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Student and teacher perceptions of the functions of research in the context of a design-oriented STEM module

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Abstract
Technological design is a core activity in Science, Technology, Engineering and Mathematics (STEM) education. During the design process, students often employ research activities to enhance the quality of their design decisions and to rise above a mere trial-and-error approach to designing. There are many functions of research within the design process, for example theoretical research, user research, or testing a prototype. In this study, we aimed to examine student and teacher perceptions of the functions of research in the context of a design-oriented STEM module in Dutch secondary education. To do so, we first examined in what ways students and teachers who conducted or respectively taught the STEM module recognized functions of research within design. We also looked at the value students attributed to these functions, and how teachers described their facilitation of the functions of research within design. During the STEM module, students conducted a design project related to an authentic problem in biomedical technology, while using research activities to support their design decisions. Results from student focus groups and teacher interviews showed that they recognized several ways in which research activities contribute to a design process. Students valued the functions of research within design as important for the end product, although some students preferred to skip research and start building their design right away. Some teachers employed strategies to ensure students learned to do research steps, for example by a reverse design exercise. The results from this study raise the question whether all students should apply research activities in the same order during a design process, since different students seem to prefer different ways of designing. A design-oriented STEM module like this one is an appropriate way to start showing students the functions of research within design, however differentiation between different students' preferences could possibly enhance this learning process.

Keywords Functions of research within design · STEM · Perceptions · Secondary education · Research · Design · Value · PCK · Students · Teachers

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Introduction

Design activities lie at the core of D&T (Design & Technology) and STEM (Science, Technology, Engineering and Mathematics) education worldwide (NGSS 2013; NRC Framework 2012; ITEA 2007). In STEM education, students often work in teams on an authentic problem related to a professional STEM context, and the teacher mostly acts as a facilitator. The notion that students construct their knowledge and skills in a social and authentic context relates to constructivist learning theory (Savery and Duffy 1996). By solving design problems, which are often complex and ill-structured (Burghardt and Hacker 2004; Hathcock et al. 2015), students develop design thinking skills which function as a knowledge base for interdisciplinary practices, attitudes and knowledge students must pursue, in order to succeed in work and life in the twenty first century (Christensen et al. 2016). However, design activities are often used as an instructional strategy where trial-and-error dominates the process (Burghardt and Hacker 2004). To rise above this trial-and-error approach, it is important to include systematic research activities into the design process, for example to systematically test or analyze a prototype, or to examine the wishes of the target group (Crismond and Adams 2012; De Jong and Van der Voordt 2002). While there are already studies on the pedagogy of design processes (see Crismond and Adams 2012), there is a deficiency of studies that explicitly investigate these functions of research within the design process, and how students and teachers perceive research within design-oriented STEM projects.

Connecting research and design activities is not yet self-evident in education (Kolodner et al. 2003a; Van Breukelen et al. 2016) and does not yet have a well-established epistemology (De Vries 2006; Doyle et al. 2019). As the format of many modern education systems focusses on grading of 'right' or 'wrong' answers, it may be difficult for teachers and students to switch to more open and adaptive approaches of research and design, opposed to traditional, structured projects that have to fit into the requirements of assessment schemes (Bevins and Price 2016; Christensen et al. 2018). Students tend to skip doing research and start working on design ideas immediately, a phenomenon that frequently occurs in beginning designers (Crismond and Adams 2012). However, students need to employ research activities in their design projects, in order to get grip on the ill-structured design problems, and to enhance the quality of their designed solutions (Christensen et al. 2018; Crismond and Adams 2012). Scholars have suggested that students' tendency to treat a design project as a sequence of linear steps, without interference of scientific methods, indicates that they view the design problems as well-defined instead of ill-structured (Christensen et al. 2018). The STEM teachers that are expected to guide students through complex design projects, often have very little experience in combining research and design activities themselves (Love and Wells 2018; Vossen et al. 2019). We do not know which functions of research for design they recognize, nor how they act upon this knowledge in their classrooms. It is also unclear whether students recognize the importance of research in design, since they often skip these steps in design projects.

In this article, we performed a multiple case study aimed to find out how students and teachers perceived research within a design-oriented STEM project. To explore these perceptions, we first examined which functions of research within the design process students and teachers recognized. We also examined in what ways students valued the activity of doing research within design, and how teachers facilitated these activities in the STEM module, according to their own explanations. We interviewed five STEM teachers who taught the design-oriented STEM module 'Technical Design in Biomedical Technology'

(TDBT) and held student focus groups among their four classes at four different secondary schools. In this module, students have to complete exercises in order to get familiar with the design process, and carry out a design project themselves while using research to support their decisions. The TDBT module is taught in the context of the Dutch secondary school subject NLT (nature, life and technology), a STEM oriented and project-based subject. Our study adds to the existing body of literature by adopting a qualitative approach including a students' point-of-view, aimed at discovering their perceptions of the function of research for design and its value to their projects. With this study, we aim to give recommendations on how teachers can facilitate different forms of research within design projects.

Theoretical framework

The technological design process is often depicted in educational textbooks as a variation of a block diagram which "encloses each stage of the process in a block and depicts flow through the stages using arrows, typically double-ended to signify iteration between phases" (Mosborg et al. 2005). Different models have been described in literature (e.g. Kolodner et al. 2003a; Mehalik et al. 2008; Van Dooren et al. 2014), but the design process generally consists of some reciprocal phases: clarifying the problem; assembling a program of requirements; planning the design; constructing a prototype; testing the prototype; optimizing the prototype; analysing the product; and presenting the product to the client or target group (Vossen et al. 2018). During the design process, in which one aims to develop or improve products or services (De Vries 2005), doing research activities is often necessary (Crismond and Adams 2012; Downton 2003; Frankel and Racine 2010; Sanders and Stappers 2008). By research activities, we mean collecting and analysing data, to explore, explain or compare information or certain conditions (Creswell 2008). These activities enhance the quality of the designed product or service by facilitating making informed design decisions (Crismond and Adams 2012 p. 752): "*Research can help designers change their focus or reframe a design problem, enrich their representation of the problem in their minds, clarify relevant underlying principles, as well as uncover clues to potential solutions.*" De Jong and Van der Voordt (2002) suggest that a design process without research can rather be labelled as art than as design. Research within a design project can take many shapes and forms. Frankel and Racine (2010), for example, explain the function of research within design with the term *research for design*: research to enable design, for example to examine material characteristics, to obtain data about users or to test the product for usability, by using qualitative and quantitative methods.

In their review paper, Crismond and Adams (2012) describe a number of functions of research activities in the design process. They state that while research activities are typically done by expert designers early on in the design process to generate concepts and for problem scoping, the need to do research can arise at any moment in the design process. For example, designers need to look up information in order to acquire domain-specific knowledge relevant to their design (Wild et al. 2010). While designing, one also needs to analyze principles that help clarify the design problem, methods of how to construct the design (Kuffner and Ullman 1990), types of materials to use and their costs (Bursic and Atman 1997), legislation and safety issues (Bursic and Atman 1997), and user preferences (Christiaans and Dorst 1992). This last research activity can also be performed by doing role-playing or simulation activities, for example to tape sticks to the fingers to experience the challenges which rheumatism patients face. Designers also analyze products or services that already exist, for the sake of not having to reinvent products (Cross and Cross 1998), or to make a product history report to inform the design process (Crismond and Adams 2012; Frankel and Racine 2010). One can do research about design, to learn from good or failed practices (Crismond and Adams 2012; Frankel and Racine 2010). Lastly, the built prototype can be investigated though analytic troubleshooting, experimenting and testing, and check-ups with the target group (Crismond and Adams 2012). Ideally, these research activities are not only employed once, but revisited as the design process iterates. There is no fixed order in which these activities must take place because the design cycle has multiple varieties, and its nature is iterative rather than linear (see for example Van Dooren et al. 2014).

The importance of doing research for design in the secondary school context has been mentioned by other authors (Apedoe et al. 2008; Kolodner et al. 2003b; Mehalik et al. 2008). Kolodner et al. (2003a, b) visualize this as a back-and-forth interaction between the research and the design cycle, where a 'need to know' indicates a need for research within the design process, and a 'need to do' implies the need to incorporate knowledge gained from research into the design. Burghardt and Hacker (2004) state that informed design requires inquiry, research and analysis activities in order to gain the necessary conceptual or design knowledge. Often in design projects, students are guided to do research preceding the building phase of their design (Burghardt and Hacker 2004). Inquiry is in many cases automatically part of the design cycle that is presented to students. For example, during the framing and analysis of the design problem, students should do research to gather additional information, instead of generating solutions solely based on the problem statement or design brief (Rowland 1992). In the study of Mehalik et al. (2008), students conducted a design project where they had to assemble different electronic components and engage in inquiry and discovery in order to embody their design plans in working devices and improve their performances.

Students need to employ the above-mentioned research activities in their design projects, in order to get grip on the ill-structured problems they are faced with, and to enhance the quality of the designed solution (Christensen et al. 2018; Crismond and Adams 2012). This means that ideally, students initiate activities like clarification of the problem (by looking up information), idea generation (e.g. brainstorming) or research on users and stakeholders (Christensen et al. 2018). However, Hjorth et al. (2015) and Christensen et al. (2016) showed that fewer than 3% of the participating students took this 'designerly stance towards inquiry'. Novice designers like students often start from their first idea and continue to pursue single, finalized solutions (Christensen et al. 2018; Crismond and Adams 2012; Moore et al. 1995). This is called 'idea fixation'. This indicates that the ill-structured nature of design problems is ignored by the students, leading to poor performance in design education (Simmonds 1980; Portillo and Dohr 1989). One of the reasons why students tend to ignore the ill-structured nature of design problems, could be that students do not recognize the functions of research for design. Another reason could be that they are not willing to learn or apply the functions of research in design, because they do not appreciate the value of this way of working. According to Brophy (1987), no effort will be invested in a task if the perceived value or relevance is missing, or if students do not believe they can succeed on the task at hand.

As students do not always conduct research activities during a design project themselves, it is the role of the teacher to guide students through the design process and ensure the design decisions made are of sufficient quality, which can be enhanced by research activities. However, teachers of STEM subjects are usually not experienced designers themselves (Banilower et al. 2013; Vossen et al. 2019). Teaching design can pose problems for teachers, and this can lead to design not being used to maximum pedagogical advantage in the classroom (Burghardt and Hacker 2004). To learn more about the way teachers facilitate the use of research activities for design in a design-oriented STEM module, we need to know what strategies teachers employ (or report on employing) in the classroom. These so-called instructional strategies can be general approaches to describe strategies and their phases, like the design cycle, but also more topic-specific approaches like the use of representations (illustrations, examples, models, or analogies) and activities (demonstrations, simulations, investigations, or experiments; Magnusson et al. 1999). A better understanding of teachers' perceptions of their own teaching, and their knowledge about instructional strategies, can be obtained by evaluating their pedagogical content knowledge (PCK). PCK is described in literature as the amalgam of teachers' professional understanding of content and pedagogy (Shulman 1987). This content-specific knowledge enables teachers to plan for teaching a certain practice to cater for different learning preferences. In our article, we use the construct of PCK in a broad sense, as the 'content' is not topic-specific, but rather practice-specific (Henze et al. 2007) and formed by the functions of research activities within the design process. The teachers were asked about their knowledge of and reasoning behind teaching a design-oriented module, with the particular learning goal to include functions of research within the design process, using particular strategies while catering to their students' needs, which complies with the concept of PCK (Gess-Newsome 2015).

Research questions

In this article, the main research question is: What are students' and teachers' perceptions of the functions of research within a design project? We broke down this question into a research question that focusses on students (RQ1), and one that focusses on teachers (RQ2):

1. In what ways do students recognize and value the functions of research within a design process in the context of a design-oriented STEM module?
2. In what ways do teachers recognize and report on facilitating the functions of research within a design process in the context of a design-oriented STEM module?

Method

In this explorative study, we used a qualitative multiple case study approach, as we investigated students' and teachers' recognition of the functions of research within design by exploring four cases within a bounded system, namely, a teacher and his or her class performing a particular design-oriented STEM module (Creswell 2007).

Context

The context of this study was a design-oriented STEM module within the Dutch STEM subject NLT (nature, life and technology). NLT is a completely project-based subject that works with authentic STEM contexts and is taught as an elective subject in Grades 10–12 in addition to the regular science subjects at approximately 220 secondary schools in The Netherlands. NLT is an interdisciplinary STEM subject, has a strong emphasis on career orientation in science and technology fields, integrates technology and science, and shows how mathematics is used within science and technology topics (SLO 2012). The module

TDBT (technical design in biomedical technology) consists of three parts in which the students (1) get familiar with the design cycle (Fig. 1) through different short exercises and reading material in the project booklet; (2) simulate patients with a physical limitation and create a tool for them by completing all steps of the design cycle; and (3) choose a topic related to biomedical technology for a large design project which they conduct in teams (for an index of the module, see "Appendix A"). Within the larger design projects, students design, for example, a cheap urine test that can be used at medical outposts in developing countries, a chair that can regulate good posture, or a portable dialysis machine. Exercises in part 1 include fast prototyping with basic objects to build a prototype of a product (for example a seed sorting machine, a spider catcher, etc.), getting familiar with user groups, practicing with formulating requirements for the design brief, practising with relating purposes, characteristics and manifestations of ideas in an "idea table", and analysing unfamiliar products. The research activities that the paper version of the module touches upon are: user research, simulation, examining existing products, generation of requirements for the design brief, product analysis and testing the prototype. In The Netherlands, teachers have quite a lot of freedom in their own classrooms when shaping their teaching and teaching materials, though they also have to ensure that student learning meets national requirements. Therefore, we also described for each teacher the different characteristics of the way in which the module was taught (Table 1).

Participants

Five NLT teachers from four different schools participated in this study. We approached several NLT schools of which was known that they were teaching the module 'Technical Design in Biomedical Technology'. Because NLT teachers can choose different modules from a database, not all schools who offer NLT teach the same modules. Three teachers (Joanne, Samuel and Lisa) responded. Teachers Mary and Mitchell voluntarily joined later after Mary was contacted by the first author through the first author's network. Active ethical consent was obtained from all teachers. The students who participated in this study came from the NLT classes of each of the five teachers. For Mary and Mitchell, these students were the same, as they co-taught the NLT module to one class. As NLT is only taught

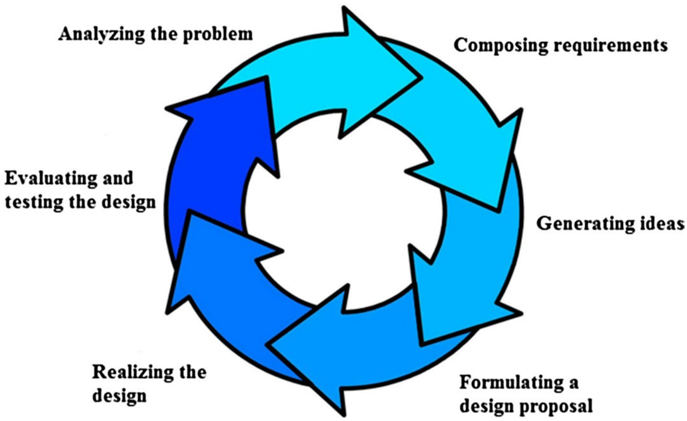

Fig. 1 The design cycle as presented in the TDBT module. Adapted and reprinted from the Dutch course material with permission of the authors

Table 1 Background information on participating teachers and student focus groups

	Joanne	Lisa	Samuel	Mary	Mitchell
Gender	F	F	M	F	M
Age	56	56	60	40	32
Background	University level chemistry. PhD in chemistry. Worked as a research employee for a chemistry company. Teaches chemistry and NLT. Was at the moment of this study also enrolled in a design course for chemistry teachers	University level biology. PhD in biology. Worked as a researcher for an agricultural inspection service. Teaches biology and NLT	Academy of visual arts. Postgraduate academy. Worked as a visual artist and a product designer. Teaches visual arts, history of art, and NLT	University level chemistry. Worked as a project manager at the Dutch Authority for Food Safety. Teaches chemistry and NLT. Was at the moment of this study also employed as a part-time PhD student	General higher teacher education. Teaches physics, mathematics, science and NLT
Teaching experience (total)	23 years	21 years	18 years	11 years	10 years
Teaching experience (NLT)	7 years	10 years	5 years	10 years	7 years
Teaching experience (module TDBT)	6 years	8 years	5 years	2 years	- (this was his first year)
Format of TDBT module	The module was taught for 2 h a week during a period of a quarter of a school year.	The module was adapted to fit the format of a new subject called 'About Research and Design'. Students had 2 h a week during a period of half a school year to complete this module. Extra exercises were added. All hours of the module Lisa co-taught with an art teacher	Instead of 2 h a week, Samuel gave this module 1 h a week during half a school year. He included some extra exercises	The module was taught for 3 h a week during a period of a quarter of a school year. 1 h was taught by Mary, two hours were taught by Mitchell	See Mary
Grade level	10th Grade	10th Grade	10th Grade	11th Grade	See Mary
Nr. of students	9	8	12	12	See Mary

Table 1 (continued)

<table>
<tr><th></th><th>Joanne</th><th>Lisa</th><th>Samuel</th><th>Mary</th><th>Mitchell</th></tr>
<tr><td>Nr. of focusgroups</td><td>3</td><td>3</td><td>4</td><td>4</td><td>See Mary</td></tr>
<tr><td>Nr. of boys | girls</td><td>5 | 4</td><td>1 | 7</td><td>4 | 8</td><td>7 | 5</td><td>See Mary</td></tr>
<tr><td>Ages of students</td><td>15–16</td><td>15–16</td><td>15–17</td><td>16–18</td><td>See Mary</td></tr>
</table>

All teachers, except Mary and Mitchell, taught at different secondary schools situated between Amsterdam and The Hague, in The Netherlands in upper secondary school, the students who participated were either in 10th of 11th Grade. Students were asked to participate voluntarily, and ethical consent was obtained following the guidelines of each different school. Ethical approval was obtained from the Ethics Committee at Leiden University Graduate School of Teaching. More information on each teacher and his or her students can be found in Table 1.

Data collection

Data on how students recognized and valued the function of research within the design process were collected by open to semi-structured focus groups of 3–4 students at the time, just before the end of the TDBT module. This means that at that time, students had already acquired some knowledge about and experience with the design cycle and had nearly/almost finished their design projects (part 3 of the module). For most students, this module was (one of) the first systematic design projects they had done at school. The questions asked in the focus groups can be found in "Appendix B".

Data on teachers' recognition of the function of research within the design process were collected by individual, semi-structured interviews ("Appendix C"). The first interview was held just before the start of the module TDBT, so that the teachers were primed to pay attention to the functions of research within design during the project itself. This interview included an evaluation of one example research module and one example design module, to elicit ways in which teachers saw research as relevant within a design or vice versa. The way in which the teachers had facilitated the TDBT module and their reasoning behind the strategies they used was elicited in a second individual, semi-structured interview at the end of the module ("Appendix C"). Because teachers' knowledge about instructional strategies is connected to other knowledge domains within PCK (Barendsen and Henze 2017; Magnusson et al. 1999), we based the interview questions on four domains of the PCK model of Magnusson et al. (1999): (M1) knowledge of goals and objectives; (M2) knowledge of students; (M3) knowledge of instructional strategies; (M4) knowledge of assessment. All interviews and focus groups were audio recorded and transcribed in verbatim.

Analysis

The transcripts of the student focus groups and the teacher interviews were the main data sources in this study. First, the interviews were read several times to familiarize ourselves with the data. Second, the answers from the teachers and students were summarized according to the questions of the interview protocols ("Appendixs B and C") to uncover main themes. Then, the student focus groups and teacher interviews were coded in Atlas.ti version 7.5.6, using an in vivo coding approach (King 2008). This means that, where possible, we described the data in the wording of the respondents. Below, we further discuss the analyses of the data per research question.

We analyzed the student focus groups for functions of research within design using deductive coding according to the functions of research for design as found in literature, and using inductive coding to add codes that emerged from the data to the code list. "Appendix D" provides a full overview of all the individual codes found related to the functions of research for design. Coding commenced by refining categories, merging similar codes, renaming codes, and regrouping codes under bigger meaningful categories (Popping 1992). During this process, a code category for students' autonomy emerged, relating to statements students made about their freedom to structure their

Table 2 Main code categories per research question

Main code category	Explanation	Research question
Functions[c] *code abbreviation: FUN*	Functions that research activities can have within the design process	RQ1[a], RQ2[b]
Key ideas[c] *code abbreviation: KEY*	Key ideas about the design process, for example that it is an iterative process that can have multiple outcomes	RQ1, RQ2
Relevance/Value[c] *code abbreviation: REL*	Reasons why it is relevant for students to include research within their design project	RQ1, RQ2
Autonomy	The sense of autonomy that students felt to make choices about the design project themselves	RQ1
Behavior	The actual functions of research for design that students mentioned they used during the project	RQ1
Expectancy	The expectancy of students about their ability to complete the project (this was mostly influenced by context factors such as time restriction)	RQ1
Image	The image that students and teachers had about research and/or design	RQ1, RQ2
Knowledge of goals and objectives (M1)	Teachers' knowledge of the goals and objectives of the TDBT module and the learning goal of using research within a design project	RQ2
Knowledge of students (M2)	Teachers' knowledge of student requirements and difficulties for students when learning to use research within a design project	RQ2
Knowledge of instructional strategies (M3)	Teachers' knowledge of instructional strategies to help facilitate the learning goals to their students	RQ2
Knowledge of assessment (M4)	Teachers' knowledge of the dimensions that are important to assess, and assessment methods	RQ2

[a]RQ1: In what ways do students recognize and value the functions of research within a design process in the context of a design-oriented STEM module?

[b]RQ2: In what ways do teachers recognize and report on facilitating the functions of research within a design process in the context of a design-oriented STEM module?

[c]The individual codes belonging to each of these main categories are explained in further detail in "Appendix D"

design project themselves. The main code categories that emerged from the data are listed in Table 2. The first, second and third author agreed upon the merging, renaming or grouping of codes and the coding of difficult text segments (see Table 3). After consensus on the individual codes and the bigger code categories was reached, we performed a cross-case analysis (Miles et al. 1994) using large code tables (an adapted version of such a code table is shown in "Appendix D") and comparative summaries of themes in the interviews and focus groups.

The teacher interviews were analyzed regarding their knowledge about functions of research within design. These codes were derived from the student code list, in order to be able to compare student and teacher data. Some new codes were added as a few functions of research for design were only mentioned by teachers, that is: use research to justify the making of design decisions, use research to systematically compare design ideas, use research to decide what the design should look like esthetically, examine which research or design methods to apply, and test whether the materials used are adequate. The second teacher interview at the end of the module was analyzed according to four domains of the PCK model of Magnusson et al. (1999) to acquire information on the instructional strategies they said to have used in their classroom to facilitate the functions of research within design. Both teacher interviews were coded in Atlas.ti version 7.5.6, again using an in vivo coding approach. Consensus was reached between the first, second and third author on the assignment of the codes to certain interview segments (see Table 3).

Table 3 Coding examples of difficult text segments and the eventual consensus codes

Text segment	Initial code	Final code	Reasoning
"Well, it's handy that when something in your house is broken, you first investigate why it's broken and then design the solution" - Student focus group (Mary, D)	REL? Image_researchfirst	REL_realworld Image_researchfirst	Because the student mentions using research for design is 'handy' if you have to fix something at home, we coded this as relevance of research for design in the 'real' world
"Let's see, you think of a method, that's part of doing research, but maybe also of design. I would say that thinking up those methods is part of the research, in the step of method design […] So the thinking of the methods and the design of the installation enhances each other. There, research and design enhance each other." - Mary, first interview, evaluation of an example project	FUN_RforD? FUN_DforR?	FUN_RforD_method[1] FUN_DforR[2]	Because Mary talks about examining which methods to apply for the design of an installation, she mentions a function of research for design[1]. Also, she mentioned method design as a design step within the research process, therefore acknowledging that design can have a function for research too[2]

The abbreviated codes are explained in "Appendix D"

Results

First, the results are discussed according to the research questions. Subsequently, since students' and teachers' images of research and design appeared to be a recurrent theme, we present more in-depth findings with regards to these images.

Ways in which students recognized and valued the functions of research within a design process

The results show that students who participated in this study recognized a range of functions of research within a design project (main category: Functions). However, *"You have to do research before you want to design something"* without further specification was also mentioned a lot. This statement shows that students did recognize the use of research for design but were not (yet) conscious of the different ways in which this connection manifests itself. Among students, other most mentioned functions of research were 'looking up information', mostly in the form of internet searches, and 'looking up designs that already exist', because students found it relevant to have an original design. It seems like these were the basic research actions during design that were logical to students. Investigating the relevance for the design was also mentioned as important, because "*you can go and design something, but what are you designing if you don't know what it's for, when you don't have a problem?*". Students from all teachers recognized that research was needed to improve existing designs, to examine the user group, to test your design or prototype, and to clarify the problem statement. Other functions of research for design were only mentioned by a few student groups, for example using research to find out how a design works: *"You're going to ask questions: why does it function like this or like that? And if it doesn't work: why is it not functioning?"* (students of Mary + Mitchell); or to examine the location in which the design has to function: *"We did research on the different situations, because we wanted to make a design for in the shower too, so that's important. That the materials are resistant to water."* (students of Samuel). Students also mentioned recognition of some key ideas, for example that iteration is important in design, and that multiple design outcomes are possible (main category: Key ideas). In the focus group interviews, students mentioned more functions of research within design than they mentioned to have actually used during their project (main category: Behavior). Some students stated that they would have wanted to do user research, or test their prototypes, but that there was no time to do so: "*Now you make your prototype, and that's it. In other situations, the project is about the elderly and sick people, so you have to go to those people to see if your design works. But you don't have time for that*." Students of teachers Lisa, Samuel, Mary and Mitchell mentioned this time pressure (main category: Expectancy).

In most focus groups, students mentioned that doing research within the design process was useful and a logical thing to do (main category: Relevance/Value): *"Because we learned it that way, every time we had to do research it was clearly stated. Actually, it's always like that. So it becomes a logical thing to do."* (students of Lisa). Students stated different reasons why doing research within their design projects was relevant: because research improves the quality of the product, because integrating research in the design process reflects real world practices, because research helps to improve existing products, and because research is needed to make sure you do not design something that already exists. Also, the more general statement *"you cannot start designing out of the blue"* was mentioned as a reason of doing research. Some students stated they did research during their design project, not because doing research in itself was relevant, but because it was required in the module booklet or because their teacher told them so: *"The teacher says it, and we have to follow a sequence of steps. […] I mean, we get a lower grade if we don't do so"* (students of Mary + Mitchell). It seemed that some students of Samuel did not see the value of doing research for design: *"I think it's really boring, I would never do it myself. I'd probably skip it and just start designing"*. However, when asked later, even these students also tentatively mentioned that they saw the logic of doing research for their design, and the reason for their aversion towards doing research was uncovered: "*If I could choose for myself, I wouldn't do research. Well, maybe I'd look up what already exists, and how we can make that better. Just for a little. But not eight lessons in a row*". This quotation indicates that these students did not feel they were free to make their own decisions about the design process (main category: Autonomy). Too much time and task regulation by the teacher can thus work aversively on students' autonomy while doing research in their design project. Students of Samuel and Lisa mentioned this lack of autonomy during the module: *"They should give us more time and not say: you have to do it like this. And every time that design cycle, really, every lesson they say at the beginning: don't forget this, don't forget that."* (students of Lisa). Only in the case of Mary and Mitchell, some students mentioned that they experienced too much autonomy: they mentioned that the TDBT project was vague to them, and that they did not get enough explanation of their teachers.

Ways in which teachers recognized and facilitated the functions of research within a design process

Like their students, the teachers mentioned different ways in which research could be embedded in the design process (main category: Functions). The most important difference between the functions that students and teachers mentioned, was that teachers mentioned design choices in general should be justified by research, something that students did not refer to: "… *and you see that they have more moments in which they have to make choices. If you start building, you can go about it at tinkering a little, but it would be better to do that in phases, so that you can justify what you say: we declined that possibility for this or that reason. The justification just becomes less strong when you are only adjusting things by tinkering."* (Joanne). Also, Joanne and Samuel mentioned the use of research to compare different design possibilities to each other, something that was not mentioned by students at all. Lisa was the only teacher who mentioned design could be used for doing research as well, such as designing an experimental setup. Mary also hinted at this option, but much less explicit. It is notable though that only students of teachers Lisa, Mary and Mitchell mentioned this function as well. Also, teachers seemed to mention the function of 'testing' more than students. Some functions were only mentioned by one teacher, for example, 'investigating how a design works' and 'investigating how to make the design' were only mentioned by Samuel. This implies a more practical approach to designing, possibly because of his background as a visual artist and designer. When compared to students, teachers also mentioned a few different reasons why learning to do research within a design project is relevant: because it helps students in other school subjects, because it can lead to deeper learning of related concepts, and because it stimulates students to develop an investigative attitude (main category: Relevance/Value). The statements that teachers made about the different functions of research within design were not necessarily reflected by the statements their students made. For example, Samuel mentioned different key ideas of designing, which none of his students mentioned during the focus groups (main category: Key ideas). All teachers except Mary explicitly mentioned the key idea that design in itself is an iterative process.

We also asked teachers in what way the functions of research within design should be taught or facilitated. Their answers were coded according to four domains of PCK, as described by Magnusson et al. (1999): (M1) knowledge of goals and objectives; (M2) knowledge of students; (M3) knowledge of instructional strategies; (M4) knowledge of assessment. All teachers expressed some learning goals (M1) for their students regarding the function of research within design in the TDBT module. Mitchell was the only teacher who said he did not have this explicit learning goal, however, he did want students to include all parts of the design cycle in their project, research as well as design, in a 'right' way. Samuel had this same learning goal for his students. Lisa wanted her students to include deeper forms of research in the module, however, she found that the research activities in the module were quite limited and not really suited for this learning goal. She included an assignment about serendipity (finding something unexpected and useful while doing research on a totally different topic), to show her students that doing research could lead to unexpected useful findings. She said that students did not spontaneously do research, a sentiment shared by Samuel.

Overall, all teachers mentioned that students had difficulty with examining different design ideas to eventually choose the best solution (M2). They also mentioned that students had the tendency to want to start designing immediately after thinking up their first ideas. Mitchell illustrated both of these issues in his second interview: *"They find it hard to really think about the problem. And then actually what most students immediately do is say: this is the problem, so that is the solution. You could see that from the first design they made. They have trouble making the idea table, and to include all the different tasks and characteristics with different solutions. So they all think: well this is the problem, this is what we thought of, we like this idea, and now we are going to make it. without really thinking about it."* All teachers tried to somehow require their students to think about their designs before they started making them and keep to the steps of the design cycle. All teachers verbally advised students to start the design cycle with certain research activities (M3). This indicates that within teachers, the assumption that research should precede design influenced their teaching strategies. For example, Joanne wanted students to be able to describe the design problem, while Mary found it important that students used literature research before they started designing. Both teachers made requirements in the assessment form to make sure students would not skip these steps (M4). Samuel did not allow his students to continue building their prototype if they had not done research first.

The most important difference between the teachers was that Lisa and Samuel included extra instructional strategies in the module which they inserted themselves, whereas Joanne, Mary and Mitchell kept to the exercises as stated in the module and did not add any extra instructional methods (M3). For example, Lisa included a guest lesson, an assignment on serendipity, a video and poster presentations as an addition to the exercises in the module. Samuel made a website with design guidelines for his students, provided an exercise and a video on creativity, and developed a strategy in which he let students go through the design steps 'in reverse', which connected to his students' preferred way of working. This strategy was positively appraised by his students: "*We did the design steps in the reversed order. So you would make the design first, then you would make the final sketch, then the rough sketches, and only then do research at the end. So we did the same, but reversed. […] This was easier.*" Some students stated that the reverse design exercise had made them see research was important for the design process: "*Yes [I'd prefer to start* *building], but this shows that it's also important to do research first and all.*" Samuel also saw that this approach to the design process was easier for students, because normally they had trouble visualizing and sketching their design. However, the intended learning outcome Samuel envisioned for this reverse design exercise was that students would come to see that 'the real design cycle', in which research always precedes design, was preferable over the reversed strategy. When Samuel saw that later on in the module his students still did not always employ research before starting to build their design, he was disappointed and he became unsure of what to do. He mentioned he would have to structure the module perhaps even more: *"Yes, I reckon this as a disadvantage, I feel forced to structure the module more and more. I think that, if I want the module to work out better, I have to plan the activities per lesson […] and I think that is completely contrary to what designing is."* This would restrict his students' autonomy even further, which could cause students to become more resistant to start their design from research activities, eventually leading to a vicious cycle. Instead of viewing the reverse design exercise as a pedagogical solution for students who preferred a different way of designing, Samuel seemed to view the exercise as a possible weakness in his teaching approach.

In their second interview at the end of the TDBT module, the teachers made some recommendations on which instructional strategies they would employ when teaching the module for a next time (M3). Samuel, Mary and Mitchell mentioned that next time, they would pay more attention to the structure and planning of the module. Lisa said that she found some of the exercises and context of the module outdated, and had some ideas to include other exercises instead, for example, an exercise on divergent thinking or including a Harris profile (table to compare design ideas to design criteria; for an example, see Gardien et al. 2014). Joanne and Mitchell stated that next time, they would give more attention to helping students with defining the design problem and generating and structuring ideas. All teachers stated that it was very important to plan enough time for the bigger design project students had to make during part 3 of the module. They were positive about one of the starting exercises of the module, tinkering through fast prototyping. The teachers said that students were overall quite enthusiastic during this module, because they liked building their designs, the opportunity to work in teams, and the autonomy to choose their own topic for their design projects.

Importance of underlying image of research and design

A recurring issue in this study was that students and teachers appeared to have a strong image that, theoretically, research should preferably always precede design (main category: Image). Contrastingly, both respondent groups also mentioned that in practice, a substantial proportion of students preferred to start designing from their first ideas, while doing no or little precursory research: "*Ideally, we should describe the problem first and look up all the information, doing research, and only then start designing. But we start with the design and do the theoretical part afterwards.*" (students of Mary + Mitchell). Even students who also saw the relevance and possible benefits of starting from research, mentioned that they would personally rather start designing first, because *"It [designing] is more proactive. Now, you're just sitting in a chair. […] It's just another way of working, not fun. It's not nice for children our age to only sit behind the computer and look up stuff."* (students of Samuel).

Remarkable is that students had different images of which parts of their project they were actually designing. Some saw the preparation and thinking phase as the real designing, and not building the prototype: *“[about whether designing includes making the product] Well, not really, I’d say that designing is everything you do before. The plan you make, but carrying out the plan is not really part of designing, it’s something else”* (students of Lisa). However, some students’ image was that the building phase was the actual design activity, and all the preceding steps were not really design, but rather research related or even ‘filling out’ questions: *“For example during the design you have to find all kinds of information first, see what the target group is […] you have to start with a lot of stuff that does not have to do a lot with designing, and then only can you start with the design.”* (students of Joanne). It could be that students who fell into the category of the first example saw good reasons for doing research first, congruent with the general image of how the design cycle should operate, and also naturally started with these steps. The students from the second example would perhaps rather start building the design from their first idea, or at least spend less time on research-related design phases prior to building. Samuel is an interesting example of a teacher who employed a reverse design teaching strategy, thereby tailoring to the wishes of the students who would like to start building, while his primary goal was still to teach his students that the design process should start with research activities.

Discussion

In the discussion, we will comprehensively evaluate our two research questions: (1) In what ways do students recognize and value the functions of research within a design process in the context of a design-oriented STEM module?; and (2) In what ways do teachers recognize and facilitate the functions of research within a design process in the context of a design-oriented STEM module? We discuss student and teacher perceptions in relation to each other, as some of these findings were connected.

This study showed that students, after following a design-oriented STEM module, recognized and were able to name numerous functions of research within a design process. These findings give a more positive image of students’ perception of research within design when compared to research of Christensen et al. (2018), who found that students did not transcend knowledge development on the level of routine expertise and concluded that it was difficult for students to develop a ‘designerly’ stance towards inquiry as a default approach to design problems. In our study, however, we also found that students tended to prefer skipping the design phases of orientation research and idea generation in favour of pursuing to build their first ideas. This is congruent with literature on novice designers (Christensen et al. 2018; Moore et al. 1995). It has been suggested that students seek single, ‘correct’ solutions because they view design problems, that are invariably ill-structured or ‘wicked’ in nature, as well-defined and ‘tame’ problems (Portillo and Dohr 1989). According to Christensen et al. (2018), this is one of the reasons why students do not recognize the importance of a designerly stance towards inquiry. However, in this study, we found that students certainly perceived different ways in which research has a function within design. This raises the question whether students are not *able* to recognize they have to include research steps in their design project, or whether they are not *willing* to.

Students’ willingness to include research activities could be related to their sense of autonomy, a non-anticipated theme that emerged while coding. When students’ autonomy was restricted by the teacher (as was the case with Samuel and Lisa), students became less motivated and mentioned that they did not see the relevance of doing research activities or only did it because the teacher had told them so. Data from our study show that too much time and task regulation by the teacher can work aversively on students' motivation towards doing research in their design project. We know from literature that student motivation is enhanced when their need for autonomy is met (Brophy 2004). However, even students who did not want to do research, mentioned to see the relevance of doing research for design and could also mention different functions. This supports the notion that student motivation can be enhanced by increasing their sense of value or relevance of the activities that they are doing (Brophy 1987). For example, doing research for design was relevant to some students because it was logical to them as it would improve their product, but for some students it was relevant simply because it was required of them by the teachers. Some of these statements on the relevance of doing research for design correspond to levels of external motivation (Guay et al. 2000). The examples above indicate that motivation might thus play a role in students' preparedness to include research activities in their design projects, and further research would need to look further into the influence of different motivational factors.

Other possible reasons why students might not be willing to include research activities in their design projects that were mentioned in this study are the time pressure students experience to complete their tangible designs, and students' enthusiasm and preference to build, instead of first having to work through information processing tasks related to research. Earlier studies indeed show that students with some design experience evaluate design activities as significantly more enjoyable as research activities (Vossen et al. 2018), possibly because they experience that research projects give way to an inordinate amount of report writing (Bevins et al. 2011). The way in which students evaluate research within design projects probably depends on the image they have of doing research. Findings above and from our student data suggest that students generally view doing research as looking up information and writing reports, "passive" activities that most students do not regard as enjoyable. In many STEM professions, however, numerous forms of research within a design process are possible (such as experimentation, target group interviews, testing prototypes, etc.), also depending on the kind of design that needs to be conducted. Further research on students' images of doing research is needed to examine whether they indeed mainly view research as passive information processing activities, whether this influences their willingness or motivation to engage in research activities, and whether some forms of research are evaluated differently than others.

The results of this study indicate two types of images that students might hold about design: (1) some students characterized design by sketching and building and therefore preferred to skip research and start building, while (2) other students instead characterized design by the research and scoping phases and therefore saw the logic of starting from research. Studies on expert designers show that neither of these two options are necessarily wrong approaches to designing. For example, in one study, some advanced designers ranked 'clarification of the problem' and 'communication' as the most important characterizations of design and ranked 'building' low, while some experts have also been found to start from their first ideas, and then adapt the prototype by continuous improvement (Mosborg et al. 2005). These images that students have about the design process, could be related to their preferred way of working or learning. Different students can have different preferred ways of learning, depending on their differing academic readiness, interests about the identified learning goals, and preferred processing modes or conditions (Tomlinson 2001). More research on students' images and preferred ways of learning is needed to determine whether these indeed influence their different approaches to designing.

Teachers in this study, much like their students, recognized a wide variation of functions of research within design that were not necessarily all related to precursory research. Still, all teachers did employ instructional strategies to let their students start the design cycle with research steps. During the second interview, this was a recurring theme across all cases. Previous studies have suggested that teachers, due to little experience in teaching the design process tend to break down the design process to a linear sequence of steps rather than emphasize the adaptive and iterative nature of the design process (Christensen et al. 2018; McLellan and Nicholl 2011). The reduction of complex processes such as the design cycle into a sequence of steps might reduce autonomy-support of students and result in turn in decreased intrinsic motivation (Bevins and Price 2016). This focus on precursory research could also cause students to get stuck on the information gathering phase, a pitfall literature shows that student designers are prone to (Christiaans and Dorst 1992) and which leads to designs of lesser quality (Atman et al. 1999). If students get stuck on the early research phases of the design cycle, the opportunity to engage in other research activities that are typically employed later on in the design process, such as analysing different design solutions or comparing prototypes, is decreased. Indeed, students in this study named some specific functions that are typically employed "early" in the design cycle more often than others, for example, 'looking up information' and 'looking up designs that already exist' and mentioned that they did not have time for testing. Another reason for this behaviour could be that these forms of research are the easiest to do for students, as they require only an internet connection to employ these activities. STEM teachers and project developers should emphasize the importance of employing research activities later in the design cycle, and help students to plan for research activities like testing their prototype, to prevent them from skipping these steps due to time restrictions.

Results from this study also uncover some good practices of instructional strategies for employing research during the design process, which were discussed positively by the teachers and students. For example, user research through simulation was mentioned as a research strategy that was positively evaluated by students and teachers. Also, Samuel employed a reverse design exercise that was positively appraised by his students, because this way of working was easier for them. Literature confirms this notion: some students indeed have difficulty to visualise non-existing products and make better sketches after they have modelled their artefacts first (Anning 1997; Lemons et al. 2010). Crismond and Adams (2012) therefore state that "the standard sketch-then-make sequence might well be reversed" (p. 760). The tendency of students and teachers to reduce the design cycle into a sequence of steps which all students must follow, mismatches the notion that instruction should be differentiated, as not all students have similar needs or preferred ways of learning (Tomlinson 2001). For example, teachers could be flexible in their approach of the design cycle and include active forms of research (simulations, user research, prototype testing) or alternative approaches to the design cycle (like reverse designing) allowing students to start from different steps in the design cycle. Follow-up research on differentiated instruction regarding design pedagogy in practice, related to the development of teachers' pedagogical content knowledge on this issue, is recommended. A limitation of the present study is that it uses teacher interviews and student focus group interviews only. Future studies on students' and teachers' perceptions of research and design could include students' end products and classroom observation in order to further triangulate the data.

Conclusion

This multiple case study has shown that teachers and students in the context of a design-oriented STEM module could recognize and name many different functions of research within the design process. Most students perceived the value of doing research for design, for example, to improve their product or to get a sense of what designing is like in 'the real world'. All teachers verbally emphasized the importance of research for design, and some added assessment requirements or instructional strategies to the module (especially Lisa and Samuel). The finding that both students and teachers have the firm image that research should always precede design, implies that students and teachers need to become familiar with different and more flexible versions of the design process. Including experts from design industry in school projects, or stimulating students and teachers do internships in a STEM industry, may help them to gain experience with alternative design processes. Despite the fact that this study did not aim to evaluate the TDBT module, we have formulated some recommendations for instructional strategies for teachers who wish to implement design-oriented STEM modules. For example, attention should be given to students' perception of value and autonomy during a design project, and teachers should use differentiated instruction regarding the sequence of the design cycle, for example, by employing a reverse or flexible design strategy. We recommend that focused implementation of these instructional strategies is examined in follow-up studies, to assess their influence on student learning and motivation.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval Of all participating teachers, active informed consent was obtained. Ethical approval was obtained from the Ethics Committee at the Leiden University Graduate School of Teaching.

Appendix A

Technical design in biomedical technology

NLT module

Index

Explanation for the students

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1.5 Formulating a design proposal (phase 4) and realizing the design in a prototype (phase 5)
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2. Tools for the elderly and the physically challenged

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Appendix B

Interview protocol of the semi-structured student focus groups.
3–4 students per group, each focus group lasted about 20 min.

Introduction

Thank you for participating in this study about the NLT module TDBT. During this interview, we will discuss your perceptions of the research and design projects that you conduct during the subject NLT. There are no right or wrong answers, just talk about the things that come to mind. These honest answers are the best and would help me tremendously. The answers that you give are confidential; your teacher will not hear about them. Do you have any questions before we start?

Introductory questions (10 min)

1. My study focuses on research and design projects in the classroom. What is doing research, according to you? What does it consist of?

   a. Have you ever done research yourself?
   b. What was that like? What does the research process look like according to you?
   c. In which subject was that? Was it during NLT?
   d. Can you give an example?

2. What is designing, according to you? Can you describe what designing looks like?

a. Have you ever designed something yourself?
b. What was that like? What does the design process look like according to you?
c. In which subject was that? Was it during NLT?
d. Can you give an example?

3. I study the subject NLT. Do you like this subject? What are, according to you, the most important things you learn during NLT?
4. Within NLT, I specifically look at the module TDBT. What kinds of things do you learn during this module?
5. The module is about technical design. Where in this module do you see parts related to designing? Can you point them out?
6. Did you also do research during this module? If yes, in which parts of the module was that? Can you point them out?
7. Are there differences between research and design according to you? If yes, which differences are there?

Questions about the functions of research within design (10 min)

1. Do you think that research and design have something to do with each other within this module? If yes, how so?

   a. Did you apply this during the assignments? If yes, how? If no, why not?
   b. Did your teacher say something about this? If yes, what did he/she say? How does he/she make that clear to you? Did you do something with that knowledge, for example during the project or in your report?

2. Do you recognize in other NLT projects that research and design might have something to do with one another (or is this the first time you experience this connection)? If yes, how? If not, why?
3. Do you think that research and design have something to do with each other in "the real world"? If yes, in which ways do they connect?

   a. Does your teacher talk about this? How does he/she make that clear to you? Did you do something with that knowledge, for example during the project or in your report?
   b. Is it important for you to know something about this?

4. You just said … [function of research within design]. Do you use this idea during this NLT module, in your project or your end report? If yes, how do you do that? If not, how come you don't?
5. Does your teacher make clear to you whether research and design have something to do with each other? If yes, how? Did you do something with that knowledge, for example during the project or in your report?

Thank you for your time and participation.

Appendix C

Interview protocol of the semi-structured teacher interviews.

Each interview lasted about 45–60 min.

Interview 1 (before module)

Introduction

Thank you for participating in this study about the NLT module TDBT. During this first interview, we will discuss your perceptions of research and design, and the connection you possibly recognize between these two activities. There are no right or wrong answers: this is an explorative interview. Before we begin I would like to ask you to read and sign this informed consent form to confirm that you agree that the interviews are recorded and that the data is handled confidentially.

Introductory questions (10 min)

1. During this interview, we will talk about the subject NLT that you teach. What are, according to you, the most important goals of this subject?
2. In this study, I only look at the module TDBT. What are, according to you, the most important goals of this module?
3. Where in this module do you see parts related to designing? Can you point them out?
4. Are there also research-related activities in this module? If yes, in which parts of the module?

Questions about the functions of research within design (10 min)

1. Looking at the specific module of TDBT, are research and design connected according to you? If yes, how are they connected?
2. Are research and design generally connected in the subject NLT?
3. Are research and design connected in professional, real-world practices (outside the school environment) according to you? If yes, in which ways can they be connected?
4. Are there differences between research and design according to you? If yes, which differences to you see?
5. What should students be able to know or do with this connection between research and design? Why is this important for students to know?
6. Do you adopt these ideas about the connection between research and design (and your ideas about the learning goals related to them) in the NLT lessons of this project? If yes, how? If no, why not?
7. How do you view your role as a teachers in making clear to students that research and design have something to do with each other?
8. Do you, as a teacher, make the connection between research and design explicit for your students? If yes, how?

a. In a plenary fashion? During group work?
b. Which instructional strategies do you use for this end? Can you give examples?
c. What are advantages/disadvantages of this instructional strategy?

9. Do you have any experience with design yourself?

a. What was that like? What does the design process look like according to you?
b. Can you give an example?

10. Do you have experience with doing research yourself?

a. What was that like? What does the research process look like according to you?
b. Can you give an example?

Evaluation of example research and design modules

Lastly, I have two examples of STEM modules. Would it be possible, according to you, that in these modules research and design activities can enhance each other? If yes, could you explain how?

1. Example of a research module.
2. Example of a design module.

This was all I wanted to ask. Do you want to make any additions to the answers you gave? Is there something that I did not ask, but that you do think is important to mention?

Thank you for your time and participation.

Interview 2 (end of the module)

Introduction

Thank you for your participation in this study about the NLT module TDBT. During this last interview, we will look back on the module and the pedagogies you used. There are no right or wrong answers. I would like to hear your reflections on the teaching of this module: what went very good, and what went less well. Some questions may seem familiar to you, as they are adaptations of questions I already asked in the first interview.

8. Are research and design connected according to you? If yes, in which ways can they be connected?

a. Do you recognize these ways of connection in the TDBT module?

9. Do you think it is important for students to know something about the connection between research and design? If yes, why is this important?

a. Did this influence your lessons during the TDBT module? If yes, how?

10. What should students be able to know or do with this connection between research and design? Why is this important for students to know? (M1)

    a. Did you give specific attention to these learning goals during the module? If yes, what did you do? (M3)
    b. What do you think that the students have actually learned about the connection between research and design? (M2)

11. How did you make the connection between research and design explicit for your students during the module? (M3)

    a. In a plenary fashion? During group work?
    b. How did students react to this? Were they interested? (M2)

12. What difficulties did you and your students encounter during the module? (M2)

    a. What caused these difficulties? How did you react to them?

13. Did you encounter any difficulties related to the connection between research and design within the design projects? (M2)

    a. What difficulties did you encounter? What caused these difficulties? Can you describe the situation?
    b. Do you intend to deal with this differently should you teach the module again next year? If yes, how?

14. What went really well during the TDBT module?

    a. How come that these things went so well? Can you describe the situation?
    b. Did something go really well regarding the connection between research and design?

15. What instructional strategies did you use during the module? (M3)
16. Did you use any instructional strategies related to the connection between research and design? (M3)

    a. What did that look like in the classroom? What did you do?
    b. What are advantages/disadvantages of this instructional strategy?

17. How did you motivate students for a project in which they had to do both research and design activities? (M3)
18. How did you assess whether the students had reached the learning goals regarding the connection between research and design? (M4)

    a. Why did you choose for this form of assessment? (advantages, disadvantages)
    b. What exactly do you mean by … [portfolio, test, etc.]?

19. Which dos and don'ts would you recommend to a colleague who was also going to teach this module?

20. Are there things you would do differently next time?

This was all I wanted to ask. Do you want to make any additions to the answers you gave? Is there something that I did not ask, but that you do think is important to mention?

Thank you for your time and participation.

Appendix D

All individual codes belonging to the main categories of Functions, Key ideas and Relevance/Value of doing research for design. Some codes of funtions of research within design are based on literature (deductive; see references behind the explanation), and some codes emerged during analyses (inductive).

Code	Explanation + literature
Functions of research within design	Functions that research activities can have within the design process
FUN_RforD_notspecified	"You need research to do a design". The exact function of research within design is not specified
FUN_RforD_lookingup	Looking up information about the topics involved in the design project (Christensen et al. 2016; Wild et al. 2010)
FUN_RforD_whatexists	Research to learn from designs that are already there (for example by making a product history) (Crismond and Adams 2012; Cross and Cross 1998)
FUN_RforD_relevance	Research to discover whether the product you (want to) make actually solves a problem
FUN_RforD_improve	Research is used to improve existing ideas (Mehalik et al. 2008)
FUN_RforD_users	Target group/user research (Christiaans and Dorst 1992; Crismond and Adams 2012)
FUN_RforD_users_experience	Research on users from your own experience
FUN_RforD_users_simulation	Research on users by simulating their situation, for example by roleplay (Crismond and Adams 2012)
FUN_RforD_test	When designing, one can also do research by testing and experimenting. (Crismond and Adams 2012)
FUN_test_troubleshoot	Experiments with prototypes: 'analytic/diagnostic trouble-shooting' by testing hypotheses (Crismond and Adams 2012)
FUN_test_users	Checking prototype with target group (Crismond and Adams, 2012)
FUN_test_materials	Testing whether the materials used in the prototype are adequate (Mehalik et al. 2008)
FUN_RforD_clearproblem	Orientation research for problem formulation (Christensen et al. 2016; Crismond and Adams 2012)
FUN_RforD_PoR	Research to compose the Program of Requirements
FUN_RforD_materials	Research on which materials are suitable for the design (Bursic and Atman 1997; Crismond and Adams 2012)
FUN_RforD_solvedesignproblems	Analysis of problems that arise during designing
FUN_RforD_collabresearchersanddesigners	Researchers can collaborate with designers to make a product

Code	Explanation + literature
FUN_RforD_ideatable	Investigating alternative options for each requirement, and systematically compare these options in a table of ideas
FUN_RforD_analysing	Critically analyzing the workings of the designed product on paper
FUN_RforD_askexperts	Acquire information from contact with experts on the design topic
FUN_RforD_bestidea	Researching which idea is best
FUN_RforD_costs	Analyzing the costs of (different parts of) the design (Bursic and Atman 1997; Christensen et al. 2016)
FUN_RforD_howitworks	Analyzing critical questions in regard to how the design works (Crismond and Adams 2012)
FUN_RforD_howtomake	Research on how to manufacture the product/prototype (Crismond and Adams 2012; Kuffner and Ullman 1990)
FUN_RforD_location	Research on the location in which the designed product is to be used
FUN_RforD_marketing	Research on which marketing strategies to use to promote the product
FUN_RforD_otherfields	Retrieving information from other fields related to the area in which the design problem is positioned
FUN_RforD_safety	Research on safety and legal issues (Bursic and Atman 1997; Crismond and Adams 2012)
FUN_RforD_justify	Use research to justify the making of informed design decisions (Crismond and Adams 2012)
FUN_RforD_compare	Analyzing and systematically comparing different design ideas to one another
FUN_RforD_exteriordesign	Research on what the design should look like esthetically
FUN_RforD_methods	Examine which research or design methods to apply
FUN_DforR	Design can enhance a research project when there is a 'need to do': for example, by designing an experimental setup. (Kolodner et al. 2003; Vossen et al. 2019).
FUN_RaboutD	One can do research *about* design, to learn from good or failed practices (Crismond and Adams 2012; Frankel and Racine 2010)
Key ideas	Key ideas about the design process, for example that it is an iterative process that can have multiple outcomes
KEY_iteration	Design *is* iteration (Crismond and Adams 2012)
KEY_multiplecycle	The design cycle has multiple varieties, can be conducted more than once, is not linear, and has multiple dimensions (Van Dooren et al. 2014)
KEY_multipledesignspossible	There is not one single right solution for a design problem, multiple designs are possible
Revelance/Value	Reasons why it is relevant for students to include research within their design project
REL_improveproduct	Doing research within design is relevant because it helps students to improve existing products
REL_dontstartoutoftheblue	Doing research within design is relevant because you cannot just start designing from nothing
REL_originalproduct	Doing research within design is relevant because research helps students to determine whether their product is original or innovative

Code	Explanation + literature
REL_qualityproduct	Doing research within design is relevant because it enhances the quality of the designed product/service (Crismond and Adams 2012)
REL_realworld	Doing research within design is relevant because it reflects real world practices (Sanders and Stappers 2008; Vossen et al. 2019)
REL_study	Doing research within design is relevant because it will help students in their further studies (Vossen et al. 2019)
REL_school	Doing research within design is relevant because it can help students in other school subjects or projects
REL_deeperlearning	Doing research within design is relevant because it can lead to deeper learning and mastery of theoretical concepts
REL_stimulateinvestigativeattitude	Doing research within design is relevant because it can stimulate student to develop an investigative attitude
REL_negative	Doing research within design is perceived as irrelevant or boring by students
REL_external	Doing research within design is relevant because it is externally required, for example by the teacher, the module, or to get a good grade
REL_logical	Doing research within design is perceived as relevant by students, because it is logical or better to so

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