Misconceptions as a trigger for enhancing student learning in higher education

A HANDBOOK FOR EDUCATORS
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MISCONCEPTIONS AS A TRIGGER FOR ENHANCING STUDENT LEARNING IN HIGHER EDUCATION

A HANDBOOK FOR EDUCATORS

Introduction

Misconceptions are naïve understandings held by students that conflict with currently accepted concepts and empirical findings. They pose a significant challenge for university educators, particularly in STEM (Science, Technology, Engineering and Mathematics) because they are often strongly held and resistant to correction. This is particularly the case in large class teaching where students’ misconceptions are more likely to be missed, or where it can be difficult to help individual students achieve conceptual change through higher order thinking activities. Large class teaching is standard in many STEM courses in universities worldwide. Providing personalised interventions to help students overcome misconceptions in this context is therefore a difficult challenge.

This handbook presents practical information for university educators looking to confront and correct misconceptions held by their students. It first introduces misconceptions and explains why they are a problem, and then defines misconceptions outlining what they are, where they come from, the different kinds of misconceptions students hold, and how they relate to the concepts of prior-knowledge, confidence, and self-regulation. The handbook examines the approaches and tools that have been used to identify misconceptions and considers the stages and conditions required for conceptual change. Finally, a number of established strategies commonly used to correct misconceptions are described. This includes seven case studies across different STEM fields in which misconceptions have been successfully detected and corrected. Although the misconceptions presented here are from STEM subjects, the strategies described may also be useful in other fields.

The problem of misconceptions

It is inevitable that students enter higher education with preconceived beliefs about how the world works. Often these preconceptions align with the theories and concepts to be learned in a course and do not pose a block to further understanding. Accurate preconceptions are known as anchoring conceptions and can enhance a student’s learning by acting as anchor points for new information, providing a scaffold around which to develop higher level conceptual knowledge. However, when a student’s preconceptions conflict with the accepted core concepts of a discipline they are known as misconceptions, and these can result in systematic patterns of error. Misconceptions can impede the learning of new knowledge and are often difficult to identify, strongly held, and highly resistant to correction through standard instruction. This is particularly the case in disciplines where students have extensive experience with the phenomena of study in their everyday lives, such as in physics or psychology.
While misconceptions can be significant roadblocks, they can also present opportunities to enhance learning. When a student is confronted with an inconsistency between what they think is true and what is correct, the discrepancy may generate surprise or confusion. If the student is then properly supported, these emotions can be leveraged for greater engagement and intentional learning, which in turn can result in more successful and persistent understanding. It is important that educators work with their students to identify, acknowledge and correct commonly held misconceptions, to achieve the best learning outcomes.

To ensure that students successfully attain a strong understanding of the core concepts of a discipline, it is important that any previously held misconceptions are identified, critically evaluated, revised, and replaced with information that is consistent with the accepted concepts of that discipline. However, it is often easier for students to reject or consolidate new information in favour of easier to understand, more intuitive, ‘common-sense’ understandings of the world. In the face of this challenge, educators need to listen to students and work with them to help them breakdown the misconception barrier to conceptual understanding.

References
Numerous terms have been used to describe prior knowledge that is inconsistent with the commonly accepted concepts of a discipline. Some examples are naïve science, personal epistemologies, folk knowledge, and alternative conceptions. However, the term ‘misconceptions’ is most frequently used when describing prior knowledge and beliefs that conflict with, and can impede the learning of, the core concepts of a discipline.

Conceptual learning can occur under at least two conditions. In one condition, a student may have some accurate prior knowledge of a concept, but their understanding of the whole concept to be learned is incomplete. In this case, learning is a process of filling in the gaps in their understanding with accurate knowledge. In the second condition, a student possesses prior knowledge that conflicts with the concept to be learned. In this case, learning is a process of evaluating, revising and replacing the incorrect prior knowledge with ideas that are consistent with the concept to be learned. In this second condition, the inaccurate prior knowledge is a misconception.

Before educators introduce any teaching strategy into the classroom to correct misconceptions, it is important to consider how they arise, and identify the nature of the misconceptions.

**Factual and ontological misconceptions**

Misconceptions are thought to originate in two ways. Factual misconceptions are beliefs about incorrect information that are developed through interaction with the everyday environment. These beliefs can be based on inaccurate information that an individual has encountered in the news, social media, from friends or family, or even the classroom. For example “humans only use 10% of their brains” is a relatively common misconception held by psychology students, which has no empirical basis, but is referenced in movies like *Limitless* (2011) and *Lucy* (2014), and in disreputable articles on social media. Ontological misconceptions, on the other hand, are developed through personal experience. They are naïve or common-sense beliefs that arise through an individual’s subjective experience of trying to understand and explain the world around them, often in the absence of foundational knowledge from a formal education. Many ontological misconceptions are based on anecdotal evidence – an individual’s personal account of an experience. For example, personal observation suggests that the passage of the sun across the sky each day means that the sun orbits the earth. Misconceptions of this type may indicate that a student has a particular pattern of thinking – in this case, a geocentric view of the universe. Knowing how a misconception is formed is an important step in helping students to identify and evaluate their own misconceived knowledge.
Inaccurate and incommensurate misconceptions

Interestingly, some misconceptions appear more resistant to correction than others. Chi argues that misconceived knowledge generally fits into one of two broad categories. Misconceptions can be ‘inaccurate’ or ‘incommensurate’. If a misconception is inaccurate, it is incorrect in comparison to the accepted concept, but is in the same ‘dimension’ or quality. If a misconception is incommensurate, the information relates to a different, incorrect ‘dimension’ or quality. For example, to say that a whale is the same size as a salmon is inaccurate because it is incorrect, but at least it refers to the same quality, that of size. However to say that a whale is a fish like a salmon is incommensurate, because the qualities of the animals (the former a mammal, the latter a fish) are placing them incorrectly in the same basket.

Chi breaks down these two broad categories of misconception into four sub-types. She describes false beliefs and flawed mental models as types of inaccurate misconceptions, and category mistakes and missing schema as types of incommensurate misconceptions. These four sub-types explain how misconceptions relate to our representations of knowledge, from the level of a single idea or statement, to the broad schema by which we categorise and make sense of the world around us. The following descriptions of the sub-types of misconceived knowledge are adapted from Chi’s chapter in The International Handbook of Conceptual Change (2013).

Inaccurate misconceptions

False beliefs

False beliefs refer to a misconception about a single idea, one that can generally be expressed in a sentence. They are inaccurate as they are incorrect, but still in the same ‘dimension’, or referring to the same quality, as the accepted belief. The whale being the same size as a salmon is an example of a false belief. A common biology example would be thinking that the heart is responsible for re-oxygenating red blood cells. It is the lungs that are responsible for re-oxygenating red blood cells, so this is simply inaccurate, as it names the wrong organs.

Flawed mental models

A mental model is made up of several coherent individual beliefs that form an internal representation of a concept or system of concepts. Mental models can be ‘run’ like a simulation to make predictions about the actions, relationships and outcomes of the model and its constituent beliefs. For example, one may have a mental model of ‘the solar system’ made up of mental models representing ‘the planets’, ‘the earth’, and ‘the sun’. Using this mental model, one could make predictions about the movement of the planets, how the planets relate to each other and the sun, and the characteristics of the earth. A flawed mental model has one or more
flawed ideas or assumptions that are internally consistent with one another, such as the ancient Greek geocentric model of the solar system, whereby planetary orbits around the Earth needed to include ‘epicycles’ – smaller circular movements within the planet’s overall path – to account for apparent backwards movements in the sky. Although the explanations are incorrect, they are consistent and predictable. Flawed mental models are inaccurate because the misconceived assumptions of the flawed model contradict the assumptions of the correct model. A flawed mental model will make perfect sense to the person who holds it, and this apparent consistency can make it very difficult to correct.

Incommensurate Misconceptions

Category mistakes

- Categorising is how we organise and identify the world around us. Each category has its own set of rules and behaviours that are exhibited by all the things that are in that category. For instance, anything placed in the category of mammal can be assumed to have the general characteristics of being warm-blooded, giving birth to live young, and having hair on their bodies. This is distinctly different from the category of ‘fish’ which has the general characteristics of being cold-blooded, using gills to breathe, and having scales. However, both ‘fish’ and ‘mammal’ are in the same category of ‘Living things’, which is a distinctly different category from that of ‘Artifacts’, in that a living thing has the characteristics of being able to move independently, being able to reproduce, and being responsive to their environment, whilst artifacts do not. A category mistake occurs when a thing or concept is placed in the wrong category, and thereby inherits the characteristics of that category. Thinking of a whale as a type of fish constitutes a category mistake.

Missing schema

- Category mistakes occur when a student has knowledge of the correct category, but has simply miscategorised the thing or concept. However, if a student hasn’t even conceived of a certain category existing, a miscategorisation can be said be a misconception due to missing schema. Misconceptions caused by a missing schema are particularly tenacious and hard to correct, as not only must you identify that the misconception is due to an idea or concept being in the wrong category, but then you need to familiarise the student with the correct category and its constituent characteristics (schema) before the misconceived information can be correctly integrated.

Definitions of four types of misconceptions, adapted from Chi.5

- **Inaccurate**
  - Existing knowledge or Misconception
  - Relative ease of correction
  - Inconsistent or inconsistent with the concept
  - Difficult to correct

- **Incommensurate**
  - Incommensurate False beliefs
  - Flawed mental models
  - Complex or difficult to correct

- **Category mistakes**
  - Can be complex or straightforward

- **Missing schema**
  - Missing schema must be introduced
The type of misconception determines the best approach to correct it. Correcting false beliefs might be as simple as refuting the inaccurate knowledge; for example telling a student that a whale is much larger than a salmon may correct the false belief. However, a simple refutation, such as telling a student that a whale is a mammal and not a fish relies on the student being familiar with the category of 'mammal' and the characteristics that define it. If they are familiar with the category, simply identifying that a category mistake has been made, and perhaps indicating that a whale breathes through a blowhole and not through gills, could be enough to get the student to reassign their category. However, if the student has a missing schema, due to not knowing the characteristics of a mammal, telling them that a whale is actually a mammal is unlikely to result in any meaningful conceptual change. An intervention must therefore ensure that the correct categorical knowledge (schema) and appropriate conceptual understanding is in place before attempting to correct the misconception.

While many educators will be aware of the common misconceptions held by the students in their course, it is helpful to consider the nature of the misconceptions before designing a corrective activity. There are other ways of classifying misconceptions, but this model is a useful guide for deciding how best to correct a misconception encountered in the classroom. Many misconceptions have proven highly resistant to change and this is in part due to interventions not effectively targeting the root of the misconception. In the following section, we will discuss the important steps in supporting conceptual change, and some of the challenges to watch out for.

References


7 www.universetoday.com/36487/difference-between-geocentric-and-heliocentric *(accessed 12/10/17)*
Identifying misconceptions is the first step towards correcting them. Many educators will already have a good idea of what the common misconceptions are in their field. A typical way misconceptions are identified by teachers is through marking open-ended exam questions and other written assessments. Similar errors made by large numbers of students indicate the presence of common misconceptions. Analysing incorrect answers to open-ended questions that require students to demonstrate their thought processes can shed more light on the nature and origin of misconceptions held by students. Concept inventories can also be helpful in detecting students’ misconceived knowledge. Concept inventories usually use a forced-choice (e.g., multiple choice) questionnaire in which the distractors are based on common misconceptions, and are written in the students’ words so that their choices reveal their misconceptions.

There are several additional variations on concept inventories designed to measure the extent to which a student understands a topic. For instance, asking the student how confident they are in their answer after each question can determine if the student is just guessing, is confidently correct, or is highly confident in their incorrect knowledge. Asking follow-up open-ended questions or discussing answers with students can shed additional light on the students’ thought processes and how they reach their conclusions. Concept inventories take a lot of time and effort to develop, as they require iterative testing and interviews with students and experts in the field. However, concept inventories have already been developed for many science disciplines, and are readily available for use.

References


Geocentric cosmology of the solar system by Petrus Apianus from Cosmographia, 1524
3 Correcting misconceptions

Stages and conditions for conceptual change

Once a misconception has been identified and the student made aware, much of the effort for changing the misconception must come from the student themself. However, the student can be supported and guided through this learning process. Conceptual change theory describes the most widely accepted model for supporting the correction of misconceptions. It posits that conceptual learning will only be successful if previously held beliefs and prior knowledge are critically evaluated, revised, and replaced with new, accurate information.

Evaluation process

The first step in correcting a misconception is recognising that there is one in the first place. While this may be easy from the perspective of the person with the correct knowledge, it is imperative that the person holding the misconception notices that they don’t know as much as they think they do. This evaluation process is triggered when teaching is designed to purposefully ‘activate’ prior knowledge, prompting students to access their misconceptions to answer a question or solve a problem. If they are then unsuccessful, it creates a level of cognitive conflict, as the student recognises that their understanding is not sufficient to answer the question.

Certain conditions need to be met to progress through the conceptual change process. To evaluate their prior knowledge a student must have the ability to recognise the inconsistencies between what they know and what is to be learned. They must be dissatisfied with the inconsistency and motivated to improve their understanding. In an education context, these conditions can manifest as surprise and confusion, both of which have been shown to increase engagement and motivation when properly supported. Most of the time, we know what we know and what we don’t know. Therefore, it’s surprising when we receive feedback that does not match our predictions, and surprise makes us pay more attention. This can increase engagement and motivation to change our current level of understanding. There are several ways to activate a misconception, and productively foster surprise and confusion, which will be explored in the next section.

Revision and replacement

If prior conditions have been met, and the student has recognised their lack of understanding, they will be motivated to search for more information to rectify their lack of knowledge. This process must be properly supported and assisted, and the new information given must be intelligible, plausible and useful to the student. Intelligible simply means that the student can make sense of it,
in particular that it doesn’t contradict any other unidentified misconceptions. Plausible means that in addition to understanding what the new information means, they find it to be true or believable. Useful means that the student must be able to employ the new information to solve problems.

How simple this process of revision or replacement is depends on the nature and scope of the misconception. Correcting inaccurate misconceptions may be as simple as refuting the false belief or flawed mental model and presenting the student with the correct answer. Revising or replacing incommensurate misconceptions can be more complicated, as the student must be made aware of the level at which their misconception exists before the correct information can be assimilated, and a new schema may need to be built. Telling a student that a whale is a mammal does not help if the student doesn’t know the defining features of a mammal. This new information would not be intelligible to them as it doesn’t fit within their existing schema. Different types of misconceptions need to be tackled using appropriate strategies that consider the state of the student’s knowledge and the nature of the to-be-learned information. The following section outlines a number of established strategies that have been used to correct different types of misconceptions.

References
This section describes a number of teaching strategies that have been used to correct misconceptions: Refutational approaches; ConcepTest; Analogy; and Socratic dialogue. Each strategy will be briefly explained, and the contexts in which each strategy might best be applied will be considered. An example of each strategy will be presented along with the strengths and weakness of the strategy.

**Refutational approaches (explicit or implicit)**

Also known as the ‘classical approach’ to conceptual change, refutation involves two stages: the misconception is first highlighted to the student, and then refuted with the correct answer. For example, a refutation to the misconception that “the heart is responsible for re-oxygenating red blood cells” may be refuted by first highlighting the misconception – “the heart is not responsible for re-oxygenating red blood cells” – and then providing the correct answer with additional information to support it - “re-oxygenation of red blood cells occurs in the lungs, while the heart pumps blood around the body”. In this case, the student is reminded about the role of the lungs.

Refutation has been used effectively to correct misconceptions through lectures, readings, posters, and multimedia. Lectures in which the lecturer has explicitly identified common misconceptions in their field, before providing new information, have been shown to be more effective at dispelling those misconceptions than standard lectures, which simply present the correct information without first highlighting any misconceptions. Texts that clearly identify and refute the incongruences between common inaccurate beliefs and the correct information have been found to be more effective at correcting misconceptions than standard text book readings. Refutation of misconceptions is most successful when refutational texts are combined with refutational lectures and tutorials.

### Strengths

Refutation is efficient to correct misconceptions that are based on an underlying a false belief in which the misconception is incorrect but in the same dimension as the correct information. False beliefs are often expressible in a single statement or idea. As such, belief revision should be as simple as explaining to the student that their belief is false, and outlining why it is false, before giving them the correct information in an intelligible and plausible way, often in a single statement itself.

### Weaknesses

Some flawed mental models, category mistakes and missing schema cannot be refuted easily. As these misconceptions are more complex in nature, a simple refutation may not be enough to sufficiently correct all parts of a flawed mental model, or provide enough information to appropriately target a category mistake or build a schema. In these cases, refutation may even...
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Contribute to, or reinforce, the misconception. This is known as a ‘backfire effect’. If only part of a flawed mental model is refuted at a time, the student might not acknowledge that there is an incongruence between their mental model and the incoming information. In this instance, they might end up assimilating the new information into their model, which ultimately remains flawed. If the student has made a category mistake, refuting their misconception might not make them aware that they need to shift categories. As such, the new information may not appear intelligible, plausible or useful, and may therefore be rejected by the student. If the student has a missing schema, a refutation may not provide sufficient building of new conceptual understanding before trying to incorporate the new information. Refutational strategies could be limited in that they don’t tend to encourage deeper metaconceptual thinking (thinking about learning) and intentional learning, and so the student might not learn to identify misconceptions in other areas of their learning.

ConcepTest

The ConcepTest was developed by Harvard Physics Professor Eric Mazur to test students’ understanding of concepts using multiple choice questions and peer discussion. ConcepTest presents students with multiple-choice answers to a question about a concept (similar to questions found in a concept inventory), students publically indicate their answer, then pair with another student or group of students and explain and justify how they came to that conclusion. Once all students have had a chance to explain their own answers and hear the explanations of others, they are asked to indicate their answer again. The teacher then presents the students with the correct answer and explains why it is correct. Through this process, the misconception is activated and the student is given a chance to explore their own thinking and be challenged. It is thought that this activity facilitates engagement and motivation, and ensures that the correct answer is learned with the reasoning behind it.

■ Strengths

The ConcepTest develops deeper metaconceptual awareness by encouraging students to explore, defend, and challenge their own understanding, and students may be motivated to use this strategy in other parts of their study. It can be used in lecture or tutorial settings and is often employed in lectures with large class sizes. In particular, the use of peer discussion helps maintain student engagement, and allows students to explore their misconceptions without the intervention of the lecturer, facilitating large group teaching. Discussion can shed further light on the nature of students’ misconceptions and the thinking that got them there.

■ Weaknesses

The options in the multiple choice test may not be sufficiently broad enough to identify all misconceptions. In addition, this mode of teaching is not effective if the percentage of students in the class with the correct understanding is low, as peer discussion may not enable enough students to correct their misconception.

Analogy

Analogy uses students correct preconceptions (anchoring conceptions) to scaffold further learning and combat misconceptions. A classic example of how analogy can be used is illustrated by John Clement. As he explains, a misconception held by many physics students is that a table does not exert an upward force on a book resting on it. However, most physics students will have the anchoring conception that a spring exerts an upward force on a hand pushing on it. To an expert,
the principles acting in both examples are the same. The table exerts an upward force against the book in the same way as the spring exerts upward force on the hand. Using this simple analogy may be sufficient to correct the student’s initial misconception. However, in the case that this is too large a leap to make, ‘bridging analogies’ can be used to make the relationship between the two examples intelligible and plausible. A bridging analogy is one in which an intermediate example, which shares properties with both the anchoring conception and the misconception, is used to more clearly illustrate the link. For example, in this instance the bridging analogy could be a book on a flexible board. This would help convince the student that A is analogous to B, B is analogous to C, therefore A is analogous to C.

- **Strengths**
  As with the ConcepTest, this method encourages deeper metaconceptual thinking by prompting students to consider the differences and similarities between their incongruent misconception and the correct concept. This kind of structured learning is appropriate for revising category mistakes (and with the appropriate lesson plan, missing schema).

- **Weaknesses**
  Not all analogies will work well for each individual. Coming up with appropriate analogies is time consuming and difficult. As all analogies have their limitations, using them may cause students to make assumptions that introduce new misconceptions.

**Socratic method**

As its name would suggest, Socratic method is one of the oldest forms of inquiry-based learning. It focuses on revealing the preconceptions of the student and asking questions designed to prompt the student to challenge their own assumed prior knowledge. It is a four-stage process that involves: first, eliciting preconceptions; second, asking clarifying questions to determine the nature of these preconceptions and prompt the formation of hypotheses or predictions; third, testing these propositions through further questioning, fact-checking, counter-arguments, identifying contradictions etc. which require the student to critically evaluate their preconceptions; and fourth, reassessing their thinking and deciding whether to accept or reject their preconceptions, predictions and any new information.
In a lesson on evolution, the biology teacher asks the students to explain the similarities between humans and apes.

A student proposes that humans and apes are evolutionarily related because humans evolved from apes. The student’s misconception on human evolution is thus elicited.

The teacher asks the student to clarify what is meant by ‘evolutionarily related’ or ‘evolved from’. The student clarifies the claim and posits that apes are the ancestors of modern humans.

To test the student’s proposition, the teacher asks critical questions such as “Does ‘apes evolved into humans’ imply that apes haven’t evolved, even while humans have?”, and “Why would one branch of the evolutionary tree evolve, but not another?” etc.

After testing the proposition, the students can decide whether to accept or reject the original proposition, in addition to modifying beliefs in the face of new information or probing questions.

An example of Socratic Method, Modified from Lam, F. (2011), The Socratic Method as an Approach to Learning and Its Benefits. In: Dietrich College of Humanities and Social Sciences, Carnegie Mellon University Research Showcase @ CMU (pp. 50). Available at: http://repository.cmu.edu/cgi/viewcontent.cgi?article=1126&context=hsshonors

Socratic dialogue has been used effectively in lecture and tutorial settings, as well as in videos that depict an expert questioning a novice about a concept in conjunction with explanatory animations and examples.

- **Strengths**
  It is thought that the discussion can identify preconceptions upon which to anchor further learning. It also reveals the nature of a student’s misconceptions by interrogating their underlying thought process. This process encourages deeper thinking and teaches skills in critical analysis. It can be applied to misconceptions of any type, as the dynamic process of questioning can be used to reveal the underlying assumptions of a misconception, the type of misconception can be determined, and an appropriate response can be constructed.

- **Weaknesses**
  Although it is ideal for one-on-one or small class teaching, it is hard to implement in a large class setting, where there may be many different misconceptions and it is not possible to talk with all students. In addition, it can be difficult and time consuming to design teaching resources that can explore multiple aspects of a concept, in order to deal with all the possible variations of misconception that could occur.
Predict, observe, explain

Simulations

Simulation-based learning environments use a controlled, often simplified, copy of a real world process or system that allows students to interact with the process or system and see the impact of their choices. Simulation-based digital environments that use the classical cognitive conflict approach by immersing students in scenarios that conflict with their misconceptions have been found to be significantly more effective in reducing misconceptions than didactic teaching methods in the area of correlation\(^{21}\), probability\(^{22}\), decimals\(^{23}\), diodes\(^{24}\) and diffusion and osmosis.\(^{25}\) Reductions in misconceptions have been observed in students exposed to simulation-based lab environments in the areas of evolution\(^{26}\) and diffusion and osmosis,\(^{25}\) however control groups (traditional teaching methods) were not used in these studies.

References


Established strategies for correcting misconceptions
5 Case studies

Biomedical science

Tutorial structured around a concept inventory

This case study involved 2nd year undergraduate science students in large class workshops of 150-250 students. This example contains many similarities with the ConcepTest explained above. There are several 1st year chemistry concepts that are both problematic for students, and essential for the students to comprehend Biochemistry. In a workshop, a concept inventory was administered to the students, covering these chemistry concepts. Each question was followed by a confidence question, in which the students could indicate their confidence in their answer. This score was critical for identification of the concepts that the students are confident in and yet are getting wrong: the concepts that are ‘wrong and strong’. In the tutorial, the students were told the percentage who scored wrong in a concept question without revealing the answer, and were asked to discuss it with each other, harnessing the power of peer learning. This process alone made many students rethink their answers and the overall scores increased. Making the students question and justify their answers to their fellow students was enough for many students to reset their understanding and not repeat the same misconception in the exam at the end of semester. The workshop was completed with a lecturer-led group discussion about which was the correct answer and how to understand it.

Biomedical science

The big reveal

This case involved the same class, a 2nd year undergraduate class with large class workshops of 150-250 students. The students were asked to answer a multiple choice question designed to uncover a common misconception in molecular biology, in which students forget that the directionality of DNA is critical to its function. Many of the students chose the incorrect answer. The same question was asked again but now the students were provided with the same question with a more detailed diagram showing both strands of DNA. The students were asked to share their answers with their peers, and animated discussion ensued, including times when visibly animated students grasped their mistake and explained it to their fellow student. Simply discussing the problem with their peers improved their answers, and the workshop was completed with lecturer-led discussion of the answer.
**Bioscience**

**Inventory test**

This project sought to identify misconceptions students might have around general biological concepts when they commence university study, and to measure whether a semester of first year instruction resulted in normalised gains in conceptual understanding. Students in a large first-year biology cohort were invited to participate in the Biology Concept Inventory (BCI), a 30-question multiple choice test. Each student took the BCI twice – once at the beginning of semester, and again at the end of semester. The nature of the study meant that students could not receive feedback on their performance in the pre-test (as this might influence their performance in the post-test), so this first iteration was diagnostic in nature. The results identified several key topics with which students had significant misconceptions; in particular around genetics and molecular interactions. Remarkably, the key misconceptions identified were broadly similar to those seen in students from US and Swiss tertiary institutions, suggesting that they arise in diverse educational contexts. Over the semester, gains in conceptual understanding of these topics were minimal. However, identification of these topic areas has now allowed for changes to curriculum design to address this issue, and to use the findings to highlight misconceptions to students.

**Psychology**

**Applying many concepts to one phenomenon**

This case involved a very large enrolment 1st year subject with a very broad range of students, including both Bachelor of Arts and Bachelor of Science students. In a series of lectures and tutorials the students learned about the complex neurobiology of vision, but there are many common student misconceptions about spatial and colour vision. The students were set an assignment in which they, in their own time, watched a sunset (or sunrise) from full light to full dark, taking notes only on paper and observing the changes in their vision. They wrote a report describing these changes, using the information from the lectures of the neurobiological basis of sight to explain their observations. To account for the highly varied backgrounds and aptitudes of the students, the format of the report could be anything from a laboratory or field report, to a piece of creative writing. The students reported that the task forced them to reconsider their understanding of the way that vision works, in order to describe the way they view the complex phenomenon of a sunset.

**Computing science**

**Trial and error tutorial**

Students in this Masters subject have a wide range of experience with statistics and statistical modelling. They often have the misconception that the best sort of model for data is a complex model. However, a complex model may simply model noise, and not be describing the underlying phenomenon. Students in this class worked in tutorials of 30-35 students, developing statistical models to describe data sets. The students then applied their models to larger data sets to test their models, and many discovered that they had developed models that were too complex and did not successfully apply to the larger data set. They could then go back and develop new models and they discovered that the simpler models were more successful as they modeled the trend and not the noise. This trial and error approach allowed students a safe opportunity to fail at a task, revealing the misconception, and to realise their mistake and try again.
Veterinary Science
Visualising schema

In the Doctor of Veterinary Medicine program, students participated in facilitated small group case studies each week. These sessions involved the sequential release of information about a case which applied the knowledge presented in lectures and practicals that week. During these sessions, students learned to connect their knowledge and build meaningful schema, enabling them to interpret and investigate clinical presentations. As students progressed through the case, they were prompted to discuss and expose their understanding with their peers through the use of open-ended questioning. They were also prompted to create a flow diagram of the case on their whiteboards, connecting the presenting signs of the animal to the underlying anatomical and physiological changes occurring internally. By creating a visualisation of their schema, students and roaming academic staff could quickly identify knowledge gaps and misconceptions. At the end of the case study session, academics presented a wrap-up where they directly addressed the specific aspects of the flow chart/process where students struggled to make connections (or made the wrong connections).

Agricultural science
Performance piece and structured tutorial

In the Bachelor of Agricultural Science students learn about oxidation-reduction reactions in both the light reactions of photosynthesis and during the mitochondrial electron transport chain. Both of these processes cause considerable confusion and misconceptions for students. To help students overcome this, a performance piece was staged by staff members in which the actors each took on the role of a complex or mobile element of the mitochondrial electron transport chain. This allowed students to observe how the components of the chain interact in three dimensions, and to observe the flow of protons and electrons through the chain, a common source of misconceptions. The slightly comic nature of this performance gave students confidence to ask questions about the process that they would not normally ask. This performance piece was complemented by a structured tutorial in which the students were provided with an incomplete set of the membrane components of the two processes. They needed to decide which components belonged to which chain and which components were missing. As they physically moved beads representing protons and electrons through their chains, it became apparent how these chains worked to pass these elements between the different components, and that the light reactions of photosynthesis are different to the processes occurring in mitochondria, a concept these students had previously struggled with.

Lessons from the cases

Although the situations of these cases are quite different there are some key similarities that are interesting to consider. The first is that these learning tasks allowed the students to initially get the problem wrong, revealing their misconceptions. This often generates surprise, causing the student to question their knowledge. This cognitive conflict helps them to dismantle their misconceived knowledge and rebuild it with the new, correct, concept. The second similarity in these cases is that the students were being asked to carry out challenging tasks. In most cases they were required to apply their knowledge to a new situation. Prior to the learning tasks, the average score of the
students on lower level Bloom’s taxonomy questions such as ‘list’ or ‘define’ would have been high. However, the higher level of ‘apply’ reveals the misconception. This highlights that students benefit greatly from opportunities to carry out challenging application level activities in a formative and scaffolded learning environment. Finally, many of these cases harness the power of peer teaching and learning, as students are asked to discuss their answers with their peers and therefore challenge each others’ understanding. This requires students to justify and possibly defend their answer, and this alone causes students to question their understanding.

References
The process of correcting a misconception will rarely be a smooth one. Conceptual change is complex, and in an educational context requires both that students be adept at reflecting on their own knowledge, and that teachers have an intimate knowledge of their class and their subject. On top of this, there are practical difficulties of finding an appropriate intervention or strategy for correcting misconceptions in different learning environments. Detecting misconceptions, and then promoting conceptual change, present different complications depending on the type of class being taught and the number of students. The following section outlines a number of these challenges.

**Synthetic models**

Synthetic models are formed when a student synthesises the new, correct information and their pre-existing misconceptions to create a hybrid mental model, which remains inconsistent with the correct model. This can occur when the student doesn’t notice the incongruity between their flawed prior knowledge and the to-be-learned information. In an example from Chi, consider a student with the misconception that the earth is a flat square. If this is simply refuted with “the earth is round” they may try to synthesise both these ideas, forming a mental model of the earth in which it is a flat disk, or it has rounded edges but is flat on the top and bottom. In both instances, the student’s new mental model maintains its internal consistency in assumptions, but is still flawed in comparison to the correct model.

However, Vosniadou argues that synthetic models aren’t a prohibitive issue in conceptual change, but represent steps in the additive process of learning. Synthetic models can act as intermediary steps between the naïve, misconceived prior knowledge and the scientifically correct concept. For instance, the synthetic model of the earth as round but flat on the top and bottom is arguably closer to the correct model of the earth as a sphere than the initial misconception of the earth as a flat square, and therefore constitutes a step in the right direction. Synthetic models can be recognised by checking in with the internal reasoning of the students throughout their learning process.

**High-confidence misconceptions**

Research has shown that misconceptions held with high confidence are more tenacious and harder to change than those held with low confidence. This may be because it requires more effort to revise or critically evaluate a concept of which you are very sure, than one about which you had initial doubts. Researchers have argued that this is natural, as the process of conceptual change
necessitates a gradual erosion of confidence in the misconception to the point at which the student no longer believes it and is willing to learn the new, correct information. Detecting high-confidence, potentially tenacious, misconceptions can be as simple as asking students how confident they are in their answer. This question can be added after each item in a concept inventory, or given prior to a refutation.

On the other hand, there is some evidence to suggest that some misconceptions held with high confidence are easier to change, and that these changes last longer. This phenomenon is known as the hypercorrection effect. It is thought to occur when a student receives feedback that doesn’t match their initial high confidence prediction, causing them to be more surprised and therefore more attentive to the presentation of the correct answer. For example, most people have experienced the difficulty of learning someone’s name for the first time. Despite being introduced to this person, they forget their name within minutes, sometimes on multiple occasions. However, if you are highly confident that you know someone’s name, call them this name and discover it is wrong, the ensuing embarrassment will ensure you are more likely to remember their name the next time you meet them.

Class-specific challenges

Many misconceptions are formed through a process of lived experiences and exposure to a myriad of different media and people, and so students may have many different misconceptions, or even similar misconceptions formed in very different ways. When attempting to correct misconceptions in a one-on-one setting, this doesn’t present a significant issue, since a learning strategy can be specifically tailored and dynamically changed to detect, evaluate, and revise the misconceptions of an individual student. However, this is not always easy in a university setting. Tailoring a specific intervention to each student based on a thorough process of two-way feedback is impossible in a lecture with 400 students.

Some challenges that arise when attempting to correct misconceptions in large classes are: detecting the common misconceptions; keeping students engaged while attacking various misconceptions; providing immediate, intelligible, plausible, and useable feedback; and measuring the final conceptual change. When designing strategies to correct misconceptions for large classes, these are important challenges to keep in mind. The use of videos, clickers or immediate feedback techniques, and peer discussion have been shown to be effective ways of tackling some of these challenges.

Making use of ‘clickers’, or online polling, in lectures can be a powerful tool for activating common misconceptions, revealing them to students, and providing immediate feedback to avoid creating further misconceptions. This needn’t just involve revealing the correct answer to students. A lecturer could illustrate to their class the predominance of a misconception by displaying the percentage of the cohort who got it correct/incorrect. Knowing, for instance, that 70% of their peers answered a question wrong, but were highly confident about it could make the students surprised and increase their engagement.

To make a large group more manageable, breaking the class into smaller groups or encouraging one-on-one or small group discussion with peers can be a useful strategy. Peer discussion is an important part of ConcepTest and can be used in many different situations. Students are then exposed to different perspectives and are encouraged to challenge, defend, and evaluate their own ideas. Peer discussion is an effective tool for maintaining engagement, and promoting reflective thinking and metacognition.
References
Students enter university with a host of preconceptions and misconceptions about the subjects they will study. It is important to identify and correct these misconceptions from an early stage, as, if they are allowed to persist, they can impede the learning of more complex concepts later in the course or degree.

While lecturers and tutors can prompt and encourage conceptual change through their course design and teaching, correcting misconceptions ultimately relies on the critical thinking and reflective abilities of the students themselves. Many of the strategies set out in this handbook are not only effective at correcting misconceptions, they offer students a chance to learn and practice these metacognitive skills.

Ultimately, by confronting misconceptions, teachers are engaging and including their students in the learning process. By being aware of what their students already know, don’t know and (more importantly perhaps) think they know, a teacher is better able to tailor their course to the needs of their learners. By including the students in the learning process they are encouraged to feel a sense of ownership over their studies, and are given opportunities to monitor and pursue their own learning.

The information in this handbook is designed to give educators ideas about how to design strategies to confront and correct misconceptions held by students. It is hoped that it will provide an entry point for deeper thinking about the nature of knowledge and their own teaching practice. What is accepted as true at any one time is dynamic, and as we learn more and advance our knowledge in all fields, misconceptions are an ever-present danger.
MISCONCEPTIONS AS A TRIGGER FOR ENHANCING STUDENT LEARNING IN HIGHER EDUCATION
A selection of STEM concept inventories and tests

**Astronomy**

**Chemistry**

**Computer science**

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**Appendix**

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**Geoscience concept inventories**


**Life science concept inventories**


Appendix


**Mathematics**


**Physics**

Appendix

Psychology


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