such that the flow induced by the artefact does not prevent the student from thinking through to the challenge of the task beyond. The aim is to minimise the risk of flow hindering learning by attracting students to the wrong aspects of the learning environment.

A key to this is the feedback provided by the artefact. In a learning context the feedback needs to inform students as to whether they are developing appropriate ideas or not. A simulation often provides rich feedback that is intrinsic to the nature of the simulation, but its value relies on the ability of the students to correctly interpret it. Without appropriate skills in this interpretation the feedback merely encourages play with the artefact. The ability and skills of the students should inform the designer as to the nature of feedback appropriate for those particular students who are likely to use the software.

7.2.3 Reflection: exploring a complex learning domain

It is appropriate here to reflect on how the three experiments of this thesis contribute to our knowledge of students exploring a complex learning domain. The challenges presented by the use of interactive multimedia in a conceptually complex learning task are different from those of tasks involving the acquisition of simple knowledge (Pearce & Howard, 2004). The subject domain studied here was highly conceptual and represented a domain that is well documented with the misconceptions that students bring to it and the problems that they have in learning about it (Arons, 1990; Clement, 1982; Halloun & Hestenes, 1985a; McCloskey, 1982; Thornton & Sokoloff, 1998). The knowledge to be learnt was well beyond basic skills and provided a rich exploratory environment that was likely to be a fertile arena for flow experiences. However, this research has highlighted two consequences of choosing this complex physics domain.

Control

For effective learning, the degree of control offered to students must relate to their abilities in the subject domain. Students need to be given a degree of learner control, but how much? In the first experiment students were allowed to move freely between a static and dynamic version of the learning content. This they did and they found their own ‘comfort zone’ of control. For some, this was to be found through the use of the simulation, for others simple text and static images were preferred. In the second experiment, control was more carefully restricted to one mode with higher degrees of freedom (simulation) and one of lower degrees of freedom (movie-clips). Whereas the statistics could not confirm in which mode students perceived the greater control, they did confirm that the students with higher ability in physics perceived greater control than those of lower ability. This assessment of control, however, is likely to reflect not only control over their immediate environment but also a perception of control over the learning task itself. Whereas the simulation offered many more opportunities for control than did the movie-clips, this was not useful in a ‘learner control’ sense unless the student could interpret the outputs and use them to guide their learning. For a low (physics) ability student, this could make the simulation mode into one that offered a lower perception of control than the use of an appropriate movie-clip.

In the learner’s mind the notion of control, and hence the degree of interactivity of an environment, is inextricably tied to his or her ability in the particular task and domain.
The nature of learning
In exploratory learning environments the designer of the materials must relinquish some control over what is being learnt. This relates to the nature of the learning expected to take place. In this study the exploratory nature of the learning relied, for its effectiveness, on feedback from a simulation or movie clip. Some observe that feedback can impede the learning of complex tasks as it diverts the attention from the task itself (Balzer, Doherty, & O’Connor, 1989). However, in the experiments reported here, the learning content was procedural and learning was expected to take place in a constructivist manner supported by internal feedback that supports learning (Chai, 2003; Clark, 1994). In a rich learner environment, such as this one, there is always a diversity of learning that may take place. This is in contrast to some other studies into the effect of multimedia on learning that conclude a minimal learning effect, but do so in a situation of declarative learning and learning outcomes measured using true out of false questions (Haseman et al., 2003).

The scores in the post-tests obtained in the experiments reported here only reflected the students’ ability with those particular test items. I did not attempt to measure other possible instances of learning. For example, developing an understanding of more basic physics that was assumed as prior knowledge, or developing a better understanding of, and skills in, interpreting graphical representations of variables. A learning environment such as this one, rich in interactivity and potential for exploration, provided many more learning opportunities than I tried to measure. The link between flow and these incidental learning outcomes is still unknown.

Flow offers no control over what knowledge is being constructed by the learner. It is up to the instructional designer to create learning tasks that led students along an appropriate path to support learning; such tasks should be adapted to the learner rather than the learner to the task (Chai, 2003). The relationships between learner and task, and the role of flow in focusing the learner’s attention, are delicate ones. They offer a timely reminder of the early criticisms of multimedia learning systems as being high on glitter but low on substance.

7.3 Criticisms and recommendations
The research presented in this thesis has given new and innovative insights into flow in online learning contexts. However, there are aspects that, with hindsight, I would have done differently.

7.3.1 The notion of ‘challenge’
The interpretation of the term ‘challenge’ has been noted by others as a problem in flow studies (H. Chen et al., 1999; Ellis et al., 1994). In Experiments Two and Three some students associated challenge with ‘difficulty’ rather than a more positive interpretation of the presentation of a cognitively stimulating task. There is significant overlap between the two concepts but clearer wording, or a different approach, might have helped to remove this ambiguity from the experiments.

7.3.2 Individual differences
Flow is a highly individual experience and some people are thought to have an ‘autotelic personality’ that predisposes them to experiencing it (Csikszentmihalyi, 1975; Logan, 1988). These individual differences can be important and are worth considering when exploring factors that influence flow (J. E. Voelkl &
Ellis, 1998). This might have had impact some of the assessment of factors influencing flow in the last
two experiments. Future research into the flow experience itself might benefit from moving away from
this ‘real life’ cohort of typical students towards a select group who show signs of an autotelic
personality.

7.3.3 Challenge-skill measures
Challenge-skill measures formed the basis of much of this research and provided an interesting difference
from what was expected. Two aspects of these measures could have been handled differently. First, five-
point Likert scales were used in their measurement as has been done by some others (Massimini & Carli,
1988). These were adequate for mapping students’ coarse movements through challenge-skill space and a
finer resolution would not have offered more information. However, for comparison with other research
examining the frequency of occurrences of various flow states, a finer scale would have been preferable.
Secondly, although this challenge-skill measurement technique has been well accepted in the research
community, it is not without its critics (Ellis et al., 1994; J. E. Voelkl & Ellis, 1998). Given the
significance of the task-artefact distinction in this research it would have been advantageous to focus the
challenge-skill probes in a more well-defined manner towards the task that the student was focusing on at
the time. Ellis, Voelkl and Morris (1994) suggest considering the type of challenge and skill: physical,
emotional or cognitive. This would have been particularly apt in the physics context of this research. No
attempt was made to normalise the challenge-skill ratings as this was thought inappropriate. However, it
might have been appropriate to attempt to calibrate individual student’s scales by asking them to rate
specific extreme experiences in order to give them reference as what each scale value indicated.

7.3.4 Student interviews
The interviews in Experiment Three explored a wide range of elements of flow. The distinction between
task and artefact emerged from the interviews. To have decided ahead of time to probe more deeply into
this aspect of flow would have yielded more definite information about students’ focus of attention.
Whilst the interviews established whether each student experienced the elements of flow, I did not
ascertain the timing of these experiences. It is possible that some elements of flow were present at one
time, and others at different times. This was not allowed for in the analysis.

7.3.5 Generality of problem & solution
Research into flow has crossed many different contexts and this research has focussed specifically on
learning activities in a particular subject domain. We must be cautious not to apply the conclusions from
this research into inappropriate areas. For example, in some endeavours, there is essentially no conceptual
task beyond an immediate and direct interaction with an artefact. Whereas in other endeavours, the
designer’s aim it to make the artefact completely transparent so that the user interacts seamlessly with the
task in a direct engagement manner (Hutchins et al., 1986). The learning context studied in this research
required both task and artefact to play important roles in learning and motivation, respectively. Hence the
view of flow developed is particular to that style of interaction and might not be appropriate in some
other contexts.

Similarly, the conclusions from this research should not be applied to learning in general without careful
thought about the learning context. This research has focused on a specific learning context of conceptual
physics in which misconceptions are well documented (Halloun & Hestenes, 1985a; 1985b; Hestenes & Halloun, 1995; Hestenes & Wells, 1992; McCloskey, 1982; Thornton & Sokoloff, 1998). This is a difficult area of learning in the sense that many of the concepts are hard to grapple with. On the other hand, it is intrinsically motivating in that students can be presented with simulation outputs that produce surprising conflict with what they might expect. Different styles of learning activities, such as the simple acquisition of knowledge for example, might produce different flow experiences.

7.3.6 Identifying flow
The interview data were coded and analysed by myself with no independent third party providing a check on this process. The validity of the analysis would have been improved with such a check.

7.3.7 Subjects for experiments
The total number of subjects in Experiment Two was sufficient for the statistical analyses performed on the large cohort of students. However, when divided into course groups (IS and Physics) the Physics numbers were generally too low to give significant results for some aspects, as was noted in Chapter 5. This was primarily an issue of finding sufficient subjects for such an experiment.

As is so often the case in research of this nature, the subjects were not a random sample of any particular population. Experiment One used psychology students who had little or no expertise in the subject domain. This was not a significant issue as these results were not generalised to a wider population, but were used to help identify issues to pursue further. Experiment Two had a mix of Information Systems students and Physics students. Both had adequate backgrounds to provide valid data as to how novice and higher skilled learners engaged with the activities. However their backgrounds were quite diverse, including a mix of local and international and students, presenting a variety of cultural and learning style backgrounds. No attempt was made to identify these differences and account for them. With more time and resources it would have been informative to explore the effect of different cultures and learning styles on students’ interactions.

7.3.8 Analysis of visual data
The visual data in this research (interactivity patterns and flow-paths) were analysed using qualitative methods involving recognising and identifying patterns in the data. These data told a rich story in themselves, but it is recognised that there are limits to such qualitative data analysis and a dependency on the researcher in making the interpretations. A quantitative methodology for analysing patterns, such as the interactivity patterns, might have yielded additional perspectives on the behaviour of the various groups of students. However I was not aware of any such method that would have been appropriate for the data gathered.

7.3.9 Learning
The prime focus of this research was not learning but the behaviour of students in a learning environment. Nevertheless, learning was an important aspect of the context. The learning outcomes of the students were defined essentially by their performance on a physics test. Whilst the test questions were well validated, they did not offer any insights into incidental learning that may have taken place. In an environment supporting the construction of meaning and offering a rich potential for experimentation and
play, there is a strong possibility that other learning occurred. This is particularly relevant to flow since one reason for desiring flow in a learning setting is that students might explore voluntarily and learn beyond what has been set for them. Apart from such incidental learning outcomes, changes in attitudes and motivation to the subject content might have taken place. Although the opportunities for this to happen in the short time duration of the experiments were slight, I had no way to identify whether such outcomes were achieved.

This research should not be regarded as an attempt to provide the ‘best’ learning experience for students. The aim was to explore how an individual working alone with a computer might interact with an online environment to engage in a meaningful learning activity enhanced by the flow experience.

7.4 Future directions

7.4.1 Improved measure for flow

This research has presented flow as a dynamic process that needs to recognise the roles of task and artefact, yet the measurement techniques did not take this recognition into account. There is a need to develop a reliable measure for flow that can be used in a non-intrusive manner during a learning activity that is cognisant of the students’ changing focus from task to artefact. Such a technique could derive a measure of ‘flow with task’ and ‘flow with artefact’. This research would need to examine more closely the distinction between task and artefact in the students’ minds. This would enhance our theoretical understanding of the flow process and also be of a practical value to instructional designers.

7.4.2 Acknowledging the individual

A description of flow has been presented which describes the interaction between the student, the artefact and the task, yet no characteristics of the student were considered in this description. Individual personality traits, learning styles, cultural backgrounds and abilities all have an impact on both flow and learning. Further research is required to identify the significance of these and what their effects are. Such research would seek to identify whether personality traits are a significant factor in encouraging flow in learning contexts, how these might interact with a learner’s preferred style of learning and to explore why one person might enjoy being immersed in challenging learning material whilst another might give up after the challenge rises above a certain level. The suggestion that we, as ‘digital immigrants’, should adapt our learning resources to suit better the ‘digital natives’ (Prensky, 2001a; 2001b) should be investigated with the flow experience in mind.

7.4.3 Different learning conditions

This research has focused on the individual, yet much effective learning takes place due to the interaction amongst groups of learners. To introduce collaborative learners into the flow experience would extend our understanding of flow to envelop social interactions that share a common goal (learning). This would add an additional dimension beyond task and artefact, yet in a manner different from the way Finneran and Zhang (2002; 2003) have included the notion of ‘person’ into their flow model.
7.4.4 Learner control

The notions of ‘learner control’ and ‘being in control’ are still not well understood. Highly interactive environments offer high potential for control, but we don’t yet understand what features of the environment are used to gain control by different types of learners. Research into how different learners perceive their control over different interactive elements would add to our understanding of control, interactivity and how to optimise these for learning effectiveness.

7.5 Concluding comments

This research project has woven a path through the exploration of interactivity, student emotions, flow interactions and learning experiences. My starting point was that studying the online interactions experienced by students would inform me about how those interactions can support their learning. This was soon found to be an inadequate view that did not take into account the nature of the students themselves. As the research progressed it became clearer that the issue was a complex one and had as much to do with the individual as with the technology that they used.

Flow has proven to be a valuable lens through which to explore this student behaviour. By taking this approach, I have begun an exploration of the complex interactions between the highly sophisticated technologies available today and the highly adept students who tackle the challenge of learning from them. The students of today have adopted many technologies that are fast-paced, vibrant, personal and ubiquitous. The challenge of predetermining what they should learn, motivating them, and then maintaining that motivation, is one that will only become harder as the new waves of digital natives land on our shores. There is a clear need to provide rich learning environments that students find valuable and enjoyable for their own sake, even in the face of their native distractions. This research has made significant inroads into how a better understanding of flow might satisfy that need.
References


References


References


Zirkin, B. G., & Sumler, D. E. (1994). Interactive or Non-interactive?: That is the Question!! Journal of Distance Education, 10(1).
Appendix A

Experiment One
Appendix A-1  Consent form and Plain Language Statement

STUDENT CONSENT FORM and PLAIN LANGUAGE STATEMENT

(You will be given a copy of this form to keep)

Project:  Measuring Flow in an Online Learning Environment
Investigator:  Jon Pearce, Department of Information Systems

This is a research project investigating ways that students respond to learning exercises delivered on the Web. You will be presented with a learning task about an issue in physics and will be asked about your reactions as you progress through it.

During the session you will experience:

- some questions about your background;
- a short test on the physics topic;
- an exploratory physics learning task;
- a further short test;
- a task in which you explain to another student some physics ideas;
- some follow-up interview questions.

You should be able to complete this within about one-and-a-half hours.

All data resulting from this investigation will be treated as confidential subject to limitations of the law. You will be given an identification number to use on the computer. The link between this number and your name will be securely stored and only be used by the researcher should he wish to make follow-up contact for any reason.

When the project is complete and the data analysed a report of the findings will be available to participants on request. If you wish to receive a copy of the findings indicate in the tick-box below.

This project is for research purposes only. No results obtained will in any way affect any ongoing assessment within your course.

Your participation in this project is entirely voluntary. If at any time you wish to withdraw from the project you are able to do so. The data will be stored securely in the department for five years after last publication after which time it will be destroyed.

If you have any concerns about the conduct of this research project you may contact the Executive Officer, Human Research Ethics, The University of Melbourne. Ph: 8344 7505.

If you are happy to participate in this project, please sign in the space provided below.

I __________________________ (print name) consent to participating in this research project.
I would like a copy of the report emailed to me when complete (tick box if 'yes'): ☐

Signed: _______________________________  Date: _______________________________
Appendix A-2  Student Booklet

When  Meet

This booklet provides space for you to write your answers to questions presented on the Web site.

Section 2: One source of waves

- Crests are coloured ________________
- Troughs are coloured ________________

Section 3: The concept of 'wavelength'

- Comparing short and long wavelength patterns:

Long wavelength            Short wavelength

<p>| | |</p>
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Comment on short and long wavelength pattern:
Section 4: But what *is* wavelength?

One wavelength:

Section 5: Two sources of waves interfering

Destructive interference:
Sources and nodes:

Section 6: Exploring antinodes

Node:

Antinode:

Path differences for antinodes:

Behaviour of path difference along an antinode:

Section 7: Why do nodes form lines?

- Distance from centre antinode to first node: wavelengths
- Distance from centre antinode to second node: wavelengths
- Path differences for nodes:
Section 8: What when you change the wavelength?

- Effect changing wavelength has on a wave pattern:
- How a node behaves as you change wavelength:

*Please hand in this booklet after completing this section (Section 8).*
Appendix A-3  Extract from Web server log

Below is a very short extract from the Web server log for a session of Experiment 1. The complete log is many thousands of lines long for a one-hour session. The lines have been numbered here for ease of reference.

The log shows students (identified by s511, s500, s517, s503 and s518) who have navigated to various pages and interacted with the simulation. Each line shows the IP number of the computer, login name of the student, date and time information, information on pages visited or files accessed, error codes, browser information and operating system information.

Only some of this information is relevant to this study. For example, in line 4, student s500 has visited the page ‘page6.html’. In line 6 a different student, s503, has set the wavelength of the simulation to a value of 3.

These data are filtered and analysed by my software iFilter.

1. 203.10.110.173 - s511 [29/May/2001:12:54:54 -0700] "GET /projects/interact/waves2/navfiles/navig/c7_o.gif HTTP/1.0" 200 834 "http://multimedia.dis.unimelb.edu.au/projects/interact/waves2/navfiles/c2nav.htm" "Mozilla/4.0 (compatible; MSIE 5.5; Windows 95)"
2. 203.10.110.172 - s511 [29/May/2001:12:54:54 -0700] "GET /projects/interact/waves2/navfiles/navig/c8_o.gif HTTP/1.0" 200 823 "http://multimedia.dis.unimelb.edu.au/projects/interact/waves2/navfiles/c2nav.htm" "Mozilla/4.0 (compatible; MSIE 5.5; Windows 95)"
3. 203.10.110.172 - s500 [29/May/2001:12:54:54 -0700] "GET /projects/interact/waves2/navfiles/c6nav.htm HTTP/1.0" 200 10374 "http://multimedia.dis.unimelb.edu.au/projects/interact/waves2/intro/waveframe1.htm" "Mozilla/4.0 (compatible; MSIE 5.5; Windows 95)"
5. 203.10.110.174 - s517 [29/May/2001:12:54:56 -0700] "GET /cgi-bin/waves/processw.pl?data=Event%3a+dragStartTo+139+117 HTTP/1.0" 200 0 "-" "Mozilla/4.0 (compatible; MSIE 5.5; Windows 95)"
6. 203.10.110.172 - s503 [29/May/2001:12:54:57 -0700] "GET /cgi-bin/waves/processw.pl?data=Event%3a+WavelengthTo+3 HTTP/1.0" 200 0 "-" "Mozilla/4.0 (compatible; MSIE 5.5; Windows 95)"
7. 203.10.110.172 - s518 [29/May/2001:12:54:59 -0700] "GET /cgi-bin/waves/processw.pl?data=Event%3a+dragStartTo+139+117 HTTP/1.0" 200 0 "-" "Mozilla/4.0 (compatible; MSIE 5.5; Windows 95)"
8. 203.10.110.172 - s517 [29/May/2001:12:54:59 -0700] "GET /cgi-bin/waves/processw.pl?data=Event%3a+WavelengthTo+3 HTTP/1.0" 200 0 "-" "Mozilla/4.0 (compatible; MSIE 5.5; Windows 95)"
9. 203.10.110.172 - s517 [29/May/2001:12:55:00 -0700] "GET /cgi-bin/waves/processw.pl?data=Event%3a+WavelengthTo+2 HTTP/1.0" 200 0 "-" "Mozilla/4.0 (compatible; MSIE 5.5; Windows 95)"
Appendix A-4  Pre-survey

Information about you

(Just answer the questions that apply to you)

Student ID #:  

Gender: Select  

Age: Select  

Course: Select  

Combined Course: Select  

If doing a combined course indicate second degree: Select  

Year in Course: Select  

Highest level of Physics Studies: Select  

If you have done Year 12 Physics what was your final score: Select  

If you completed Year 12 in the last 5 years:

Tertiary Entrance Rank
(TER or ENTER): Select  

Year: Select  

What is your first language (mother tongue)? Select  

When you have answered all the questions that apply to you, click on the Submit button below.

Click only once, there will be a delay of several seconds before you see the next screen.

Submit my information
Appendix A-5  ‘Approaches to learning’ survey

Approaches to Learning

The following statements refer to different ways that students approach learning about something new. Use the rating scale to show how much this is like the way you approach a new subject or new course material.

Please answer every question.

1. I want to learn as much as possible.
2. My goal is to get a better grade than most of the other students.
3. I always want to do well to show my ability to my family, friends and others.
4. I just want to do as much as I have to in order to get by.
5. I like trying to figure things out.
6. The most important thing for me is to understand the content as thoroughly as possible.
7. I prefer subjects that really challenge me.
8. I like subjects best when the exams are easy.
9. I usually want to do as little work as possible.
10. Getting good marks is the most important thing for me right now.
11. I prefer course material that arouses my curiosity even if it is difficult to learn.
12. I want to do well so that others don’t think I’m not very clever.

When finished, click on the submit button below. Again, only click ONCE and be patient!
Testing your initial knowledge

These questions test your initial knowledge of the content presented in this exercise. Answer each question as best you can and show how confident you are about your answers. However, if you have not studied physics recently, that's fine! Please make a guess at the answers. When you have finished, click on the ‘submit’ button at the end of the page to proceed.

Please answer every question as best you can.

**Question 1**
Which of the following waves has the greatest wavelength?

A  
B  
C  
D  

How confident are you of your answer? Just a guess

**Question 2**
What is the value of the wavelength of the wave shown below?

A. 2  
B. 3  
C. 4  
D. 6  
E. 8  

How confident are you of your answer? Just a guess
Question 3
A child dips her two fingers up and down in water producing two sets of circular waves. Which statement below best describes the meaning of the statement "the two fingers are moving in phase"?

- A. Both fingers go up and down together
- B. When one finger is down (in the water) the other is up (out of the water)
- C. The two fingers go up and down at the same rate.
- D. The two fingers go up and down at different rates.

How confident are you of your answer? [Just a guess]

The picture shows a still photo of the top-view of the wave pattern produced by the two fingers dipping up and down in water. The next 2 questions relate to this picture.

Question 4
How would you describe the behaviour of the water in the black and white regions marked A?

- A. The water is calm.
- B. The water is moving up and down and appears to move away from the sources.
- C. The water is moving up and down and appears to move towards the sources.
- D. The water is moving up and down but appears not to move towards or away from the sources.

How confident are you of your answer? [Just a guess]
Question 5
How would you describe the behaviour of the water in the grey regions marked B?

- A. The water is calm.
- B. The water is moving up and down and appears to move away from the sources.
- C. The water is moving up and down and appears to move towards the sources.
- D. The water is moving up and down but appears not to move towards or away from the sources.

How confident are you of your answer? [just a guess]

Question 6
A ‘node’ refers to a region where:

- A. Wave troughs meet other troughs and produce calm water.
- B. Wave crests meet wave troughs and produce disturbed water.
- C. Wave crests meet other crests and produce disturbed water.
- D. Wave crests meet wave troughs and produce calm water.
- E. Wave troughs meet other troughs and produce disturbed water.

How confident are you of your answer? [just a guess]
Question 7
Consider again the wave pattern made with two sources in phase. If the distance from one source to a point on a node is 3 wavelengths, which of the following could be the distance from the other source to the point?

- A. 2 3/4 wavelengths
- B. 3 wavelengths
- C. 3 1/2 wavelengths
- D. 3 3/4 wavelengths
- E. 4 wavelengths
- F. Any of the above are possible.

How confident are you of your answer? [Just a guess]

---

Question 8
If the path difference from a point on a node to the sources is 5 1/2 wavelengths, what is the path difference from a point on the next antinode closer to an imaginary line running through the centre of the pattern?

- A. 4 1/2 wavelengths
- B. 5 wavelengths
- C. 6 1/2 wavelengths
- D. 6 wavelengths
- E. Can't say since you need to know just where the points are on the nodes.

How confident are you of your answer? [Just a guess]

---

This is the end of the test.

If you are happy with your answers, please click on the "Submit my answers" button below:

[Submit my answers]
Appendix A-7  Screenshot from ‘WAVES’ learning sequence

This image shows a “static mode” screen for page 4 of the learning sequence.

A4 But what is the ‘wavelength’?

Now let’s consider how we can determine the actual value of a wavelength.

The first wave pattern below shows the cork to be at the bottom of a trough. The second pattern shows the cork sitting on top of the crest next closest to the source. The third pattern shows the cork in a trough again. The distance that the graph has “moved” as we go from the first picture to the last is what we define as one wavelength.

We would observe the same one-wavelength curve moving from any crest to any adjacent crest, or from any trough to adjacent trough.

1. Draw in your booklet what section of the graph represents one wavelength.
2. Draw in another ‘one wavelength’ segment, but starting from a different point on the graph.

We could use a ruler to measure this distance from one trough to the next, or measure the same distance on the graph. The value we would get is called the wavelength of the water wave.
Appendix A-8  Extra (‘transfer’) questions for Post-test

Question 9
A loud speaker is a device that produces circular waves of wavelengths from 5 cm to 100 cm. Two of these loud speakers are used at an open-air rock concert in a large arena. The band is using them to test the acoustics of the arena by playing sustained notes from a keyboard. A member of the audience walks across the back of the arena from one side to the other to get a drink.

Describe, in a few words, any changes to the sound loudness that she would hear as she walks across the arena. Give reasons for your answer.

How confident are you of your answer? [just a guess]

Question 10
The same person as in the previous question walks back to her seat while the band is playing a different note of much shorter wavelength. Compare the behaviour of the sound this time to that of the previous time.

How confident are you of your answer? [just a guess]

This is the end of the test.

If you are happy with your answers, please click on the "Submit my answers" button below:

Submit my answers
Appendix A-9  Physics tests answers and marking scheme

Correct Answers to Pre & Post-test Questions

Q1  c
Q2  c
Q3  a
Q4  b
Q5  a
Q6  d
Q7  c
Q8  b

Question 9 (5 marks)
As she walks across the arena she would hear the sound getting louder and softer several times. This happens because she is walking past the ends of nodes and anti-nodes. The sound would be louder at the antinodes and softer at the nodes. This happens because the nodes are places where the waves destructively interfere (that is, troughs and crests cancel), whereas the antinodes are places where the waves constructively interfere (that is, troughs and crests reinforce).

Scoring:  

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<tr>
<th></th>
<th>Marks</th>
</tr>
</thead>
<tbody>
<tr>
<td>hear the sound getting louder and softer:</td>
<td>1</td>
</tr>
<tr>
<td>several times:</td>
<td>1</td>
</tr>
<tr>
<td>walking past the ends of nodes and anti-nodes:</td>
<td>1</td>
</tr>
<tr>
<td>nodes are places where the waves destructively interfere</td>
<td></td>
</tr>
<tr>
<td>or</td>
<td>1</td>
</tr>
<tr>
<td>antinodes are places where the waves constructively interfere</td>
<td></td>
</tr>
<tr>
<td>nodes =&gt; troughs and crests cancel</td>
<td></td>
</tr>
<tr>
<td>or</td>
<td>1</td>
</tr>
<tr>
<td>antinodes =&gt; troughs and crests reinforce.</td>
<td></td>
</tr>
</tbody>
</table>

Question 10 (3 marks)
She would still notice loud and soft regions, but they would be more closely spaced. This is because the effect of a shorter wavelength is to reduce the spacing of the nodal lines. That is, more would be observed across the back of the arena. (No overall change in loudness of the sound).

Scoring:  

<table>
<thead>
<tr>
<th></th>
<th>Marks</th>
</tr>
</thead>
<tbody>
<tr>
<td>still notice loud and soft regions (this might just be implied in the ans)</td>
<td>1</td>
</tr>
<tr>
<td>more closely spaced (or more frequent):</td>
<td>1</td>
</tr>
<tr>
<td>shorter wavelength =&gt; reduce the spacing of the nodal lines:</td>
<td>1</td>
</tr>
</tbody>
</table>
Appendix A-10 Learning strategy exit survey

Some final comments!

The following statements refer to strategies that students use when they are learning new topics. Mark the number next to each item to indicate what you were doing while you were going through the material on the properties of waves.

Please answer every question.

While doing the task I was trying to:

1. Make up memory aids.  
2. Work out the key concepts in my own words.  
3. Connect the things on the screen with what I already know.  
4. Work out how everything fitted together.  
5. Just learn it all off-by-heart.  
6. Relate all new concepts to each other.  
7. Memorize things that seemed important.  
8. Learn the important definitions and rules.

[Scale: Not at all (1), Somewhat (2), Fairly Well (3), Very well (4), A lot (5)]
Appendix A-11  Section of a Web log

203.10.110.172 - s519 [29/May/2001:12:48:34 -0700] "GET /projects/interact/waves2/navfiles/navig/c2.gif HTTP/1.0" 200 555 "http://multimedia.dis.unimelb.edu.au/projects/interact/waves2/navfiles/c3nav.htm" "Mozilla/4.0 (compatible; MSIE 5.5; Windows 95)"
203.10.110.175 - s505 [29/May/2001:12:48:34 -0700] "GET /cgi-bin/processw.pl?data=Event%3a+dragStopAt+226+118 HTTP/1.0" 200 0 "Mozilla/4.0 (compatible; MSIE 5.5; Windows 95)"
203.10.110.173 - s505 [29/May/2001:12:48:34 -0700] "GET /cgi-bin/processw.pl?data=Event%3a+dragStartTo+226+118 HTTP/1.0" 200 0 "Mozilla/4.0 (compatible; MSIE 5.5; Windows 95)"
203.10.110.173 - s525 [29/May/2001:12:48:36 -0700] "POST /cgi-bin/wavesformlog.p1 HTTP/1.0" 200 170 "http://multimedia.dis.unimelb.edu.au/projects/interact/waves2/intro3_pretest.html" "Mozilla/4.0 (compatible; MSIE 5.5; Windows 95)"
203.10.110.175 - s525 [29/May/2001:12:48:38 -0700] "GET /projects/interact/waves2/intro/4_choice.html HTTP/1.0" 200 4363 "Mozilla/4.0 (compatible; MSIE 5.5; Windows 95)"
203.10.110.172 - s504 [29/May/2001:12:48:39 -0700] "GET /projects/interact/waves2/intro/probe.html HTTP/1.0" 200 17304 "Mozilla/4.0 (compatible; MSIE 5.5; Windows 95)"
203.10.110.174 - s500 [29/May/2001:12:48:40 -0700] "POST /cgi-bin/wavesformlog.p1 HTTP/1.0" 200 170 "http://multimedia.dis.unimelb.edu.au/projects/interact/waves2/intro3_pretest.html" "Mozilla/4.0 (compatible; MSIE 5.5; Windows 95)"
203.10.110.173 - s504 [29/May/2001:12:48:40 -0700] "GET /projects/interact/waves2/style_a/pagea2.html HTTP/1.0" 200 5946 "http://multimedia.dis.unimelb.edu.au/projects/interact/waves2/intro/2waveframe1.htm" "Mozilla/4.0 (compatible; MSIE 5.5; Windows 95)"
203.10.110.173 - s504 [29/May/2001:12:48:40 -0700] "GET /projects/interact/waves2/navfiles/a2Nav.htm HTTP/1.0" 200 10204 "http://multimedia.dis.unimelb.edu.au/projects/interact/waves2/intro/2waveframe1.htm" "Mozilla/4.0 (compatible; MSIE 5.5; Windows 95)"
203.10.110.174 - s500 [29/May/2001:12:48:42 -0700] "GET /projects/interact/waves2/intro/4_choice.html HTTP/1.0" 200 4363 "Mozilla/4.0 (compatible; MSIE 5.5; Windows 95)"
203.10.110.174 - s500 [29/May/2001:12:48:42 -0700] "GET /cgi-bin/processw.pl?data=Event%3a+WaveLengthTo+4 HTTP/1.0" 200 0 "Mozilla/4.0 (compatible; MSIE 5.5; Windows 95)"
Appendix A-12  T-test for pre- post-physics tests

Paired T-test on pre and post tests for questions 1 to 8.
Question scores are from a maximum of 16

**Paired Samples Statistics**

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>N</th>
<th>Std. Deviation</th>
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</thead>
<tbody>
<tr>
<td>Pair 1</td>
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<td></td>
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<td>post test correct responses</td>
<td>5.2929</td>
<td>99</td>
<td>1.59241</td>
<td>.16004</td>
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**Paired Samples Correlations**

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<th>Sig.</th>
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</thead>
<tbody>
<tr>
<td>Pair 1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>pre test correct responses &amp; post test correct responses</td>
<td>99</td>
<td>.513</td>
<td>.000</td>
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</table>

**Paired Samples Test**

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<th>Mean</th>
<th>Std. Deviation</th>
<th>Std. Error Mean</th>
<th>95% Confidence Interval of the Difference</th>
<th>t</th>
<th>df</th>
<th>Sig. (2-tailed)</th>
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<tr>
<td></td>
<td></td>
<td>Mean</td>
<td>Std. Deviation</td>
<td>Std. Error Mean</td>
<td>Lower</td>
<td>Upper</td>
<td></td>
<td></td>
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<tr>
<td>Pair 1</td>
<td>pre test correct responses - post test correct responses</td>
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<td>1.58657</td>
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<td>-1.8417</td>
<td>-1.2088</td>
<td>-9.565</td>
<td>98</td>
</tr>
</tbody>
</table>

Appendices 237
Appendix A-13  One-way ANOVA for learning improvement

One-way analysis of variance on test score improvement (post-pre) comparing different interactivity modes.

### Descriptives

#### improvement in test score

<table>
<thead>
<tr>
<th></th>
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<th>Std. Deviation</th>
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<td>Lower Bound</td>
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<td>static-static</td>
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<td>1.5909</td>
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<td>Total</td>
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<td>1.5253</td>
<td>1.58657</td>
<td>.15946</td>
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### ANOVA

#### improvement in test score

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<td>.375</td>
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<td>Within Groups</td>
<td>245.936</td>
<td>96</td>
<td>2.562</td>
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<td>Total</td>
<td>246.687</td>
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</table>
Appendix A-14  Univariate analysis of Q 9 and 10 mean scores

Univariate on questions 9 & 10 with pre-test as covariate
Question scores are from a maximum of 8

Descriptive Statistics
Dependent Variable: DLEARN

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<tr>
<td>inter-inter</td>
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<tr>
<td>Total</td>
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<td>2.08323</td>
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Tests of Between-Subjects Effects
Dependent Variable: DLEARN

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<td>CHOICE3</td>
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<td>Error</td>
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<td>Corrected Total</td>
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a  R Squared = .308 (Adjusted R Squared = .287)
Appendix A-15  Paired samples t-test on confidence scores

Paired samples t-test on confidence scores of pre and post-tests. Scores stated here were out of a maximum of 16. They were scaled to a score out of 2 in the main text. Hence a mean of 5.17/16 scaled top 0.65/2, and 11.57/16 scaled to 1.45/2.

Paired Samples Correlations

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<th>Sig.</th>
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Paired Samples Statistics

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<td>CONF_AFT</td>
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Paired Samples Test

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<th>t</th>
<th>df</th>
<th>Sig. (2-tailed)</th>
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Appendix A-16  ANCOVA analysis of Q 9 and 10 confidence scores

ANCOVA on Q 9 & 10 confidence scores with pre-test as covariate.
Confidence scores are a maximum of 2

### Descriptive Statistics

<table>
<thead>
<tr>
<th>choice1-3</th>
<th>Mean</th>
<th>Std. Deviation</th>
<th>N</th>
</tr>
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<tbody>
<tr>
<td>static-static</td>
<td>1.3750</td>
<td>1.58640</td>
<td>16</td>
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<tr>
<td>mixed</td>
<td>1.7391</td>
<td>1.60163</td>
<td>23</td>
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<td>inter-inter</td>
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<td>1.47542</td>
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<td>Total</td>
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<td>1.53737</td>
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</tr>
</tbody>
</table>

### Tests of Between-Subjects Effects

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<th>Mean Square</th>
<th>F</th>
<th>Sig.</th>
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<td>1.738</td>
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<tr>
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<td>Corrected Total</td>
<td>205.625</td>
<td>87</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

a R Squared = .290 (Adjusted R Squared = .265)
Appendix B

Experiment Two
Appendix B-1 Introductory survey

Information about you

(Just answer the questions that apply to you)

The Log-in name you logged in with:  
Gender: Select  
Age: Select  

Highest level of physics studies: Select  
If you have done Year 12 Physics, what was your final score: Select  
If you completed Year 12 in the last 5 years:  
Tertiary Entrance Rank (TER or ENTER): Select  
Year: Select  

What is your first language (mother tongue)? Select  

When you have answered all the questions that apply to you, click on the Submit button below.  
Click only once, there may be a delay of a few seconds before you see the next screen.

Submit my information
Appendix B-2  Physics pre & post test

Pretest on Physics Knowledge

This test is to give us an idea of your physics background. Work through it fairly quickly. Don't worry if you don't know the answers - just leave the default selection of I don't know.

This test has 19 questions grouped into 4 sets

(Note that scrolling your mouse scroll-wheel immediately after selecting an answer from the drop-down menus might change your selection. Take care!)

Question Set A

A sled on ice moves in the ways described in questions 1 to 7 below. Friction is so small that it can be ignored. A person wearing spiked shoes standing on the ice can apply a force to the sled and push it along the ice. Choose the one force (A to H below) which would keep the sled moving as described in each statement below.

You may use a choice more than once or not at all but choose only one answer for each question.

A. The force is toward the right and is increasing in strength (magnitude).

B. The force is toward the right and is of constant strength (magnitude).

C. The force is toward the right and is decreasing in strength (magnitude).

D. No applied force is needed.

E. The force is toward the left and is decreasing in strength (magnitude).

F. The force is toward the left and is of constant strength (magnitude).

G. The force is toward the left and is increasing in strength (magnitude).

H. None of the answers is correct.

1. Which force would keep the sled moving toward the right and speeding up at a steady rate (constant acceleration)?

2. Which force would keep the sled moving toward the right at a steady (constant) velocity?

3. The sled is moving toward the right. Which force would slow it down at a steady rate (constant deceleration)?

4. Which force would keep the sled moving toward the left and speeding up at a steady rate (constant acceleration)?
5. The sled is moving toward the left. Which force would slow it down at a steady rate (constant deceleration)?

I don't know

**Question Set B**

Questions 6 to 8 refer to a toy car which is given a quick push so that it rolls up an inclined ramp. After it is released, it rolls up, reaches its highest point and rolls back down again. Friction is so small it can be ignored.

Use one of the following choices (A to H) to indicate the net force acting on the car for each of the cases described below.

A. Net constant force down ramp
B. Net increasing force down ramp
C. Net decreasing force down ramp
D. Net force zero
E. Net constant force up ramp
F. Net increasing force up ramp
G. Net decreasing force up ramp
H. None is correct

6. The car is moving up the ramp after it is released.

I don't know

7. The car is at its highest point.

I don't know

8. The car is moving down the ramp.

I don't know

**Question Set C**

Questions 9 to 11 refer to a coin that is tossed straight up into the air. After it is released it moves upward, reaches its highest point and falls back down again. Use one of these following choices (A to H) to indicate the force acting on the coin for each of the cases described below. Ignore any effects of air resistance.

A. The force is down and constant.
B. The force is down and increasing.
C. The force is down and decreasing.
D. The force is zero.
E. The force is up and constant.
F. The force is up and increasing.
G. The force is up and decreasing.
H. None is correct

9. The coin is moving upward after it is released.

I don't know
10. The coin is at its highest point.

I don't know.

11. The coin is moving downward.

I don't know.

**Question Set D**

Questions 12 to 19 refer to a toy car that can move to the right or left along a horizontal line (the positive part of the distance axis).

Assume that friction is so small that it can be ignored.

A force is applied to the car. Choose the one force graph (A to H) for each statement below which could allow the described motion of the car to continue.

You may use a choice more than once or not at all. Answer choice I if you think that none is correct.

A.  

B.  

C.  

D.  

E.  

F.  

G.  

H.  

I. None of these graphs is correct.

12. The car moves toward the right (away from the origin) with a steady (constant) velocity.

Select your answer.

13. The car is at rest.

Select your answer.

14. The car moves toward the right and is speeding up at a steady rate (constant acceleration).

Select your answer.
15. The car moves toward the left (toward the origin) with a steady (constant) velocity.
Select your answer:

16. The car moves toward the right and is slowing down at a steady rate (constant deceleration).
Select your answer:

17. The car moves toward the left and is speeding up at a steady rate (constant acceleration).
Select your answer:

18. The car moves toward the right, speeds up and then slows down.
Select your answer:

19. The car was pushed toward the right and then released. Which graph describes the force after the car is released.
Select your answer:

If you have finished this test, click the button below to submit your results:

Submit my answers and continue
Appendix B-3  Introduction screen

Introduction

Introducing the simulation

In this session you will learn about describing motion using graphs and predicting the motion of an object based on the forces acting on it.

Your goal is to understand how a constant force applied to an object affects its motion and to be able to describe that motion graphically.

You have been given a worksheet in which you will be asked to sketch some graphs - just do your best. Feel free to jot down any other notes that you want in the worksheet.

Please do not use the browser’s ‘back’ button to navigate - there are ‘previous/next’ links on each screen as well as a navigation bar at the top right of each screen.

You should spend no more than about 5 minutes on each of the eight activities.

Now go to the start by clicking on the group that you have been assigned to:

Group A click here  Group B click here

~M Pearce, University of Melbourne. Last update April 17, 2002~
Appendix B-4  Introduction to the simulation

Activity 1: Introducing the simulation

The simulation represents a cart running along a track, where its motion is being monitored by a motion detector at the left hand end.

A few things to take note of before you explore:

1. The cart behaviour as if it has very low (zero) friction wheels.
2. You can reset the simulation to position the cart at either end of the track by using the arrows under the "Reset" button.
3. The right end of the track is always "sticky" whilst the left end is always "bouncy".
4. The time starts as soon as you click on or drag the cart, and it stops running (therefore, the simulation keeps running) until the cart leaves the right hand end of the track. You might be able to cause it to bounce forever if so, you can always force it to stop by clicking once on the "Stop" button.

(a) Exploring position

Now drag the cart back and forwards along the track while watching the top (position) graph to see how it represents the motion.

Note that position is always measured from the left end of the track.

(b) Resolving a motion

Drag the cart back and forth a little, leaving it up against the right-hand end of the track. Now click "Reset" and watch how the moving cart changes. Drag and release the cart over it until it glides along the track. Try this.

Clicking "Reset" twice will clear the graphs permanently.

Note from here on:

1. We are only interested in the section of the graph where you have released the cart (blue line). You can ignore the other part (red line) of the graph.
2. If any of your graphs go off the scale, simply change the scale and replay the motion. For example, you might click on the maximum value where to type in 15, then press "Reset" to do it.
3. Do similar to change the Y-axes scales.
Appendix B-5  First activity screen presented to students

Constant velocity

Jump to exercise...
1 2 3 4 5 6 7 8 9

Activity 2: Steady (constant) velocity

Run the movie opposite which shows a cart being given a little push at the start and then moving away from the motion detector at a constant velocity (click the text on the movie to run it). Ignore the motion during the push for this and all other activities. Also ignore any jerky motion in these movies - this is just an artifact of the movie!

Think about what a position-time and a velocity-time graph would look like for this motion. (Assume that the positive direction is to the right so that the cart will have a positive velocity.)

Sketch your predicted position-time and velocity-time graphs on the axes provided in your worksheet.

When you have done this, proceed to the next screen where you will complete Activity 2 by using the simulation to check your sketches.

<Previous  Next>
Appendix B-6  Second activity screen ‘simulation mode’

Constant velocity

Activity 2: Steady (constant) velocity - checking

The simulation is set up to show position and velocity graphs. Position the cart at the left end of the track by clicking the left reset arrow.

(a) Check your graph predictions by giving the cart a gentle push to the right. Repeat this until you get a motion similar to the one you previously saw.

Note: in all these motions, we are only interested in the motion after you released the cart, that is, the blue lines not the red lines.

(b) Sketch the blue parts of the simulated position-time and velocity-time graphs on top of your predicted ones using a different coloured pen.

Try to learn from any differences between your predicted and simulated graphs.

(c) Now think about how your position and velocity graphs compare. You are trying to understand the relationship between the two graphs. Run the motion again if you want to. Maybe try a faster push and look for differences.

(With all these exercises, feel free to jot notes in your worksheet if it helps you.)

You have now completed an activity.
Before you continue please answer the following:

(a) How challenging did you find this last activity?

- too low
- just right
- too high

(b) Were your skills appropriate for understanding this last activity?

- too low
- just right
- too high
Appendix B-7  Review screen

Constant acceleration

Jump to exercise...

Activity 2: REVIEW

This is the end of the learning sequence. The next part will be some reflective questions that are short tests of the physics you have learned.

But first, you might like to spend a few minutes reviewing some of the motions. You can do this by using the navigation numbers at the top of each page to jump to the first screen for each activity.

Or you can use them to Streams in a manner of the motions and run them using the simulation opposite.

Activity 1: Introduction to the motions
Activity 2: Steady (constant) velocity
Activity 3: Constant velocity - opposite direction
Activity 4: Speeding up away from the detector
Activity 5: Slowing down away from the detector
Activity 6: Slowing down in the other way (towards the detector)
Activity 7: Slowing down & coming back
Activity 8: Motion on a ramp

<Previous  On to the final part>
Appendix B-8  Second activity screen ‘movie mode’
Appendix B-9  JavaScript code for scoring post-test

This code returns a screen to the student showing their final test score. Written by Connor Graham.

#!/usr/bin/perl

read(STDIN,$temp,$ENV{'CONTENT_LENGTH'});

@pairs=split(/\n/, $temp);
foreach $item(@pairs) {
    ($key,$content)=split (/=\n/, $item, 2);
    $content =~ tr/+/ / ;
    $content =~ s/%(.+)/pack("c",hex($1))/ge;
    $fields{$key}=$content;
}

#this part of the script opens and writes to file

open (formlog, ">> /Local/Users/jon/logs/imotionlog.txt");
#open (formlog, ">> /student/web/projects/amyfinal/logs/imotionlog.txt");

($sec,$min,$hour,$mday,$mon,$year,$wday,$yday,$isdst) = localtime;

$name = $ENV{'REMOTE_USER'};
$stro = $ENV{'REMOTE_ADDR'};
$dash = '-' ;

$mname= ('Jan', 'Feb', 'Mar', 'Apr', 'May', 'Jun', 'Jul', 'Aug', 'Sep', 'Oct', 'Nov', 'Dec ' )[$mon];
$yr=eval $year+1900;
print formlog "\n$name $stro $dash $fields{nextpage'};

foreach $key (sort keys %ENV) {
    #print $key (sort keys %ENV) { 
    #print formlog "$key -> $ENV{$key}\\n";
    #}

close (formlog);

#this part of the script computes the score and spits out html

print "Content-type: text/html\\n\\n";
print "<html\\n\\n";

#I got rid of the redirect
# print "<meta http-equiv="refresh" content="0; 

#These are the right answers placed in an array

@answer=('"Posttest-mov","qqq-2","qqq-4","qqq-6","qqq-1","qqq-1","qqq-5","qqq-5","qqq-5","qqq-5","qqq-2","qqq-7","qqq-7","submit=Please+wait+a+moment... nextpage=introExit%2F6-exit.html');
# These are the right answers in plain form
#2 4 6 6 2 1 1 1 1 5 5 1 5 2 2 7 5

# This scalar is used to compute score
$score=0;

# This was just a temp variable for testing
#@temp=("qqq-2","qq-2");

# This selects the array elements to be compared against the answer array
for ($x=1; $x<20; $x++)
{
#
# This compares elements 1 through 20 inclusive: user input in the pairs array
# against the array created above
if (@pairs[$x] eq @answer[$x])
{
#
# This computes the score
$score=$score + 1;
}
# else
#
# $score=$score;
#
#
# The HTML
print "<body>
"
print "<title>Survey</title>"

# Link to stylesheet
print "<link rel="stylesheet"
    ract/imotion/imotionStyles.css"
    type="text/css">
</head>
"
print "<body bgcolor="$FFFF00" text="$000000">
"

# First formatting table
print "<table width="100%" border="0" cellspacing="3"
    cellpadding="3">
# First row

---

**Appendices**

# IMotion image

print "<tr valign="top">";

# Second row

print "<tr valign="top">";

# The score and That's all

print "<p class="myTitle" align="center">You scored $score out of 19.</p><p class="myTitle" align="center">That's the end of your session.</p>";

# The final instructions: note that the invisible form previously here has been removed.

print "<p class="standardText" align="center">Please <font color="#CC0000">quit from your web browser</font> and collect your reward.</p>";

# The footer

print "<tr valign="top">";

print "";
Appendix B-10  Post-survey questions

Questions (grouped by factor). Response key was from “Not at all” to “A lot”.

Control:
(a) I felt in control of what I was doing
(f) I was frustrated by what I was doing \((\text{negatively scored})\)
(j) I knew the right thing to do

Engagement:
(b) I was absorbed intensely by the activity
(d) I thought about other things \((\text{negatively scored})\)
(h) I was aware of distractions \((\text{negatively scored})\)
(k) It required a lot of effort for me to concentrate on the activities \((\text{negatively scored})\)

Enjoyment:
(c) I found the activities enjoyable
(e) I found the activities interesting
(g) the activities bored me \((\text{negatively scored})\)
(i) the activities excited my curiosity

Calculating aggregate scores:
Control = \((a + (6 - f) + j))/3\)
Engagement = \((b + (6 - d) + (6 - h) + 6 - k))/4\)
Enjoyment = \((c + e + (6 - g) + i))/4\)
Appendix B-11  Post-survey Web pages

A few final questions...

Before you proceed, please hand in your worksheet!

Please respond to the following six questions about the exercise you have just completed:

**Question 1.**
During the session:

- (a) I felt in control of what I was doing
- (b) I was absorbed intensely by the activity
- (c) I found the activities enjoyable
- (d) I thought about other things
- (e) I found the activities interesting
- (f) I was frustrated by what I was doing
- (g) the activities bored me
- (h) I was aware of distractions
- (i) the activities excited my curiosity
- (j) I knew the right thing to do
- (k) It required a lot of effort for me to concentrate on the activities

<table>
<thead>
<tr>
<th></th>
<th>Not at all</th>
<th>A little</th>
<th>A lot</th>
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<tr>
<td>(a)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(b)</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>(c)</td>
<td></td>
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</tr>
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<td>(j)</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>(k)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Question 2.**
During the session you were frequently asked how challenging the task was. Which meaning of the word "challenge" is closest to the interpretation that you used:

- the tasks were difficult for me to do
- the tasks tested my abilities in a stimulating way
- the software was difficult to use
- other:

**Question 3.**
The graphs and cart motions presented by the animations gave you a check on your predicted graphs and showed you what would happen if you did various things to the cart. How effective was this to you as feedback on your thinking?

- very poor feedback
- 
- 
- 
- very good feedback.
Question 4.
Were there any moments when you were aware of actually learning something new?

[ ] yes  [ ] no

If you answered ‘yes’ above, please answer the questions below; if not, go on to question 5.

a) Describe briefly what it was:

b) Describe briefly what you were doing at the time (e.g. thinking about the text, watching a movie, etc.):

[c] Did you feel any particular emotions at that time? If so, describe them below:

---

Question 5.
Did you at any time during these tasks find yourself so caught up in them that you were not aware of time passing?

[ ] yes  [ ] no

If ‘yes’, which part of the task were you working on? What did you find particularly absorbing or engrossing?

---

Question 6.
If you have any suggestions about how your learning experience could have been improved during these tasks, please enter them below.

---

J M Peace, University of Melbourne. Last update: April 17, 2002
Appendix B-12  Factor analysis process

Preliminary analysis

N = 59
Correlation matrix shows no issues with multicollinearity (determinant > 1E-05) or singularities
  correlation coefficients > 0.9):

Correlation Matrix

<table>
<thead>
<tr>
<th></th>
<th>Q (a)</th>
<th>Q (b)</th>
<th>Q (c)</th>
<th>Q (d)</th>
<th>Q (e)</th>
<th>Q (f)</th>
<th>Q (g)</th>
<th>Q (h)</th>
<th>Q (i)</th>
<th>Q (j)</th>
<th>Q (k)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q (a)</td>
<td>1.000</td>
<td>.075</td>
<td>.007</td>
<td>-.072</td>
<td>-.049</td>
<td>-.516</td>
<td>-.092</td>
<td>-.053</td>
<td>.104</td>
<td>.500</td>
<td>-.484</td>
</tr>
<tr>
<td>Q (b)</td>
<td>.1000</td>
<td>1.000</td>
<td>.594</td>
<td>-.370</td>
<td>.688</td>
<td>-.148</td>
<td>-.548</td>
<td>.015</td>
<td>.565</td>
<td>.087</td>
<td>-.016</td>
</tr>
<tr>
<td>Q (c)</td>
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<td>.000</td>
<td>-.142</td>
<td>.682</td>
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<td>-.492</td>
<td>-.132</td>
<td>.505</td>
<td>-.068</td>
<td>-.098</td>
<td></td>
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<tr>
<td>Q (d)</td>
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<td>-.363</td>
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<td>Q (e)</td>
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<tr>
<td>Q (f)</td>
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<td>-.516</td>
<td>.604</td>
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<tr>
<td>Q (g)</td>
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<td>-.395</td>
<td>.067</td>
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<tr>
<td>Q (h)</td>
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<tr>
<td>Q (i)</td>
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<tr>
<td>Q (j)</td>
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<tr>
<td>Q (k)</td>
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</tbody>
</table>

a Determinant = 4.894E-03  \( p < 0.05 \), \( ** p < 0.01 \)

However, the Anti-image matrix shows that one item, Q (h), had a MSA < 0.5 and was dropped. In the consequent analysis item Q (d) was also dropped for the same reason, resulting in the following anti-image matrix with all items having MSA > 0.5:

Anti-image Matrices

<table>
<thead>
<tr>
<th></th>
<th>Q (a)</th>
<th>Q (b)</th>
<th>Q (c)</th>
<th>Q (e)</th>
<th>Q (f)</th>
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<th>Q (i)</th>
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<tbody>
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Diagonals of anti-image correlations are measures of Sampling Adequacy (MSA) \( p < 0.05 \)

The KMO measure of sampling adequacy was 0.748, which is good (Kaiser, 1974) and Bartlett’s test is highly significant \( p < 0.001 \) indicating that the R-matrix is not an identity matrix and that factor analysis is appropriate:

KMO and Bartlett's Test

Kaiser-Meyer-Olkin Measure of Sampling Adequacy:  .748
Bartlett's Test of Sphericity: Approx. 221.620
Chi-Square df 36
Sig. .000
Factor extraction

The eigenvalues show 2 factors extracted explaining 64.6% of the variance.

Total Variance Explained

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<th>Rotation</th>
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Extraction Method: Principal Component Analysis.

Communalities

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Extraction Method: Principal Component Analysis.

The rotated component matrix (sorted by size, values < 0.1 omitted) shows the loading of each item on the two factors.

Rotated Component Matrix

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</table>

Extraction Method: Principal Component Analysis. Rotation Method: Varimax with Kaiser Normalization. Rotation converged in 3 iterations. Values < 0.3 not included.

Appendices
Appendix C

Experiment Three
Appendix C-1  Physics pre and post-test

Pretest on Physics Knowledge

This test is to give us an idea of your physics background. Go through it fairly quickly.

This test has 14 questions grouped into 4 sets

Question Set A

Questions 1 to 3 refer to a coin that is tossed straight up into the air. After it is released it moves upward, reaches its highest point and falls back down again. Use one of these following choices (A to H) to indicate the acceleration of the coin during each of the stages of the coin's motion described below. Take up to be the positive direction Ignore any effects of air resistance.

A. The acceleration is in the negative direction and constant.
B. The acceleration is in the negative direction and increasing.
C. The acceleration is in the negative direction and decreasing.
D. The acceleration is zero.
E. The acceleration is in the positive direction and constant.
F. The acceleration is in the positive direction and increasing.
G. The acceleration is in the positive direction and decreasing.
H. None is correct
I. The coin is moving upward after it is released.

1. The coin is moving upward after it is released.

Select your answer...

2. The coin is at its highest point.

Select your answer...

3. The coin is moving downward.

Select your answer...
Question Set B

Questions 4 to 8 refer to a toy car that can move to the right or left on a horizontal surface along a straight line (the positive part of the distance axis). The positive direction is to the right.

Assume that friction is so small that it can be ignored.

Different motions of the car are described below. Choose the acceleration-time graph (A to H) which corresponds to the motion of the car described in each statement.

You may use a choice more than once or not at all. Answer choice H if you think that none is correct.

4. The car moves toward the right (away from the origin), speeding up at a steady rate.
   [Select your answer]

5. The car moves toward the right, slowing down at a steady rate.
   [Select your answer]

6. The car moves toward the left (toward the origin) at a constant velocity.
   [Select your answer]

7. The car moves toward the left, speeding up at a steady rate.
   [Select your answer]

8. The car moves toward the right at a constant velocity.
   [Select your answer]
Question Set C

Questions 9 to 12 refer to a toy car which can move to the right or left along a horizontal line (the positive portion of the distance axis). The positive direction is to the right.

Choose the correct velocity-time graph (A to I) for each of the following questions. You may use a graph more than once or not at all.

A. velocity time

B. velocity time

C. velocity time

D. velocity time

E. velocity time

F. velocity time

G. velocity time

H. velocity time

I. None of these graphs is correct.

9. Which velocity graph shows the car moving towards the right (away from the origin) at a steady (constant) velocity?

Select your answer...

10. Which velocity graph shows the car reversing direction?

Select your answer...

11. Which velocity graph shows the car moving toward the left (toward the origin) at a steady (constant) velocity?

Select your answer...

12. Which velocity graph shows the car increasing its speed at a steady (constant) rate?

Select your answer...
Question Set D

13. The positions of two blocks at successive 0.2-second time intervals are represented by the numbered squares in the figure below. The blocks are moving toward the right.

Do the blocks have the same speed?

A. No
B. Yes, at instant 2.
C. Yes, at instant 5.
D. Yes, at instants 2 and 5.
E. Yes, at some time during the interval 3 to 4.

Select your answer...

14. The positions of two blocks at successive 0.2-second time intervals are represented by the numbered squares in the figure below. The blocks are moving toward the right.

The accelerations of the blocks are related as follows:

A. The acceleration of “a” is greater than the acceleration of “b”.
B. The acceleration of “a” equals the acceleration of “b”. Both accelerations are greater than zero.
C. The acceleration of “b” is greater than the acceleration of “a”.
D. The acceleration of “a” equals the acceleration of “b”. Both accelerations are zero.
E. Not enough information is given to answer the question.

Select your answer...

If you have finished this test, click the button below to submit your results:

Submit my answers and continue
Appendix C-2  Web-based materials

The following 5 pages show the text from the Web-based learning materials for Experiment Three. The interactive simulation ‘iMotion’ was displayed on the screen to the right of the text.

Introduction to the simulation

(Spend about 5 minutes on this screen exploring the simulation as outlined below)

The simulation "iMotion" opposite represents a cart running along a track. A device at the left end of the track measures the position of the cart, and hence its velocity and acceleration.

A few things to take note of before you explore:

1. the cart behaves as if it has very low (zero!) friction wheels;
2. you can 'Reset' the simulation to position the cart at either end of the track by using the arrows under the 'Reset' button;
3. the right end of the track is always "sticky" whilst the left end is always "bouncy";
4. "time" starts as soon as you click on or drag the cart, or click the release button. The simulation keeps running until the cart touches the right-hand end of the track. You might be able to cause it to bounce forever! If so, you can always force it to stop by clicking one of the 'Reset' buttons.
5. Position is always measured from the left end of the track.

To familiarise yourself with iMotion try this:

Drag the cart back and forth a little, leaving it up against the right-hand end of the track. Now click 'Replay drag' and see how the motion replays. Drag and release the cart and it will glide along the track. Try it.

Clicking 'Reset' twice will clear the graphs permanently.

Changing graph scales

If any of your graphs go off the scale, simply change the scale and replay the motion. For example, you might click on the maximum time value "10", type in "15", then press Return to fix it.

Do similar to change the Y-axes scales.

Next>
Question 1

"I want to understand the idea of velocity - what it means and what a steady (constant) velocity would look like on a velocity-time and on an acceleration-time graph. Also the idea that velocity has direction - what do positive and negative mean in relation to velocity?"

Approach

Drag cart around, or give it a push and let go, to produce positive & negative velocity-time graphs.

Before continuing, please answer the following...
(a) How challenging (or stimulating) did you find what you just did?

- challenge
  - too low
  - just right
  - too high

(b) Were your skills appropriate for understanding it?

- my skills
  - too low
  - just right
  - too high

<Previous Submit and on to next page >
**Question 2**

"Tell me about the idea of *acceleration*. For example:

* What does it mean? What does the motion of an accelerating cart look like?
* What is a steady (constant) acceleration? How do you get one?
* What would a steady acceleration look like on a velocity-time and an acceleration-time graph?"

**Approach**

Use the fans as a “unit of push” to produce different constant accelerations. Look at how this affects the graphs. Remember to explore both directions of motion.

Be sure also to watch the cart and see if you can observe the accelerating motion.

Before continuing, please answer the following...
(a) How challenging (or stimulating) did you find what you just did?
   - challenge too low
   - challenge just right
   - challenge too high

(b) Were your skills appropriate for understanding it?
   - my skills too low
   - my skills just right
   - my skills too high

<Previous    Submit and on to next page >
Question 3

"I don't understand the idea of acceleration having direction. For example,

* what is a negative acceleration?
* what would the motion of a cart look like with a negative acceleration?

I want to work out the acceleration when I attach a fan, or shove the cart in different ways, or do both at the same time (both by describing the motion of the cart and by describing either graph)."

Approach

To get steady accelerations, use the fans. Try to understand any links between direction of velocity, direction of acceleration and change in velocity (and in which direction is the change). You will need to be able to explain things like "if I push the cart this way, with a fan blowing that way, it will move like this ... etc."

Try all combinations of velocity direction and fan direction (acceleration) than you can think of so as to be sure you understand what is going on.

Before continuing, please answer the following...
(a) How challenging (or stimulating) did you find what you just did?
challenge too low  challenge just right  challenge too high

(b) Were your skills appropriate for understanding it?
my skills too low  my skills just right  my skills too high

<Previous  Submit and on to next page >
"I’m not sure that I understand the nature of the acceleration of a ball when it is tossed into the air. For example, how does its acceleration compare on the way up, at the top of the flight, and on the way down?"

**Approach**

You can raise the left end of the track by dragging it. Now the cart will run up and down the track as if it were in a "weakened" gravity field. Use this "weakened gravity" to explore a ball tossed in the air by "tossing" the cart up the slope.

Again, see if you can observe the accelerating motion of the cart.

Before continuing, please answer the following...
(a) How challenging (or stimulating) did you find what you just did?

- challenge too low
- challenge just right
- challenge too high

(b) Were your skills appropriate for understanding it?

- my skills too low
- my skills just right
- my skills too high

<Previous    Submit and on to next page >
Appendix C-3  Interview questions

Experiment Three: Interview questions

I want to ask you ten questions about various aspects of the experience you have just been through and how you felt.

A. Antecedents

1. The learning session you just completed set several tasks for you to explore. Could you please comment on how clear the goals were for the tasks you had to do?
2. Tell me about how you perceived the feedback you received while trying to achieve those goals?
   - was it adequate?
   - was it helpful?
   - how did you know when you had explored enough?
3. How challenging did you find the session?
   - Can you illustrate with particular instances?
   - What about your skills to meet these challenges?
   - And your meaning of challenge?

B. Experiences

4. Action & awareness – (not used)
5. Tell me about how hard you had to concentrate during your exploration.
   - Any particular parts or actions?
6. Can you comment on what degree of control you felt you had while you were exploring the 4 questions?
   - what do you mean by control or lack of? (example?)
   - did you feel confident in what you were doing?

C. Effects

7. At any time did you feel a loss of self-consciousness – that is, being unaware of what was going on around you?
   - when? what were you doing at the time?
8. At any time did you feel that time was passing quickly?
9. To what degree did you enjoy the activity?

D. Flow

Some people describe a condition they call “flow” when they get very involved, engaged in an activity. One person put it this way:

“My mind isn’t wandering. I am not thinking of something else. I am totally involved in what I am doing. My body feels good. I don’t seem to hear anything. The world seems to be cut off from me. I am less aware of myself and my problems.”

and

“I am so involved I what I am doing, I don’t see myself as separate from what I am doing.”

10. Can you comment on any feelings you had similar to those during this session?
   - what were you doing at the time?
   - do you recall learning anything in particular at that time?
   - can you recall your emotions? how you felt?
11. Finally, what have you learnt from this exercises that you didn’t know before? What you were doing at that time?
Appendix C-4  Profiles booklet of students - sample

(Front page plus one sample student page only)

Summary

Distribution of states:

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Linking Test Questions to task Questions (TQ)

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Averages

Average time: 57 minutes
Average clicks: 198
Experiment Two – Subject profiles  ID: s543, S1, ‘Physicist_A’

Name: S1  Gender: M  Age: 21-25  Language: English

Physics background:  Yr 12, 36-40  VCE: 91-95

Survey:  

Control: 3.3  Engage: 3.0  Enjoy: 3.8

Challenge/Skill:  

Q1 2:4  Q2 4:2  Q3 4.2  Q4 3:3

Times:  

Intro 2.0  Q1 2.3  Q2 5.1  Q3 6.4  Q4 2.8  Total: 19.1

Physics concepts scores:  

(Sum of test Q’s relating to each learning question)

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0 1 2 3 4 5 6 7 8 9 10 11 12 13 14

Flow Path for s543  
Tests: 11, 14, 3. (+vV0: 3, 11, 0, 0)
MyFlow: 59%  JonFlow: 0%

Student pre-post scores in learning areas

Appendices 275
20Sep/2002; start time was 10:36:49. Session number 4. IP: 128.250.6.134. Login was: s543
Interactions: 2.4% of time; total time was: 2042 secs, 118 clicks.
### Appendix C-5  Physics understanding from ‘Teaching session’

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<td>How is acceleration represented on v-t graph</td>
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<td>5</td>
<td>5</td>
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<td>5</td>
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<td>How is acceleration determined by force</td>
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<tr>
<td>Velocity of cart on hill</td>
<td></td>
<td>4.2</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>1</td>
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<td>1</td>
<td>0</td>
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<tr>
<td>Acceleration of cart on hill</td>
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<td>5</td>
<td>5</td>
<td>4</td>
<td>5</td>
<td>2</td>
<td>5</td>
<td>1</td>
</tr>
<tr>
<td>Velocity of ball in flight</td>
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<td>5</td>
<td>5</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Acceleration of ball in flight</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tbody>
</table>

**Average scores for groups of concepts (by question):**

<table>
<thead>
<tr>
<th></th>
<th>Q1</th>
<th>Q2</th>
<th>Q3</th>
<th>Q4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average</td>
<td>5.0 5.0 4.8 5.0 5.0 4.8 2.5 2.8</td>
<td>5.0 5.0 4.2 5.0 4.6 3.8 1.0 1.4</td>
<td>5.0 5.0 2.8 4.3 1.5 0.5 0.8 0.5</td>
<td>5.0 4.8 3.8 2.5 1.5 2.3 0.5 1.8</td>
</tr>
</tbody>
</table>

**Rating scale:**

No knowledge 0; Very poor 1; Poor 2; Satisfactory 3; Good 4; Excellent 5

**Research assistant’s comments:**

Both S5 and S4 when talking about the cart on the slope started to talk about velocity as the slope on their v-t plots. Both seemed very sure of their answers (which were all correct) up until this point and both said they were confused and thought they might have it wrong.

Although S8 did get the acceleration correct for the slope and the ball I believe that she didn't fully understand what was going on and was just remembering what the program had shown.

Unfortunately I did not ask S7 about the cart on the flat I also did not ask many of them at all about the effect of initial conditions or the relationship between acceleration and force. For the latter I was able to make assumptions as a few people made some kind of connection between the two.

S3 I found quite difficult to do as it was often hard to decipher between lack of confidence and whether she just didn't know. I think in most cases she didn't understand, especially acceleration.

S5, S4 and S7 did very well when explaining general concepts but were not good at applying these concepts to the motion of the cart and ball.
Appendix C-6  QuickTime AppleScripts

These scripts were used to program QuickTime Player so that keyboard controls could be used to control the video clips of interviews (stop, back-up, play at fast and slow speeds).

Script to back up 5 seconds and play (for reviewing)

-- Move back 3 secs and play

property seconds2select : 5
tell application "QuickTime Player"
  try
    if not (exists movie 1) then error "Jon's script: No movies are open!"
    -- CHECK FOR QUICKTIME PRO
    if QuickTime Pro installed is false then
      set the target_URL to "http://www.apple.com/quicktime/download/"
      display dialog "This script requires QuickTime Pro." & return & return
      & "If this computer is currently connected to the Internet, " & ¬
      "click the “Upgrade” button to visit the QuickTime Website at:" & ¬
      return & return & target_URL buttons {"Upgrade", "Cancel"} default
      button 2
      ignoring application responses
      tell application "Finder"
        open location target_URL
      end tell
    end ignoring
    error number -128
  end if

  set the time_scale to the time scale of movie 1
  set the current_time to current time of movie 1
  set the movie_length to the duration of movie 1
  set the selection_length to (time_scale * seconds2select)
  if (the current_time - the selection_length) is less than 0 then
    set current time of movie 1 to 0
  else
    set current time of movie 1 to the current_time - the selection_length
  end if

  tell movie 1
    play
  end tell

on error error_message number error_number
  if the error_number is not -128 then
    beep
    display dialog error_message buttons {"Cancel"} default button 1
  end if
end try
Script to toggle 9 x to 4 x speed

```
tell application "QuickTime Player"
    if the rate of movie 1 is less than 8 then
        set rate of movie 1 to 9
    else
        set rate of movie 1 to 4.5
    end if
end tell
```

Script to toggle play

```
tell application "QuickTime Player"
    if the movie 1 is playing then
        stop movie 1
    else
        play movie 1
    end if
end tell
```
Appendix C-7  Interview summaries document (sample)

(One sample student page only)

ID:    S1

Background

Language, gender, physics

Improve test score from 11 to 14/14!

Control, engage, enjoy
3.3, 3.0, 3.8 Bit below av on engage (3.5) and enjoy (4.0).

Time and Interactivity
34 minutes (av. 57) and 118 clicks (av. 198). Low on clicks.

Flow elements

Goals
First question had clear goals. Later on caused a little confusion relating to learning goals. First question a bit broad/vague on specifics; Q 2 & 3 more specific and he understood what was meant, but Q 3 the physics was harder. The simulation helped and he thought a lot about the concepts: “I think maybe I wasn’t quite looking at parts of the question as in the whole negative positive distinction”. He was focused on the test and would like to have had a copy to help him know what to learn.

Feedback
Feedback to him was “Watching the graph while the cart’s moving”. He appeared to appreciate how the design of the simulation linked to learning outcomes. He distinguishes feedback from sim’n and feedback to help learning. The latter was not there – he wanted something to say “that’s wrong or try again or … try and explain why you got it wrong”. Seems to think of general understanding of the concepts and specific understanding that will help answer questions.

Challenge
Q 1 & 2 quite easy and he grasped them (=> easy wrt skills). Q3 & 4 more difficult – got a bit muddled. This is slightly different from his flow-path that shows 2, more difficult, 3 less so, and 4 more difficult. He says 3 & 4 weren’t intrinsically difficult, “It’s just the concepts, getting your head around it”.

Skills
But he rates his skills as good enough to meet the challenges. On the path he rates both his skills low and challenge high.

Concentration
He got absorbed in the simulation. Concentration was high.

Control
Enjoyed the sim – driving the cart. He felt in control of the cart (artefact) – but not know exactly what he was doing (task). But describes detailed control of the simulation. Except the difficulty in getting the speed he wanted. Suggested typing in a number “I suppose it wouldn’t be as enjoyable but if you just set it off at a certain speed…you typed in a speed and that’s how it goes.”

Loss of self-consc.
Was not distracted by other things except near end – played with sim “There may have been one point where you get a bit silly and you’re just moving things around maybe not taking it in and not thinking about it. Just seeing how the program works or pressing a few buttons. Maybe you get a little bit distracted there.” Describes this as just exploring – interesting or novel.
Felt relatively absorbed, most of his concentration “going into the computer” but would have responded pretty quickly if someone walked in. Not that absorbed!

**Time**
He felt time went quickly for Q1 & 2 – he thought about being half way through. After 100 minutes he thought 40 minutes had gone past!

**Enjoyed**
He enjoyed it. He liked seeing something happen then trying to get it (graph and cart) to do something different – even with poor ideas of pos & neg acceleration,

**Flow**
Learning session – absorbed and flowing – not probed as much as when teaching.

Teaching also flowed: “you’re searching for ideas otherwise you’re interacting with the person and it can be flowing quite well”. But also found it stopped when had to explain something he didn’t understand fully.

Talks about the “probing” by Vic as interrupting flow. If the computer has kept giving feedback as to right, wrong, etc, that would have interrupted flow too.

**Learning**
During the sim’n he felt he was learning the concepts but not specifically aimed at the test questions. He didn’t have good understanding of neg and pos aspects of accel and vel, but now has better understanding, esp. with velocity.

**Other**
He felt confident with his learning but a bit concerned about explaining to someone else with the sim’n in from of him.

**Relate to Flow-path**
Flow-path shows q 2 being more of a challenge than he recalls. He see Q 2 & 4 as quite hard, and his skills low, but he said Q 2 quite easy, Q 3 & 4 harder, but his skills OK to cope!

**Summary**
Andrew thought deeply about his work. Goals were clear to begin with, but got more confused later on. He got good feedback from the simulation, but really wanted some feedback about his physics thinking. He got absorbed and confidently went though the exercise, yet he still marked it as generally more challenging than his skills in the scales. Maybe this indicates that people mark an appropriate challenge as ch>sk?

He was in good control of the simulation, yet recognised that less direct engagement might have made it easier – but less fun. He certainly got carried away time-wise and was fully immersed. He reports flow and articulates that frequent computer feedback (right, wrong, etc.) might have broken this flow as it did when got to difficulty parts in teaching Vic.

He improved his already excellent performance on the test and believes that it was while using the simulations that he learnt.

Interesting that once started he was always “anxious”.

---

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<table>
<thead>
<tr>
<th>Overall</th>
<th>Task</th>
<th>Artefact</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Challenge-skills</strong></td>
<td>Q 1 &amp; 2 OK</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Q 3 &amp; 4 harder – talks about concepts. Thought his skills ok.</td>
<td></td>
</tr>
<tr>
<td><strong>Antecedents</strong> (goals, feedback, control, merger action &amp; awareness)</td>
<td>Goals clear but not relate to what he wanted – test.</td>
<td>Good control of sim’n.</td>
</tr>
<tr>
<td><strong>Experience</strong> (concentration, loss of self-consc, time distortion, telepresence)</td>
<td>Lost track of time. Absorbed, not distracted.</td>
<td>Lost conc’n at near end while exploring/playing with sim. Concentration was high – moving things, interpreting. Esp. at end.</td>
</tr>
<tr>
<td><strong>Consequences</strong> (positive affect, autotelic)</td>
<td></td>
<td>Enjoyed seeing the interactions and controlling them,</td>
</tr>
</tbody>
</table>

**Did he flow?**

*What was this flow (or not flow) based on? (e.g. lots of interest, enjoy, not worried about failure, task challenges not offset by sim difficulties, etc.):*

Yes. Esp. in learning session – broken with Vic. Lost time. Enjoyed it, Played with sim’n. Probably more flow than most. Had a good understanding of physics even though had some holes. Filled them!
Appendix C-8  Sample of interview analysis process

This appendix illustrates how a section of the analysis of interview data was carried out. An excerpt from a transcript is presented below. This excerpt is taken from the interview with S5 (Learner_A).

--- Start of excerpt ---

Int: And you’re thinking in terms of graphs and velocity graphs and iMotion. Did you find the simulation helpful in reminding you of all of that?
S5: {Learn} It reminds me of parts of it but if I had more time to think about it and ... I found it very helpful with the cart and the resulting graph and when you plot it out I could tell that the more steep it is, what are the results with velocity and acceleration. {Learn}

Int: And you were thinking back to your Physics last year quite a bit I gather were you or not?
S5: {Reflect} I...yeah. {Reflect: she was thinking back to last year's physics}

1  Goals

Int: Let’s leave the Physics, I’ve got questions about things a bit different. These questions are about various aspects of the experiences you’ve had, mainly on the computer, maybe while you were talking to Vic as well. The learning session you just completed set several tasks for you to explore. Can you comment about how clear the goals were for those tasks?
S5: {Goals} It’s the concept of motion and what exactly velocity is and how if a body is moving in a particular direction at a particular gradient, what the results are. And the relationships between velocity, acceleration and distance. {Goals}

Int: So how clear was it, what you actually had to do while you were working through the simulation in those four questions?
S5: {Goals} It was quite clear there. {Goals: While working though sim’n}

Int: So you didn’t feel lost at any time or unsure of what you’re doing?
S5: {Goals} No. {Goals: not lost or unsure}

2  Feedback

Int: Can you tell me about how you perceived the feedback you received while you were doing that? Back from the simulation?
S5: {Feedback} In terms of the simulation, it was quite clear because I had the cart model to use. If I had doubts I could go back and it would still show me something that would clarify any things I was still confused about.

Int: So the feedback was helpful?
S5: Yeah. {Feedback: Helpful}

Int: Was it adequate? Was it enough to tell you what you were trying to find out?
S5: {Feedback} Yes. {Feedback: Adequate - enough to tell you what you were trying to find out}

Int: How do you know when you’d explored enough for a particular question?
S5: {Feedback} If I had some time to think about it and think...regarding how I use the model in different aspects and to show different graphs and everything. If I can see a sequence or how I everything's interrelated then I felt that the simulation was adequate. {Feedback: explored enough}

Int: So you worked until you felt you had a good sequence of what you had to explain later. That sort of thinking?
S5: Yes.

--- End of excerpt ---

Analysis of data
1st pass: syntactic

The TAMS Analyser software was used in a first pass to mark up key words in the passage, add comments where helpful, collate passages based on these codings for all interviewees, and to present them in one view. The code words were based on the 9 elements of flow (challenge, skill, control, enjoyment, etc.) as well as references to the task or the artefact. The screenshot of the output from this process below shows some of the ‘feedback’ comments shown in the previous excerpt:
Pass 2: semantic analysis

Passages with common codings were then extracted. An interpretative analysis was performed to gain an impression of how each interviewee dealt with the various issues presented. From this, ratings were recorded (low, medium, high) as to the interviewee’s response to the issue. Common or contrasting responses across the group of interviewees were also noted.

As an example, the ‘feedback’ comments grouped from the above extract made the comments:
Int: “...tell me about how you perceived the feedback...”  S5: “...it was quite clear...”
Int: “So the feedback was helpful?”    S5: “Yeah.”
Int: “Was it adequate?”  S5: “Yes”

These three positive affirmations were interpreted to give S5 a ‘high’ rating for feedback. In contrast, S7 scored a ‘low’ for feedback with comments such as:

Int: “...tell me about the feedback...”  S7: “The feedback was more keep trying, try for yourself, try and see what’s happening.”
Int: “...was that helpful...”  S7: “To some extent ... it took a while for the feedback to finally get back.”
Int: “How did you know when you’d explored enough...”  S7: “When you start repeating yourself...”

S7 indicated that the feedback prompted him to keep trying rather than give him useful guidance; it did not get through to him very quickly; he relied on his own perception of repetition rather than feedback to know when to continue.

These ratings were entered into a summary table (Table 6-2). One interviewee (S5) often gave different responses referring to different times in the learning session. These were recorded as appropriately changing ratings (L → H, H → L, etc.).
Appendix C-9  Flow comments from interviews

These are factors that students mention when asked specifically about flow, and what they were doing at the time they thought they experienced flow. *No indication of strength.*

<table>
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<th>Elements</th>
<th>S1</th>
<th>S2</th>
<th>S3</th>
<th>S4</th>
<th>S5</th>
<th>S6</th>
<th>S7</th>
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<td>✓</td>
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<th>S5</th>
<th>S6</th>
<th>S7</th>
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<th>S3</th>
<th>S4</th>
<th>S5</th>
<th>S6</th>
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<td></td>
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<td>✓</td>
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<td>lots</td>
<td>no</td>
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<td>mention simulation?</td>
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<td>no</td>
<td>no</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>mention features (graphs, questions, etc.)</td>
<td>yes: learn sess’n</td>
<td>yes (Q)</td>
<td>no</td>
<td></td>
<td>yes</td>
<td>yes</td>
<td></td>
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</table>
Appendix C-10  Online survey questions

Questions (grouped by factor). Response key was from “Not at all” to “A lot”.

Control:
(a) I felt in control of what I was doing
(f) I was frustrated by what I was doing  (negatively scored)
(j) I knew the right thing to do

Engagement:
(b) I was absorbed intensely by the activity
(d) I thought about other things  (negatively scored)
(h) I was aware of distractions  (negatively scored)
(k) It required a lot of effort for me to concentrate on the activities (negatively scored)

Enjoyment:
(c) I found the activities enjoyable
(e) I found the activities interesting
(g) the activities bored me  (negatively scored)
(i) the activities excited my curiosity

Calculating aggregate scores:
Control = (a + (6 – f) + j)) / 3
Engagement = (b + (6 – d) + (6 – h) + 6 – k)) / 4
Enjoyment = (c + e + (6 – g) + i))/4
### Appendix C-11  Responses to each online survey question

<table>
<thead>
<tr>
<th>ID</th>
<th>Code</th>
<th>Control</th>
<th>Engagement</th>
<th>Enjoyment</th>
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<td></td>
<td></td>
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**Av:** 3.3 2.5 2.9 3.5 2.6 2.4 2.9 3.6 4.1 1.6 3.8 3.2 3.5 4.0
Appendix C-12 Papers published during candidature

The three papers on the following pages are extracted from the following sources:


(14 pages inc this one)
The Ebb and Flow of Online Learning

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Abstract

Past research has suggested that Csikszentmihalyi’s flow theory describes a state that should be supportive of a student’s learning. This article reports on research that uses the constructs of flow to explore learning in an online environment. An experiment was carried out in which students worked through a learning sequence in the physics domain that had varying degrees of interactivity. Their interactions and flow states were monitored throughout the learning task. The experimental data suggest that flow can be more usefully regarded as a process rather than just an overall state. This process is represented by flow-paths that plot each student’s progress through challenge-skill space. Some flow patterns are identified that relate to the learning outcomes of the students. While there is some conflict between this process representation and outcome measures for flow, this flow-path portrayal has provided fresh insights into students’ interactions in online learning environments.

Keywords: Flow, learning, engagement, computer-based instruction

1 Introduction

One of the challenges of designing online learning tasks is to engage students and keep them engaged through the duration of the task when the rest of the Web is merely a click away. This paper reports on research in which we explored the behaviour of students engaged in such tasks by employing a model of engagement called ‘flow’ (Csikszentmihalyi, 1975). The concept of flow has been used in many different situations as a theoretical model on which to base such understanding. Research in this area often describes the frequency of flow states over an extended period of time (several days) or experiments in which a measure of flow is established after the event by interview or survey.

In the research presented here we have taken a very different approach: we have focussed on the process of flow rather than the state of flow. We have done this in order to understand the complex changes that happen to students during on-line learning. An approach based on the measurement of the overall-state is of little value in an education setting where one might want to understand how students react to learning materials during a session of relatively short duration. We speculate, on the basis of previous research, that during such sessions students will move in and out of flow according to the nature of the materials presented, their interest in them, and their own ability to cope with the tasks. Yet past research pays little attention to this process nor, in particular, to how the measures of flow vary as the task progresses.

We describe a method for representing the frequently changing sequence of states that students exhibit by monitoring their flow states at several times during a challenging on-line learning task. The Web-based task offered guided instruction in physics enhanced with different degrees of interactive multimedia. We explore the measurement of flow by adopting a process view in which a student’s state is monitored throughout the task and contrast it with an aggregate of factors obtained at the end. We are interested in any link between flow and learning as well as any impact the degree of control offered by the software might have on the flow process.

From this analysis we can move away from the ‘how much did you flow’ question and start to address issues relating to the nature of the interactions that encourage flow and how learning outcomes may or
may not be related to them. Through this we can start to appreciate the complex path that students take through a learning exercise as they may ebb in and out of flow states. We can begin to address the vexed issue of designing tasks that maintain students’ engagement in online environments.

The next section describes some models of flow and measurement techniques, including the measurement methods used in this research. Section 3 describes the experiment in which an online learning task was presented to undergraduate students. In Section 4 we analyse the results and present a view of flow based on process rather than an overall state judgement. Section 5 discusses these results and Section 6 presents a conclusion to the paper.

2 Flow models and measurement

2.1 Describing flow

In 1995 Csikszentmihalyi coined the term ‘flow’ to refer to ‘optimal experience’ events (Csikszentmihalyi, 1975). The earliest writings on flow have signalled the expectation that flow is particularly important in an educational setting. More recent research has supported this notion by showing that flow occurred more often during study and schoolwork than other daily activities of Italian teenagers (Massimini & Carli, 1988).

Flow describes a state of complete absorption or engagement in an activity. The term was introduced through the study of people involved in common activities such as rock climbing, dancing, chess, etc. (Csikszentmihalyi, 1975). The concept has been studied in a wide range of endeavours spanning the disciplines of HCI, psychology, information systems and education. For example: Web use and navigation (Chen & Nilan, 1998; Chen, Wigand, & Nilan, 1998; Chen, Wigand, & Nilan, 1999; Pace, 2000); Web marketing (Hoffman & Novak, 1996; Novak, Hoffman, & Yung, 2000); in everyday life (Csikszentmihalyi, 1975, 1997); in group work (Ghani, Supnict, & Rooney, 1991); technology use in information systems (Agarwal & Karahanna, 2000; Artz, 1996); in HCl (Webster, Trevino, & Ryan, 1993); and in instructional design (Chan & Ahern, 1999; Konradt & Sulz, 2001; Kronradt, Filip, & Hoffmann, 2003).

A ‘flow activity’ is one in which the mind becomes effortlessly focussed and engaged on an activity, rather than falling prey to distractions. Flow is not an ‘all-or-nothing’ state, but can be thought of as forming a continuum from no flow to maximum flow. Csikszentmihalyi originally summarised flow experiences as comprising nine elements (Csikszentmihalyi, 1975, 1993). Chen observed that these dimensions can be categorised into three stages: antecedents, experiences and effects (Chen et al., 1999). The antecedents comprise: a clear set of goals; timely and appropriate feedback; and, most importantly, a perception of challenges that are well matched to the person’s skills. The second stage, experience, comprises: a merging of action and awareness; a sense of control over the activity; and concentration. The final stage describes the individual’s inner experience: loss of self-consciousness; time distortion; and a feeling that the activity becomes worth doing for its own sake (‘autotelic’).

The nature of flow is elegantly put by Massimini:

‘The stream of ordinary experiences, ranging from the faintly pleasant to the boring, and the anxious, is made up of a random collection of discordant notes. Occasionally the notes fall into a harmonious chord – when that happens, information in the consciousness is ordered, and we experience flow.’

(Massimini & Carli, 1988).

2.2 Models of flow

2.2.1 Overall-state models

Csikszentmihalyi, in his early work, described flow as ‘the holistic sensation that people feel when they can act with total involvement’ (Csikszentmihalyi, 1975). People were identified as being ‘in flow’ through interviews and questionnaires about specific activities. The interviewers were looking for
evidence of the nine elements of flow mentioned earlier as well as affective attributes indicating a sense of high well-being – an ‘optimal experience’.

The flow state can be represented as a ‘channel’ on a plot of challenge versus skills, separating the states of anxiety and boredom (Figure 1). It is a dynamic quality: if the challenge of a task decreases, it might become boring; if the challenge increases but one’s skills do not improve to meet the challenge, then one might get into a state of anxiety. A learning activity might produce a progression up the flow channel as new skills are learnt and greater challenges are sought on which to exercise those skills (Csikszentmihalyi, 1975).

![Figure 1. Csikszentmihalyi’s original model of flow](image)

The ‘flow channel’ shows flow ranging from low complexity (‘microflow’, at the lower end) to high complexity (‘macroflow’, at the upper end). This model suggests that only the relative balance of challenge and skill is relevant to flow, not the absolute values. That is, an activity could offer very little challenge, yet could still produce flow if the skills of the person are commensurately low. This model has been refined to include four, eight and even sixteen different states, usually still referred to as ‘channels’ (Massimini & Carli, 1988). These are discussed later.

A complementary approach is to construct a model that represents how particular variables affect flow. Ghani et al. used a model defining flow as a 2-dimensional construct of enjoyment and involvement (Ghani et al., 1991). They found that two of the predictors for flow were perceived control and perceived challenge. Trevino and Webster used a 4-dimensional model of control, focus of attention, curiosity and cognitive enjoyment (Trevino & Webster, 1992). Novak et al. derive a simple conceptualisation of flow based on the measurement of skills and challenges alone (Novak, Hoffman, & Yung, 1997).

2.2.2 Limitations to the overall-state approach

Models of flow based on the overall-state approach have demonstrated the importance of control, skill and challenge as significant factors for the study of flow. In contrast we have focused on the process of flow exploring how flow might change across a learning episode and what factors might be associated with those changes. What we have called a process approach assumes that no single measure will adequately describe the emotional changes experienced by a student during the learning task. Ainley has shown that students’ personal characteristics will influence their initial response to a learning task and then the task itself will trigger emotions and specific task goals (Ainley, 2002). Her data indicated that students report changing emotions such as boredom, pleasure, interest, challenge, surprise, confusion and frustration, as the task progresses. Ainley’s research measured students’ emotions at just two times in the learning sequence and showed that some emotions often changed markedly between those times. This suggests that a more fine-grained measurement throughout the task would shed further light on the interaction between the task and the student’s engagement with it.

By regarding flow as a process or succession of states we have been able to explore changes throughout a task and to understand some of the factors associated with those changes.
2.3 Measuring flow

2.3.1 Techniques
Several techniques have been used to measure flow. Csikszentmihalyi’s original study on flow involved people telling the story of a recent experience, then responding to a survey questionnaire relating to the elements of flow. From this the Experience Sampling Method (ESM) was developed in which respondents were electronically paged maybe 8 times a day for a week to prompt them to respond to a questionnaire (Csikszentmihalyi & Larson, 1987; Csikszentmihalyi, Larson, & Prescott, 1977). A digital implementation of the ESM (Chen & Nilan, 1998) has been used to randomly survey users going about everyday Web activities. This involved an online tool that interrupted users during their work, presenting them with a series of questions. Others have investigated flow by providing a structured activity in a laboratory or workplace, then followed it with a survey (Ghani et al., 1991; Webster et al., 1993). Some have used Web-based surveys to gather retrospective information about flow activities on the Web and in the workplace (Novak et al., 2000). From these studies conceptual models have been developed to describe the flow construct.

What appears to be lacking in these studies is a process view of the progression through a particular activity. This is important in the design of online learning activities since one might aim to trigger a flow state to optimise conditions for learning. Yet we know little about how such states change during a learning task nor what conditions influence the change. Without an understanding of this process we cannot use the theory of flow to improve learning exercises. In the research described here we captured data describing the process of working through a specific learning activity. We explored ways of representing a dynamic picture of the perceived challenge and skills during the activity and related these measures to the coarser-grained models of flow such as those of Webster (Webster et al., 1993) and Ghani (Ghani et al., 1991).

2.3.2 Challenge and skills
Amongst the various studies researching flow, an ongoing issue has been to find a method for measuring flow independently from the positive states of consciousness (such as enjoyment, concentration, control, lack of self-consciousness, lack of distraction). One solution has been to use a measure of the balance between the challenge of an activity and the participant’s perception of their skill to carry out that activity. The perception of these challenges and skills has been described as ‘theoretically, the most meaningful reference point for the presence or absence of flow’ (Massimini & Carli, 1988).

Csikszentmihalyi’s early work predicted that flow was a single ‘channel’ separating the two states of anxiety and boredom as shown in Figure 1 (Csikszentmihalyi, 1975). According to this model a challenge-skill ratio of 1:1 should indicate flow. It is now common among researchers to use models with more than 3 channels and to normalise a challenge-skill plot to the individual’s average challenge-skill value over the extended period of the study. Figure 2 shows a four-channel model and Figure 3 an eight-channel model together with the rules that define them. In such models, both challenge and skill should be above the threshold (average value) for flow to take place (Massimini & Carli, 1988).
The original flow model of Figure 1 is not contradicted by these four-channel or eight-channel models. Indeed, in the context of learning activities, it has an important place in that it represents how the process of flow might develop through a single activity. Initially, as a novice, one might have minimal skills and need appropriately low challenges in order to help develop better skills; these “novice” experiences are sometimes referred to as ‘microflow’ (Csikszentmihalyi, 1975). As the skills increase, so must the challenges in order to maintain flow. Hence the model shows the time progression as one continues to learn a new skill or technique and progresses up the flow channel. If the challenges increase too fast, then there is danger of anxiety; if the skills develop quickly and challenges are not increased there is a danger of boredom occurring.

### 2.4 A process measure of flow

#### 2.4.1 Measuring challenge and skill

We used the variables **skill** and **challenge** as primary data for our repeated measures of flow during the learning task. These have been reported to be reliable indicators for measuring flow (Novak & Hoffman, 1997). The process measure was then compared with end-of-task measures based on **control**, **enjoyment** and **engagement**. The various flow models raise an important question in the use of the challenge-skill ratio when studying flow in a short-time educational activity, such as the one-hour learning task used in this research: how does one determine appropriate thresholds of challenge and skill from which to ‘normalise’ the flow diagram? For weeklong experiments that monitor flow throughout the day, an individual’s average is a clearly appropriate choice. It represents the ‘background’ levels for an individual and flow experiences can be expected to rise above such levels. However, there is no such valid measure available for the 60 or 70 minutes that a student might undertake a learning activity. A session-average value of the challenge-skill ratio would make a student who experienced flow through an entire activity look the same as one who was consistently bored.
This study, rather than attempting to attach fine-grained labels to the overall state of an individual’s performance during an activity, takes the approach of describing the progress of the individual in terms of challenges and skills during the activity. Participants worked through a learning task comprising seven activities lasting about one hour in total. At the end of each of the seven activities a probe, using 5-point Likert scale ratings, was presented to record their perceptions of challenge and skill. The probes were positioned one above the other on the screen as shown in Figure 4 to increase the likelihood that participants would use consistent referents for both scales.

![Figure 4. Probe used to measure challenge and skills](image)

Data from these probes were used to map the movement of each student through the 2-dimensional challenge-skills space during their interaction with the activities. This was consistent with Csikszentmihalyi’s model of a learner moving up the flow channel as they progress through a learning exercise.

In categorising students’ flow-states from these challenge-skill measurements, Csikszentmihalyi’s three-channel model of flow was used. This is consistent with his ideas that the flow channel appropriately represents the movement of a learner through an activity. Students were considered to be in flow when their rating of challenge and skill scores were equal on a 5-point Likert scale, to be anxious when challenge was greater than skills, and to be bored when challenge was lower than skills, as represented in Figure 1.

2.4.2 An overall-state measure of flow

An alternative overall-state measure of flow was obtained using an 11-item survey administered at the end of the learning exercise. Ratings of engagement, enjoyment and perceived control using 5-point Likert scales were collected. Previous work has proposed that these indicators can be used to provide an overall impression of flow during learning (Trevino & Webster, 1992). The Appendix lists the 11 survey questions used. Factor analysis was used to identify common factors from these questions. This provided a much coarser-grain view of the user’s state, but a reflective one more in line with Csikszentmihalyi’s original work on flow. More details on these measures are given in Section 4.2.

3 Description of experiment

3.1 Aims

The experiment explored the relationships between flow, perceived control and learning, for a group of students engaged in an online learning task. By ‘perceived control’ we refer to the degree to which students considered themselves to be in control of what they were doing, as opposed to being ‘driven’ by the software. In this paper we focus on the specific approaches to measuring flow in such an online educational setting and make brief references to learning outcomes. A more detailed coverage of issues relating to learning will be addressed elsewhere.

The particular aims of the experiment were:

1. To explore the changing nature of students’ challenge-skill perceptions through an online learning task.
2. To compare flow measured using challenge-skill ratios to flow measured from post-survey data.
3.2 The online learning exercise

The learning exercise involved students working through a sequence of pages presenting physics ideas about velocity and acceleration as shown by the motion of a cart. There were seven activities that began with students observing an animation of a motion and then sketching on paper their prediction of what velocity-time and acceleration-time graphs of the motion would look like. For each of these seven motions the students were presented with a page that guided them to explore the motion and correct, if necessary, their predicted graphs based on what they explored.

One aim of the research was to explore the effect of varying the degree of control that students had over their environment. Hence they were randomly divided into two groups. One group, the simulation group, worked with a true simulation that allowed them to freely manipulate the simulation: drag and release the cart to set it moving; vary the slope of the track; add fans to the cart to produce acceleration; and change the scales of the graphs. The other group, the movie group, worked through the same activities except that the simulation was replaced by three or four video clips that presented animated screen-shots of the simulation showing the cart motions relevant to each particular activity. Participants could play these clips as often as they liked. The movie group was expected to perceive a lower degree of control than the simulation group because they were unable to directly manipulate the simulations.

A screen-shot from the exercise, showing the interactive simulation on the left and instructions on the right, is shown in Figure 5.

![Screen from one of the learning activities.](image)

Figure 5. Screen from one of the learning activities.

Csikszentmihalyi comments on the importance to flow of intrinsic motivation, active learning, and feedback that is informational rather than controlling (Csikszentmihalyi, Rathunde, & Whalen, 1997). The activities presented in this experiment provided intrinsic motivation through presenting an engaging and interesting multimedia object – seeing a cart run along a track, graphs being drawn, movies to watch. Active learning was encouraged through the interactive nature of the activities, namely, some fairly limited Web-page navigation, but more importantly the opportunity to play movies and (for some) interact with the simulation. The feedback provided was informational consisting of velocity and acceleration graphs being drawn dynamically as the cart’s motion progressed. Through the design of this learning exercise we set up an environment that had the potential to deeply engage students in an enjoyable activity, thereby encouraging flow.
3.3 Method

3.3.1 Participants
The participants for the research were 42 first year Information Systems (IS) students and 17 first year Physics students at a leading Australian university. Forty-five percent of the participants were male students and 55 percent female students. All were paid volunteers and spent about one hour working through the set exercise in a computer lab. All the participants had studied physics at some time during the last two years of their secondary schooling; the physics students had also been exposed to the area of physics presented by the experimental materials earlier in the year as part of their university course.

3.3.2 Procedure
Participants were randomly allocated to the simulation group or the movie group as they entered the laboratory session. All instructions were on a Web site that guided them through introductory materials, learning activities and posts-tests. Each participant worked individually. A small group of students was interviewed about their experience immediately after they finished the learning exercise.

3.3.3 Data collection
Figure 6 shows the online information-gathering Web-pages presented to participants before, during and after the learning task. They were first presented with a screen requesting general background information about themselves followed by a pre-test to establish their prior knowledge of this area of physics (19 multiple-choice items). After an introductory screen, they worked through the seven physics learning pages each immediately followed by the challenge-skill probe asking them to rate, on a 5-point Likert scale, how challenging they found the last activity and their perceived skills to meet the challenge. This probe can be seen in the screenshot in Figure 5. Finally, they were presented with a post-survey, which gathered information about affective aspects of their experience (see the Appendix), and a post-test which measured learning gains using the same question items as the pre-test.

![Image of process through the activity]

**Figure 6. Progress through the activity**

Each participants’ movement through the Web pages and their detailed interactions with the simulation were recorded using Web-logs. Together, these logs recorded page navigation, mouse clicks, movies played, actions within the simulation as well as the time spent directly manipulating the simulation (dragging the cart, in this instance).

4 Analysis of experiment

The two sets of analyses reported here relate to the more traditional survey data gathered at the end of the task and the tracking of challenge-skill data throughout the task. The former presents an *overall-state* perceptive on participants’ flow experiences whilst the latter provides a *process* perspective.

4.1 Mapping challenge and skills onto flow space

A question arises in relation to the definition of flow. Should an indication of flow be restricted to a balance of challenge and skill, but only at *high* levels? Or should a balance indicate flow even if the levels
are relatively low? Csikszentmihalyi gives a clue to the answer in his defence of his original 3-channel model compared to a normalised 4-channel model:

(It) is a composite diachronic model illustrating how the flow experience proceeds through time, in a single activity, (original emphasis) from enjoyment of small challenges when a person’s skills are limited, to an ever-complexifying enjoyment of higher challenges requiring increasingly rare skills. (Csikszentmihalyi & Csikszentmihalyi, 1988, p, 261).

We argue that in a learning context it is crucial that a flow model allows for the situation in which a novice with low skills might flow whilst interacting with an appropriate low challenge task. It is thus considered appropriate to use a model that interprets flow as happening whenever challenge and skill are balanced, whether the individual values are high or low. Whether the lower extreme of these values (challenge = 1, skill = 1) should be regarded as flow or apathy is unresolved.

The first step in mapping the challenge and skill ratings was to cross tabulate all seven pairs of responses from each of the 59 participants. The resulting patterns are shown in Table 1, which is arranged to make easy comparison with the quadrants of the challenge-skill plot of Figure 2. Some participants did not complete all ratings. The challenge and skill rating pairs were then classified as indicators of anxiety, flow, or boredom as defined by the 3-channel model of flow (see Figure 7). As indicated in Figure 7, flow accounted for about one-quarter of the 399 recorded experiences. There were also a substantial number of anxiety experiences reported (more than one third).

<table>
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</table>

Figure 7. Frequency of flow experiences

4.2 Results 1: the overall-state perspective on flow

It was expected on the basis of previous research that the eleven items in the end-of-session survey would produce a measure of flow that distinguished factors of control, enjoyment and engagement (see the

Appendices
Appendix for specific items). However, principal components analysis suggested only two factors. There were only two factors with eigen values greater than one and these two factors together accounted for 64.6 percent of the variance. After varimax rotation two of the items did not load clearly on either of these two factors and were dropped (MSA < 0.5). These two items were: (d) ‘I thought about other things’, and (h) ‘I was aware of distractions’. These two items were intended to load with item (b), ‘I was absorbed by the activity’, to produce the engagement factor. The two factors generated by the principal components analysis were labelled ‘enjoyment’, and ‘control’. Reliability analysis gave Cronbach’s alpha of 0.86 for the enjoyment factor and 0.79 for the control factor. The psychometric properties of these factors could not be improved by removing any further items. Scores on the two factors ‘enjoyment’ and ‘control’ were summed to produce a value for flow from the survey items. This score was labelled ‘flow-final’ and represents the overall-state of flow as reported by the participants reflecting on their learning experience. Separate factor scores for both ‘enjoyment’ and ‘control’ factors were also used in the analyses.

The design of the study allowed for testing how the overall-state of flow was related to learning condition, movie or simulation, and to participants’ course of study, Physics or Information Systems. This produced a 2 x 2 design and analysis of variance was used to test whether learning condition and course of study were significantly associated with ‘flow-final’. Similar analyses were performed for the two component factors of ‘enjoyment’ and ‘control’. There were no significant differences in ‘final-flow’ associated with either learning condition or participants’ course of study, and there was no significant interaction between these design variables.

When the separate ‘enjoyment’ and ‘control’ factor scores were analysed significant differences in ‘control’ factor scores were found to be associated with participants’ course of study. The IS group scored a significantly lower standardised mean factor score of -0.19 compared to the Physics group’s mean factor score of 0.46 (F(1,56) = 5.53, p < 0.05). That Physics students would feel more in control was expected given that they were more familiar with the physics domain than were the IS students. It was also expected that the simulation condition participants would report greater perceptions of control than the movie condition participants. Although the mean values of control for these two groups differed in the predicted direction (simulation: 0.12; movie: -0.13) this difference was not statistically significant. There were no significant differences between groups for the enjoyment factor but the average Likert scale score of 3.61 (s.d. 0.75) for these items indicated that participants enjoyed the experience.

### 4.3 Results 2: the process perspective on flow

#### 4.3.1 Flow-paths for individual participants

Data from the seven challenge-skill probes were used to plot each individual’s flow-path through the learning exercise. These plots give a record of how an individual’s flow state changed regardless of the number of channels in the flow model used to label those states.

Plots for two participants are shown in Figures 8 and 9. Each square represents one of the 25 possible states defined by the two five-point Likert scales as represented in Table 1. A filled diamond represents the participant’s challenge-skill perception on the first activity of the learning exercise; a smaller filled circle represents the final activity. Each point has had a small random value added to separate them on the plot. The dotted ‘flow-line’ represents the ideal flow condition of challenge = skill. The hollow circle represents the ‘centre-of-gravity’ of that participant’s plot.

The first plot, Figure 8, shows the challenge-skill path of a participant who performed very well on the exercise in terms of learning outcomes. It shows us that this participant began the exercise with relatively low skills and perceived the first activity to be relatively challenging. By the second activity she found the activity more challenging but also rated her skills as having increased to meet the challenge. The third activity presented less of a challenge and she still perceived her skills as increasing. The final two activities presented more challenge and this participant felt her skills were becoming increasingly less adequate for what the task required.
Some of this plot is consistent with a flow model of learning: the participant’s perceived challenges and skills grew together through the first part of the learning exercise. However, for this participant the final activities were difficult and she ended up in a state of some anxiety.

![Figure 8. Flow path for a ‘learner’](image)

![Figure 9. Flow path for a ‘bored’ student](image)

The second plot, Figure 9, shows the path for a participant who scored a near perfect score on the pre-test but showed a degree of boredom during the process. This participant actually obtained a lower score for his post-test than his pre-test. The plot shows the participant beginning and ending well into the boredom region, with an excursion closer to the flow line for four pages.

Inspecting such plots for the cohort of 59 participants does not show any clear pattern linking these flow-paths to any of the post-survey flow measures. For example, using a flow rating value that is calculated from summing the percentage values of the enjoyment and control factors (flow-final), the participant in Figure 8 had a flow value of 71% and the participant in Figure 9 a value of 57%. Examples can be found of participants who did spend most of their time on the flow line, yet still returned overall flow scores that were relatively low. Similarly some participants who scored highly on this flow measure spent significant time in the anxiety or boredom regions of the flow-plot. It is an interesting feature of these plots generally that participants show considerable movement throughout the challenge-skill space. Rarely does a participant stay in one cell of the space or stay on the flow-line. This suggests that a single flow measure recorded at the end of the session cannot relate well to the overall experience when viewed as a process. In section 4.4 we present a new alternative measure which captures better the flow experiences during the session.

### 4.3.2 Flow paths for groups of students

Two other visualisations have been found useful in helping to interpret these flow patterns. After identifying specific groups of participants, we calculated for them an average group flow-path point for each of the seven activities and displayed these in two ways: (i) plots of average flow paths in challenge-skill space, and (ii) plots of challenges and skills versus activity number (Figures 10 and 11). Both visualisations present the same information, but each offers a slightly different perspective.

Three of the groups of participants we identified for this exercise were groups of ten ‘extreme’ students based on their pre- and post-test scores:

1. ‘Learners’: those who learnt most by changing the greatest number of incorrect answers to correct answers
2. ‘Changers’: those who changed their thinking most, but by changing incorrect answers to different incorrect answers
3. ‘Unlearners’: those who ‘unlearnt’ most by changing correct answers to incorrect answers

A thorough analysis of the educational aspects of these data is not given here, but examining some of the plots gives useful insights to the flow process.
Figure 10 shows the average challenge and skill data for the ten ‘Learners’. Note that both challenge and skills at first rise in a similar fashion, then skills tend to fall away from challenge in the final activities. The same information is presented in as a flow path Figure 11, the participants moving up the path from bottom to top. The first section of these plots presents what one might ideally expect from participants who are engaged in the tasks and finding them well suited to their skills. For three consecutive activity pages their skills improved to match the challenges presented. On the fourth page (p5 on the plots), although they did not report the task as being any more challenging, they rated their skills as being less adequate. This moves them towards the ‘anxiety’ region. From then on the tasks appear to be increasing in challenge and their perceived skills appear to decline. The characteristics of flow that they had in the beginning shift towards anxiety. This is similar to what has consistently been reported in the arousal motivation literature. When arousal is low, increases in arousal are associated with increased performance. However, when arousal reaches the person’s optimal level further increases in arousal are associated with decline in performance.

What caused the change to skill perception on the fourth page? The task on that page introduced a physics situation that many of the participants found confronting, namely, that the cart was moving in one direction while it was accelerating in the opposite direction. This page produced the highest average challenge score for all participants. This physics situation is a counter-intuitive one that often causes physics students difficulty. It appears that it disrupted the movement up the flow line and the participants, on average, moved towards a state of anxiety. We will discuss the effects from this particular page again in the next section.

Figures 12 and 13 show representations of the ten ‘Changers’ – those who changed many answers between pre-test and post-test but were still wrong. This group perceived consistently high challenges and relatively low skills resulting in their flow-path being in the ‘anxiety’ region. Neither the challenge nor skill averages changed by very much. This is echoed by examining their individual flow-paths that shows the majority spending most of their time in the same space on the plot. These participants were clearly challenged beyond their ability. They did not report experiencing increasing challenge nor did they report changes in skill. As a group they had very low pre-test scores and generally performed worse after the exercise than before it. It is likely that they had trouble coping with the exercise and were either confused or guessing when it came to answering the post-test questions.
Figures 14 and 15 represent the ten ‘Unlearners’. When they started they perceived their skills to be higher than the task challenge, a bored pattern. However, as the activities progressed they reported challenge increasing but no change in their skills. At this point their challenge and skills ratio was well balanced. In spite of ending up in what we label the flow region, they changed many of their correct pre-test responses to incorrect in the post-test. Again, their challenge-skill ratings don’t change significantly, unlike that of the ‘Learners’. Their pre-test scores were relatively high, two of them outstanding at 17 and 18 out of 19, respectively. Yet even these highly competent students reduced their score during the post-test. They were slightly bored early on in the activity, and gained no benefit from it.

It is important to note here that these plots are averages for a group of ten participants. Although they show steady behaviour, individuals move around the space significantly. For example, the individual flow paths that contribute to Figure 15 show three participants who spend significant time on the ‘anxiety’ side of the flow-line, even though the group average shows boredom. These are, of course, balanced by other participants spending more time in the boredom area. These average plots are, however, useful in helping identify trends and suggesting hypotheses to be investigated further.

4.4 Quantifying challenge-skill mappings

The challenge-skill plots give a 2-dimensional view of the flow state in contrast to the 1-dimensional view calculated from the analysis of survey data and most published models.

In order to make statistical comparisons between these two measures, we needed to quantify the challenge-skill plots. This was achieved by defining ‘from-flow-distance’ as a measure of how far an individual challenge-skill ratio is from the flow-line (challenge/skill = 1). The resulting from-flow-distance measure has been explored in two ways. Firstly, it was used as an unsigned quantity where a value of 0 represents maximum flow and a value of 1 represents the furthest distance from flow, that is, either maximum anxiety (challenge = 5 and skill = 1), or maximum boredom (challenge = 1 and skill = 5). The second form of from-flow-distance involves using signed values such that maximum anxiety is presented by −1 and maximum boredom by +1. Both representations of from-flow-distance give similar results in the analysis described below. This is due to the fact that much of the data in these plots is from
the IS students who were generally in the anxiety region. The rest of the analyses reported here use the signed from-flow-distance quantity.

The expression for this quantity is derived from the geometry of the 5x5 challenge-skill space and is as follows:

\[
\text{from-flow-distance} = 0.25 \times (\text{skill} - \text{challenge})
\]

A value of from-flow-distance was calculated for each participant for each of their seven activities as well as an average value which was calculated for an individual’s whole experience. The seven individual activity values for each participant were correlated with their overall-state flow value in order to check for evidence of a recency effect influencing this flow value. The flow value we chose to use was the flow-final value so as to help us understand its relation to the whole task. A correlation value was calculated between the from-flow-distance and the final-flow scores for both cohorts of students for each of the seven pages of the exercise; these values are displayed in Figure 16. Correlation values for pages 2, 5, 7 and 8 were above the critical value (r_{crit} = 0.322, p<0.02).

![Figure 16. Correlations of From-flow-dist to flow-final for all students](image)

The graph shows a strong primacy and recency effects on pages 2 and 8 respectively (page 2 contained the first learning activity, page 8 the last activity). This suggests that flow-final (the overall-state) as measured by the survey may be influenced by participants’ experiences on the final page of the task. The spike on page 5 is interesting. This is the confronting task discussed in the last section that caused the ‘learners’ to have difficulty and move out of flow. We suggest that this particular challenging activity had a disproportionate influence on participants’ survey item judgements.

It is interesting to compare this analysis with the definition of flow used by Novak and Hoffman (Novak & Hoffman, 1997). They define a flow-apathy dimension as ‘skill + challenge’ and a boredom-anxiety dimension as ‘skill – challenge’. Hence their boredom-anxiety dimension is equivalent to the signed from-flow-distance defined above and suggests that the correlations in the above analysis actually relate to boredom rather than flow. A check on the distribution of flow-states suggests that this is not the case. Most of the data points are in the anxiety quadrant of the challenge-skill plots, hence the correlations are telling us how far each point is away from anxiety along the line towards flow, but rarely crossing over into the boredom region.

Recalculating these correlations for just those who rate low on the flow-final score (omitting those whose flow-final value is above the mean) gives even stronger correlations. This is the group who show greater anxiety on the boredom-anxiety dimension. That this sub-group has a stronger correlation is consistent with the more anxious participants being the ones who contribute most to the correlation, rather than those few participants in the boredom state. The fact that the signed and unsigned values of flow-final give similar correlations also supports this. A check on using Novak’s flow definition of ‘challenge + skill’ showed no significant correlation between page flow values and the flow-final value. Clearly there are many subtle nuances to these measures that require further investigation.
5 Discussion

For this investigation an online physics learning exercise dealing with issues of velocity and acceleration was presented to Physics and IS students. Two versions of the software were used, a movie simulation and an interactive simulation. All students worked through seven pages of learning activities designed to develop students’ understanding of the physics principles. Two separate measurement techniques were used to record students’ perceptions of the learning exercise in terms of their experience of flow. A survey administered at the end of the learning exercise followed traditional methods of measuring students’ overall-state of flow. The special contribution of this study has been to examine measurement of flow from a process perspective, a sequence of states that potentially might change across the course of any learning exercise. The overall-state of flow measure involves students’ reflective judgements after the learning exercise has been completed. Our new process form of measurement focuses on students’ judgements at different points in the learning sequence. By comparing the flow results generated by each of these measurement forms we have identified important issues that with further investigation will expand our understanding of the role of flow experiences in students’ learning. Two major issues raised by our comparisons of these complementary forms of measurement will be discussed: the consistency of results derived from overall-state and process approaches to the measurement of flow, and individual flow patterns for different learners.

Consistency of overall-state and process measures of flow

The process measure of flow used in the current study involved students’ ratings of their experience seven times during the learning exercise. Following the dominant practice in flow research, we defined flow in terms of balanced challenge and skill ratings. When plotted these ratings frequently indicated balanced challenge-skill ratings. Approximately one-third of all the rating pairs indicated flow. Independently, the responses to the survey questionnaires often indicated high levels of enjoyment and control, also interpreted as an indication that students did experience flow during this learning exercise. Just under one-half of the students reported in the survey that they were unaware of time passing at some stage during the activity.

However, while both forms of measurement point to students experiencing flow, at the individual level, there was no clear link between these two different methods for representing flow. We would like to have seen those students who reported high flow in the survey also having their data corroborated by many points of the challenge-skill plots being located on the flow-line. This was not the case. The flow-paths suggest ‘turbulent flow’ experiences as students progress through the activity, often moving between the three regions of flow, boredom and anxiety. This was true even for students whose post-survey data indicated an extremely high positive level of flow. Clearly these two measures of flow are measuring different aspects of students’ experience.

Although inconsistent with each other, both forms of measurement have the potential for providing insight into students’ learning experiences because their focus is different. There are two considerations to help understand these findings. Firstly, one would not necessarily expect students to flow consistently throughout a learning activity, especially one from outside their discipline area, as was the case for the Information Systems students. Although the activity comprised seven related activities, the activities were sufficiently varied that some might engender a deep fascination and engagement, flow, whilst others might allow attention to wander. The physics teachers’ holy grail of a student flowing throughout a physics learning activity and achieving deep understanding has not been observed in this study!

Secondly, we should consider whether overall-state measures of flow might reflect specific ‘high’ points in a learning exercise rather than being an average across the task. Specific points that may have undue influence on overall flow include the first (primacy effects) and the last activities (recency effects). There was some evidence in the current data that a recency effect may have been operating with the overall flow measure. We used the common technique in measuring flow of asking participants to reflect on their experience and to respond retrospectively to questions about affective aspects of that experience. Our results indicated that such reflection was not a considered average of their experience, but was significantly associated with specific points in the learning activities. The flow-distance measure gave us evidence that recency and possibly primacy effects influenced the students’ responses. We know far more about the operation of primacy and recency effects on recall of information than on recall of affect. There
was also some indication that a change in the difficulty level (challenge) of the activities may have influenced overall flow ratings. On page 5 of the learning activity the challenge-skill flow value correlated with the overall flow value. The particular physics concepts on this page might explain why students found this page challenging, but more significant is that it appeared to influence their final flow value. This suggests that retrospective measures of flow may also be influenced by one particular activity, a ‘challenging event’ effect, even though several others activities may not encourage flow. Further research is required here to help understand the meaning of an overall reflective judgement of flow and its relationship with experiences localised within the learning task.

The apparent operation of a recency effect, a primacy effect, or even the effect of a particularly distinctive activity within a learning exercise is an important result for those measuring flow in an HCI context. If flow is a useful concept to assist with the design and evaluation of a task, be it a learning task or a general computing task, then the granularity of the flow measurement is an important criterion to consider. Too fine a granularity may interrupt the flow state itself, whilst too coarse a granularity may be heavily biased by the most recent experience or by a particularly challenging one.

Finally, we agree with Ellis et al. that the label ‘boredom’ is not a good descriptor for the high-skill/low-challenge state, as boredom is not usually regarded as a pleasant experience (Ellis, Voelkl, & Morris, 1994). Students showed no negative reactions to the experience and generally showed positive enjoyment, in both formal and informal feedback.

**Different flow patterns for different learners**

By categorising students by their different learning outcomes we identified different patterns of flow behaviour. From the plots of the ‘learners’, we saw evidence of learning progressing in the manner postulated by Csikszentmihalyi (Csikszentmihalyi & Csikszentmihalyi, 1988) and a clear difference in the plots of the other groups. The plots of the ‘learners’ helped identify a point in the learning materials (page 5) where most students experienced a higher level of difficulty than was in keeping with the activities of the previous pages. Better tailoring of the activities to a reasonable development in the students’ understanding of the concepts being taught should maximize the likelihood that students such as the ‘learners’ group will remain ‘in flow’. Situations like this are likely to be the point at which many students ‘breakdown’ and either fail to benefit further from the activities or look to their browser button to head off to another Web site altogether.

Other groups of students showed no such progression in their flow behaviour and no beneficial learning from the whole exercise. The flow patterns here helped identify students for whom this particular task was not well suited at all. They either maintained a state of mismatch between challenges and skills and hence made no progress in learning physics, or they progressed from a bored state to one closer to flow, but regressed in their post-test scores.

These flow patterns highlight that the relation between flow and learning is not a simple one. But then the nature of learning is not a simple process. If we broaden our meaning of ‘learning’ to include knowledge beyond the desired physics outcomes of the activity, then the instances of flow identified in this paper might relate to incidental moments of learning. This type of learning would not show up in our tests but might include skills such as: new vocabulary, relating cart motions to graphs, impact of changing graph scales, etc. From the perspective of constructivist learning, some learning is likely to be taking place whenever students are in a state of engagement with appropriately balanced challenges and skills.

**Limitations**

A significant difficulty in measuring flow using challenge-skill ratios is to have some knowledge of the referent for the ratings made by each student. Do they use the same standards in judging challenge as when judging skill? The issue is one of the reliability of measurement. Do students use the same rating scales consistently across measurement points? More analysis of this type of design based on a sequence of individual ratings is needed before we can be confident of our measurement. In other settings an alternative approach is to use the average from all students so that each student is effectively compared to every other one (Kronradt et al., 2003). However, this is not satisfactory for the measurement of flow since the flow state is very much a personal perception of how challenging the task is and how adequate

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**Appendices**
the learners’ skills are. Particularly in learning environments, the background expertise of each individual can be very different.

Finally, we have used a definition of flow based on challenge and skills being balanced to develop our process measure of flow. Our findings have shown that while yielding some important insights into students’ experience of learning, this is not the same as the over-all state measure of flow. Extensions of this investigation are being planned in order to determine how well this process measure of flow models central aspects of students’ experiences within learning.

6 Conclusion

By recording challenge and skill ratings throughout a learning task we have gained some useful insights into students’ experience during the task. These reports were compared with perceptions reported after the task was complete. These measures were both designed to be indicators of flow and appear to be complementary approaches although both could be refined further. The notion of flow has been shown to be useful for analysing students’ responses to an online learning exercise in undergraduate physics. As measured in this study, flow was not higher with either the movie or the interactive simulation group. Further research identifying student responses to these forms of simulation may shed more light on the relationship between specific interactive design features and the promotion of flow in student learning.

In this research we have demonstrated how challenge-skill flow-paths provide a valuable way of exploring the flow process. We have explored some of these paths and gained insight into the different patterns of learner behaviour they represent. We draw the following three conclusions:

flow can be usefully regarded as a process rather than simply as a destination;
there are both consistencies and inconsistencies between process and outcome measures of flow;
the flow-path representation is a valuable tool in the analysis of the flow process.

Representing a student’s progression through a learning activity by a single value loses much of the rich information about the variable experiences within a learning session. Examining the paths that students take through the challenge-skill space gives us an exciting new view on their interactions and as a future research tool will help to improve our understanding of online learning environments.

7 Acknowledgements

The authors wish to thank Stephen Ainley and Connor Graham for their help with some of the technical aspects of this project.
Appendix

Survey questions used to measure control, interest and enjoyment

(a) I felt in control of what I was doing
(b) I was absorbed intensely by the activity
(c) I found the activities enjoyable
(d) I thought about other things
(e) I found the activities interesting
(f) I was frustrated by what I was doing
(g) the activities bored me
(h) I was aware of distractions
(i) the activities excited my curiosity
(j) I knew the right thing to do
(k) It required a lot of effort for me to concentrate on the activities.

References


Designing for Flow in a Complex Activity

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Abstract

One component of a user’s interaction with computer systems is commonly referred to as ‘flow’. Flow is an important consideration in interactive system design as it encapsulates some of the affective aspects of human behavior. The majority of current thinking conceptualises flow as a desirable and somewhat enduring emotional state that a user may enter during an activity. Analysis of data from 59 users engaged in an interactive online learning task contradicts this prevailing view. We show firstly that flow, rather than being enduring, is highly changeable during the term of an interaction. This challenges both current theoretical models of flow, and the current research methodology used to study the phenomenon. Secondly, we show that flow arises from an engagement either with the interactive artefact or the task being performed. This is an aspect of flow not well distinguished in other studies. Finally, we present initial analysis that suggests flow can be undesirable in some circumstances – that there may be competition between task and artefact for the attention of the user. In response, we present a ‘process’ view of flow as a counterpoint to the existing ‘state’ based models.

1 Introduction

In studies researching the role of affect in human interaction with computers, the related concepts of flow (Csikszentmihalyi, 1975), motivation and play are frequently explored. These are often grouped as ‘affective factors’ and used to complement the effectiveness, efficiency and satisfaction aspects of user-experience (Bentley, Johnston and Baggo, 2003). In this paper we describe an experiment in which it was found useful to focus on flow as a process rather than a state. In the context of an online interactive learning system, we consider the manifestations of flow, how to measure flow and how to design to maximize it. We present a visualization of flow as a process as well as some of the experiences that users (in this case, students) describe when they have experienced flow in this online learning context.

2 Flow

In 1975 Csikszentmihalyi coined the term ‘flow’ to refer to ‘optimal experience’ events (Csikszentmihalyi, 1975). Flow describes a state of complete absorption or engagement in an activity and has been studied in a wide range of disciplines including HCI, psychology, information systems and education. For example: Web use and navigation (Chen and Nilan, 1998); Web marketing (Novak, Hoffman et al., 2000); in everyday life (Csikszentmihalyi, 1975; 1997); in group work (Ghani, Supnick et al., 1991); technology use in information systems (Agarwal and Karahanna, 2000); in HCI (Webster, Trevino et al., 1993); and in instructional design (Chan and Ahern, 1999; Konrad, Filip et al., 2003). This section gives a brief introduction to flow and the challenges encountered in measuring it.

2.1 Flow and online learning

Flow has been postulated by many as a desirable state to support learning (Csikszentmihalyi, 1975; Webster, Trevino et al., 1993; Draper, 2000; Novak, Hoffman et al., 2000). A ‘flow activity’ is one in which the mind becomes effortlessly focussed and engaged, rather than falling prey to distractions. Such an activity will usually comprise a clear set of goals, timely and appropriate feedback, and, most
importantly, a perception of challenges that are well matched to the user’s skills. As a result, a user might obtain a high degree of control over the activity and experience deep engagement or concentration. The activity will become enjoyable for its own sake and will often lead to a lack of awareness of the passage of time.

Many flow studies use retrospective interviews and surveys to observe participants over extended periods of time: days or weeks rather than minutes or hours. Such studies describe flow as a state attained during a particular activity: for example, when engrossed in a computer game or engaged in aspects of professional work. Draper (Draper, 2000), in contrast, proposes that a user may ‘flick in and out’ of flow from moment to moment. In being critical of Csikszentmihalyi’s model of flow, he draws a distinction between flow during routine actions not requiring mental attention and flow requiring complete mental attention. It is during the latter that he postulates such rapid shifts might occur. Whilst he offers no evidence for these shifts, his postulation suggests that interviews and surveys may be instruments that are too blunt to observe flow in these situations.

In this study we were interested in monitoring flow during a short learning activity (40 minutes) in which deep engagement is essential. Whilst an educator might hope that participants maintain a high level of engagement throughout the entire activity, in reality we expected to see movements in and out of the flow state. Hence we designed an experiment to monitor flow attributes in a more fine-grained fashion and to observe users’ movements amongst the flow states.

This study was carried out in an educational setting where the motives of control, concentration and enjoyment are important. However, many of the attributes of flow are desirable in the design of other computer-based system in which the aim is to engage the user and maintain that engagement.

2.2 Flow models and measurements

The research referenced earlier [1 to 10] presents several different techniques for measuring flow. One commonly-used technique is to survey participants, after an activity, to obtain Likert scale ratings for the affective measures of control, engagement and enjoyment (Ghani, 1991; Webster, Trevino et al., 1993). From these measures a score is derived that represents the overall degree of flow for the duration of the activity. This technique is used in our research as one measure of flow.

An alternative established technique, also used in this research, is to monitor the balance between the user’s perceived challenge of an activity and their perception of their skills to carry out that activity. Flow theory predicts that a user will experience flow if their perception of the challenge of a task is balanced with, or slightly greater than, their perception of their skills to carry out the task. If these are out of balance, then the user may become anxious (challenge much greater than skills) or bored (challenge much less than skills). The perception of these challenges and skills has been described as ‘theoretically, the most meaningful reference point for the presence or absence of flow’ (Massimini and Carli, 1988) and has been established as a reliable measure of flow (Novak and Hoffman, 1997).

Often this representation of flow is presented on a 2-dimensional plot of challenge versus skills. The space on this plot can be partitioned into three, four, eight, or even sixteen ‘channels’, each channel representing an emotional state of the user. We have chosen to interpret our data using the 3-channel model shown in Figure 1 in accordance with Csikszentmihalyi’s early work on flow (Csikszentmihalyi, 1975). This choice was made in recognition of the nature of learning, which offers the potential of flow even though the learner’s skills may begin low and increase significantly during the activity. For example, a learner might begin a task with low skills and recognise that the challenge presented to her is low, yet commensurate with her skills. This low-challenge/low-skills situation could still induce a flow state. As the learning progresses, and the task increases in complexity, we might expect the learner to move up the flow channel to a region in which she is more highly challenged, but still commensurate with her (now improved) skills.
Fig. 1. Three-channel model of flow. We define the region where challenges and skills are balanced as ‘flow’. An imbalance results in a state of ‘anxiety’ or ‘boredom’.

3 An experiment to monitor flow

The experiment described here aimed to identify flow patterns in an interactive online learning context, using two measurement techniques that focused on flow as a process and a state, respectively.

3.1 Experiment

Set-up. An experiment was conducted involving 59 first-year university students who worked through an online learning exercise in the domain area of physics. The exercise included interactive multimedia elements. Students worked in a computer lab comprising about 25 computers. They were first presented with an introductory screen requesting general background information about themselves followed by a pre-test to establish their prior knowledge of this area of physics (19 multiple-choice items). After an introductory screen, they worked through the sequence of seven physics learning pages, each containing explanatory text, a simulation of a cart moving along a track with related motion graphs, and navigation elements. Although each of the learning activities was a discrete Web page, they each used the same interactive simulation and progressed naturally from one to the next. Finally, students were presented with a post-survey, which gathered information about affective aspects of their experience (control, engagement and enjoyment), and a post-test which measured learning gains using the same question items as the pre-test.

In a follow-up study, eight students individually worked through a similar exercise whilst being monitored by video in a usability lab. They were interviewed after the session about their reaction to the various elements of flow that they experienced during the session.

For students in both studies their navigation and interaction with the simulation were recorded by Web server logs for later analysis. In the discussion that follows, any references to statistics or patterns of interaction relate to the initial cohort of 59 students; references to interview data relate to the group of eight interviewed later.

Flow measurement. To obtain a fine-grained measure of flow throughout the exercise, we monitored the students’ challenge and skill perceptions at the end of each of seven learning activities. This was achieved using two 5-point Likert scale items which asked the questions: “How challenging (or stimulating) did you find what you just did?” and “Were your skills appropriate for understanding it?”. Response choices were from “too low” to “too high”. The challenge-skill ratios derived from these data enabled us to categorize students into one of the three states ‘anxiety’, ‘boredom’ or ‘flow’ after each activity in the exercise.

For comparison, we also obtained a singular measure of flow from the post-survey at the end of the exercise. These data were analyzed using two similar models of flow reported by others that involved measures of control, engagement and enjoyment (Ghani, Supnick et al., 1991; Webster, Trevino et al., 1993).
3.2 Analysis

Data from the seven challenge-skill probes were used to plot each individual’s ‘flow path’ through the learning exercise. The plot for one student is shown in Figure 2. Each square of the space represents one of the 25 possible states defined by the two five-point Likert scales measures of challenge and skill. The dotted ‘flow-line’ represents the ideal flow condition of challenge = skill.

![Flow Path Diagram](image-url)

**Fig. 2.** Flow path for a student. The path commences on the ‘flow-line’ at the lower left and progresses initially upwards, in the end representing relatively high challenge but low skills.

This particular plot shows the ‘flow-path’, in challenge-skill space, of a student who performed very well on the exercise in terms of learning outcomes. It tells the story of her progress through the seven activities of the learning task. She began the task with relatively low skills and perceived the first activity to be relatively low challenge (bottom-left of path). The second activity she found more challenging but she also rated her skills as having increased to meet the challenge. The third activity presented less of a challenge and she still perceived her skills as increasing. The final two activities presented more challenge and she felt her skills were becoming increasingly less adequate for the requirements of the task.

This student’s plot has some consistency with a flow model of learning: the student’s perceived challenges and skills grew together through the first part of the learning exercise. However, for her, the final activities were difficult and she completed the activity sequence in a state of some anxiety.

Inspecting such plots for the cohort of 59 students does not show any clear pattern linking these diverse flow-paths to the post-survey flow measures. Students moved frequently between states during the exercise indicating that flow is a more complex concept than can be represented by a singular measure. Rather than relying on a single flow measure, or state, recorded at the end of the session, we need to regard flow as a process that changes throughout the activity. We developed a new visualization of this process in order to obtain a better understanding of what was occurring.

**Flow as a process versus flow as a state.** The experiment provided data on flow both from the students’ reflections at the end of the learning activity, ‘final-flow’, as well as from data gathered throughout the activity. The question arises as to how these two different views of flow are related. The former provided us data on flow as a state, giving us insight into a student’s retrospective view of what happened during the whole activity. A student might indicate an average high or low level of flow throughout the activity, but such a blunt instrument cannot describe the changing states as the activity progresses. Students’ responses might also be biased by specific events that dominated their experience.

The data gathered throughout the activity provided us with a view of the twists and turns that occurred as the students grappled with the (complex) learning tasks. It enabled us to form a finer-grained picture of how the different challenges presented resulted in a perception of increasing skills by students who were coping, or in frustration and anxiety by students who had not yet grasped the necessary concepts. In applying flow theory to learning in this manner we expect to observe such variations as students show their individual learning differences in response to the materials and the concepts they were expected to master. The value of this process view is in the light it sheds on how different students react to different aspects of the activities, and how the activity design needs to recognize these differences and adapt to maintain an optimal challenge-skill balance.

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To make a comparison between these two measures of flow we defined the quantity ‘from-flow-distance’ as a measure of how far an individual’s challenge-skill ratio is from the flow-line (challenge/skill = 1) on the flow-path plot (see Figure 2). The expression for this quantity is derived from the geometry of the 5x5 challenge-skill space of the plot and is as follows:

\[
\text{from-flow-distance} = 0.25 \times (\text{skill} - \text{challenge})
\]

We calculated a value of from-flow-distance for each student for each of their seven activities as well as an average value from their whole experience. We looked for a relationship between the flow recorded during the activity and the flow recorded at the end (‘final-flow’) in three ways. The first way was a visual examination of the flow-path plots looking for patterns of flow-like behavior correlating with final-flow ratings. We detected no discernible patterns that linked measures of flow recorded during the activity with the final reflective value that the students recorded through their questionnaires. Next we explored a statistical correlation between the from-flow-distances and the final-flow values for the cohort of students. This also showed no correlation between these two methods for measuring an overall value of flow.

Finally, we performed a statistical correlation between each student’s seven activities’ from-flow-distances and their final-flow value. In this third analysis we observed an interesting result. This is shown in Figure 3 as a plot of from-flow-distance versus final-flow for each of the seven pages of the exercise. Pages 2, 5, 7 and 8 resulted in correlations above the critical value (\(r_{\text{crit}} = 0.322, p<0.02\)).

The graph shows strong primacy and recency effects on pages 2 and 8 respectively (page 2 contained the first learning activity, page 8 the last activity). This suggests that the final-flow value measured by the survey may be dominated by the students’ interactions on the first or final page of the activity. The spike on page 5 is interesting. The task on that page introduced a physics situation that many of the students found confronting, namely, that the cart was moving in one direction while it was accelerating in the opposite direction. This page also produced the highest average challenge score for all students. The suggestion here is that this particular challenging activity captured the students’ interest in a way that influenced their final affective rating of the task as a whole.

**Fig. 3.** Correlations of from-flow-dist to final-flow for the entire cohort for each page of the exercise.

The interesting outcome from the above analyses is the lack of a clear mapping between the students’ responses during the exercise and their reflections at the end. Even students who indicated strong engagement, enjoyment and control in the final survey did not exhibit consistent flow patterns in their flow-paths. Students experienced a variety of ups and downs in their perceptions of challenges and skills that did not necessarily relate to their final-flow values. This suggests that we should not focus too strongly on a reflective measure of an extended ‘flow experience’ but rather should look at the process through which students pass during the exercise.

We have seen that the flow process can be a convoluted one and reflects the complexity of the interactions that the students undertook. However, due to the poor correlation with post-survey flow measures, this analysis also raised the interesting question of “what is being represented by this process?”. To answer that question we interviewed several students about their experience during the exercise as discussed in the next section.

### 4 Distinguishing task from artefact

The post-interviews with the eight students aimed to explore the various elements that comprised a flow experience. We aimed to gain a richer understanding of how flow manifested itself in this online
learning context as well as how this might relate to learning. In particular, we wanted to gain a better understanding of the challenge-skill plot information provided by the students’ experiences during interaction with the learning environment.

It readily became apparent that a simple challenge-skill measure was not an adequate technique for indicating the complex behavior during a learning session. Many times during the interviews students made clear distinctions between when they were focusing on the task (in this case a learning activity) and when they were focusing on the technological artefact (a screen-based simulation). This distinction between task and artefact has rarely been acknowledged in the flow literature (Finneran and Zhang, 2002; Finneran and Zhang, 2003). It strongly influenced the students’ interpretation of both challenge and skills as their minds moved between one and the other. This was strikingly put by one student:

“the simulation wasn’t challenging but the concept that I got from the simulation was challenging.”

Without knowing what the student’s mind is focussing on at any moment, we cannot know how to interpret the challenge-skill plots in terms of flow.

Similar consideration must be given to how the students described their experience of some of the attributes of flow. For example, control and feedback, both essential elements of flow, were also interpreted as relating to either the task or the artefact. This leads to important considerations of the meaning of such terms when evaluating software involving interactive elements and a complex task.

Feedback is particularly important in an online learning environment. It is ambiguous to simply ask whether feedback is adequate. The feedback from the artefact (a simulation, in this case) might be quite clear: dragging and dropping an object on the screen might give clear feedback as to what had been achieved with the software. However, at the same time, feedback from the task might be quite confusing: the resulting output from the simulation might not assist the user in constructing the desired concepts.

Our conclusion from these experiments is that, whilst the system provided the same feedback to all students, those with better domain knowledge were able to interpret it more effectively than those with poorer knowledge. This is critical information for the design of engaging learning systems: the feedback essential for flow must take into account the individual’s prior learning or domain knowledge. Whilst students could focus their minds on the artefact, or the task, or both, when the concepts were demanding it was the task that tended to dominate this concentration. Feedback is not simply an attribute of the software, but a consequence of the user’s interaction with the system and how well its output fits their mental schema.

5 Implications for design

Others have written about considering flow in Web design and the benefits of doing this are becoming more commonly accepted (see, for example, (Novak, Hoffman et al., 1999; King, 2003). The contribution from this research is to consider how the learning gained from understanding flow in an online interactive learning environment can be applied to the design of such an environment.

The general benefits of, and requirements for, flow are quite well understood. However, these are often considered for tasks that are either not well specified (e.g. ’using the Web’) or are rather simple and confined (e.g. selecting a product from a list in an on-line shopping site). When the task itself is complex and the artefact also has a degree of complexity, then we may observe competition between task and artefact for the attention of the user.

The consequence of this is particularly important in designing for an appropriate level of challenge that will be perceived by the user. The challenges will vary from user to user but they should lead the user to focus on the task, not the artefact. This means that the artefact (Web page, simulation, etc.) must be sufficiently engaging without becoming a distraction to the user’s attention. It should be transparent and allow the user to focus on the higher order task. This is hard to achieve since it relies on some knowledge of the user’s skills both with the artefact and within the domain of the task. These are likely to vary considerably from user to user in a learning environment.

Similarly, the feedback presented to the user from the artefact should not distract the user from engaging with the task. The user needs to experience a sense of ‘direct engagement’ (Hutchins, Hollan et al., 1986) when using the artefact so that challenges from the task can be addressed and explored. Through this the user needs to derive a sense of control over both artefact and task.

To measure how successful one has been in obtaining flow with a user in a learning context, a challenge-skill measure is useful but it needs to be carefully focused on the task. Whereas flow might be experienced by a user focusing on the artefact alone (having a fun time playing with a simulation, but learning little; we call this ‘artefact flow’), our aim is to move the user’s flow into the realm of the task and to engage her there (‘task flow’) and to focus her mind on learning about specific concepts, rather
than merely playing with the software artefact. Flow could have a negative impact if it engages and
distsacts a student away from the learning task. Given the intrinsic enjoyment offered by many online
activities, and the difficulty of many learning tasks, this can be a real danger.

6 Conclusion

Flow is an important consideration in designing for the Web in many contexts. The learning context
presents challenges in terms of producing highly motivational materials in order to encourage students to
use them and learn from them. In the research reported here we took a fine-grained approach to observing
flow by monitoring challenge and skills throughout an activity and comparing this to other traditional
measures of flow. This comparison suggested that flow is better viewed as a process rather than a state.

For flow to be a useful measure in this context, we need to ensure that we distinguish between
measurements of ‘task flow’ and ‘artefact flow’. Whilst the former has potential to enhance learning, the
latter may actually distract the student from engaging with the concepts being presented.

The research prompts further questions about the relationship between flow and learning and the
nature of an interactive environment that might encourage flow. These issues are currently being
addressed by the researchers.

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End of Thesis
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Title:
An investigation of interactivity and flow: student behaviour during online instruction

Date:
2004-12

Citation:

Publication Status:
Unpublished

Persistent Link:
http://hdl.handle.net/11343/38923

File Description:
An investigation of interactivity and flow: student behaviour during online instruction

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