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Research and design in STEM education

What do students and teachers think about the connection?

ICLON, Leiden University Graduate School of Teaching

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Research and design in STEM education

What do students and teachers think about the connection?

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Table of Contents

Chapter 1

General Introduction

1.1 Introduction

Research and design activities are key processes in Science, Technology, Engineering and Mathematics (STEM) professions and practices. To prepare students to study or work in STEM disciplines, education needs to reflect the importance of research and design in STEM education. When students learn to conduct research and design activities in a STEM education context, this can contribute to their knowledge, attitudes, skills and awareness about science and engineering practices (Estapa & Tank 2017; Guzey et al., 2016; Glancy et al., 2014), enhance their worldview on possible future professions and help them understand the links between research and design (NRC, 2012). In STEM education, research and design are often employed in project-based approaches, in which students work on authentic problems related to a professional STEM context (Perrenet, Bouhuijs & Smits, 2000). However, within STEM projects the focus often lies at research activities only, or design activities only, while in reality, research and design activities are connected to each other within STEM professions (Sanders & Stappers, 2008). The practice of connecting science and engineering, or research and design, is not self-evident in education (Kolodner, Gray & Fasse, 2003a; Van Breukelen et al., 2016), as this practice does not yet have a well-established epistemology (Doyle et al., 2019; De Vries, 2006). Very few STEM teachers have a background or experience in combining research and design activities (c.f. Love & Wells, 2018), while their performance is the biggest influencing factor on the successful implementation of new educational approaches (Van Driel, Beijaard & Verloop, 2001; Van Driel, Bulte & Verloop, 2005). Furthermore, studies have shown that students experience difficulty to justify design choices with research (Hjorth et al., 2015; Christensen et al., 2016). Thus, connecting research and design in a meaningful way may pose challenges for both teachers and students.

The main research question of this dissertation is: What do students and teachers in a STEM education context think about research, design and the connection between research and design? The general aim of this dissertation is to contribute to theoretical and practical knowledge on how to connect research and design activities in secondary STEM education. Therefore, it was examined how educational practice is perceived by students as well as teachers. As science education is generally regarded by students as hard, boring or disconnected to the real world (Aschbacher, Li, & Roth, 2010; Barmby, Kind, & Jones, 2008; Potvin & Hasni, 2014), while engineering education is regarded as fairly positive (Ara, Chunawala, & Natarajan, 2011), the investigation started by looking at students' attitudes towards *doing* research activities and design activities, rather than their - already often assessed - attitudes towards science or engineering. Attitudes of two different groups of STEM teachers towards supervising research activities and design activities were also studied. Furthermore, teachers developed and evaluated strategies to combine research and design within their STEM projects. Lastly, the ways in which students and teachers saw research and design activities as connected were examined. Below, the theoretical background of connecting research and design activities in STEM education is described, as well as the context in which the studies in this dissertation took place.

1.2 The connection between research and design activities

To describe the connection between research and design, it must be clear what is meant by research and by design. It is beyond the scope of this dissertation to discuss all the various definitions that exist of research and design practices, but rather to mention the goals and a number of core elements for each activity. Research is often employed to explain, explore or compare certain situations by collecting and analysing data (Creswell, 2008). The research process generally consists of the following phases: orientation on research question; generate hypotheses; plan research; collect data; organize and analyse data; conclude and discuss; communicate and present (e.g. Kolodner et al., 2003a; Willison & O'Regan, 2008). Research activities are often employed in STEM education in the form of inquiry-based learning strategies. In inquiry-based learning, students must develop hypotheses about a puzzling situation, collect data in order to test their premises, draw conclusions and reflect on the process of inquiry (Woolfolk, 2004). Data can be collected from experiments and quantitative or qualitative measurements that students carry out themselves, or by gathering information by reading books, searching the internet or interviewing experts (Woolfolk, 2004).

The goal of design is to develop or improve products or services (De Vries, 2005), through clarifying the problem; assembling a program of requirements; planning the design; constructing a prototype; testing the prototype; optimizing the prototype; analysing the product; presenting the product to the client or target group (e.g. Kolodner et al., 2003a; Mehalik et al., 2008; Van Dooren et al., 2014). Educational textbooks often depict the design process as a variation of a block diagram which uses double-ended arrows to guide the learner through the design phases described above and emphasize the iterative nature of design (Mosborg et al., 2005). Research and design both are dynamic practices, and therefore they have no fully agreed upon consensus models within the community (Vezino, 2018). Both processes are considered iterative, concerned with challenging, ill-structured problems (Hathcock et al., 2015), systematic, purposeful and able to inform each other (Vezino, 2018).

In particular research activities are recognized as a necessary part of the design process (Downton, 2003; Frankel & Racine, 2010; Sanders & Stappers, 2008). To rise above a trial-and-error approach, and distinguish design from intuitive art (De Jong & Van der Voordt, 2002), research activities must be involved in the design process to justify design decisions. Research can be employed to benefit design practice in numerous ways, for example: using qualitative and quantitative methods to examine the use of different materials for the manufacture of a product (Frankel & Racine, 2010); testing the usability of a product (Frankel & Racine, 2010); obtaining data on human physical characteristics and understand human behaviour (Downton, 2003); looking up information to acquire domain-specific knowledge (Wild & McMahon, 2010); examining methods of how to construct the design (Kuffner & Ullman, 1990); uncovering legislation and safety issues (Bursic & Atman, 1997); investigating user preferences (Christiaans & Dorst, 1992); analysing products or services that already exist (Cross & Cross, 1998); making a product history report to inform the design process (Frankel & Racine 2010; Crismond & Adams 2012).

There are even other ways in which research and design are connected. For example, Frankel and Racine (2010) describe two other mechanisms: research *through* design, and research *about* design. In research through design, the design itself helps to provide knew knowledge in a broader context, as the emphasis is on the research objective, not the design solution. In research about design, one studies the design process – for example the history of design, design theory, or the analysis of design activity (Schneider, 2007). Furthermore, the design process can enhance research or inquiry activities as well (Shernoff et al., 2017; Stohlmann, Moore & Roehrig, 2012), for example when designing a device to take measurements, or when designing experiments (Fallman, 2003). Literature thus indicates there are many ways in which research and design activities are connected to each other. Next, it needs to be identified which of these functions of research for design or vice versa are suitable to be taught or learnt in secondary schools, in the context of short-term STEM projects.

1.3 Research and design in STEM education

Research and design are core processes that are especially related to the Science and Engineering components of STEM education. As STEM education involves multiple (but not necessarily all four) STEM disciplines (Stohlmann et al., 2012), it implies the connection of science and engineering education, and therefore, the connection between research and design activities. However, the technology and engineering components of STEM have been given less attention in education when for example compared to science and mathematics (Hoachlander & Yanofsky, 2011). There has been a call from scholars to include the design process more in STEM education, as it is seen as the 'glue' that can meaningfully integrate the different STEM disciplines (Moore et al., 2014a; Moore et al., 2014b). For example, including the design process can enhance problem solving in authentic

science and mathematics problems (Shernoff et al., 2017; Stohlmann et al., 2012), facilitate the integration of concepts from multiple STEM areas (Estapa & Tank, 2017; Guzey et al., 2016), and instil positive attitudes towards STEM careers and skills like problem solving, creativity, communication and teamwork (e.g., Glancy et al., 2014; Guzey et al., 2016; Moore et al., 2014b).

The importance of connecting research and design in integrated projects in an educational context has been mentioned in previous studies (Apedoe et al., 2008; Kolodner et al., 2003b; Mehalik et al., 2008). In one design project for example, students had to assemble different electronic components and engage in inquiry in order to make design plans, to construct a working device and to improve their performances (Mehalik et al., 2008). Kolodner et al. (2003a) describe the connection between research and design as a back and forth movement between a research (or investigation) and design cycle (Fig. 1.1). Whenever a 'need to know' arises during the design cycle, for example the need to gain more knowledge about the theoretical background of the design problem, or about the target group, students move into the research process. Kolodner et al. (2003a) describe the 'need to do' as applying the knowledge students have gained through investigation in their design, thereby placing a focus on design as the goal of the project. In the studies in this dissertation however, we interpret these 'need to know' and 'need to do' stages as equally relevant to both research and design projects. For example, just like a 'need to know' arises in a design process, a 'need to do' can arise within a research process as well: for example, the need to design a measuring method, or the need to give practical recommendations that inform a product or service.

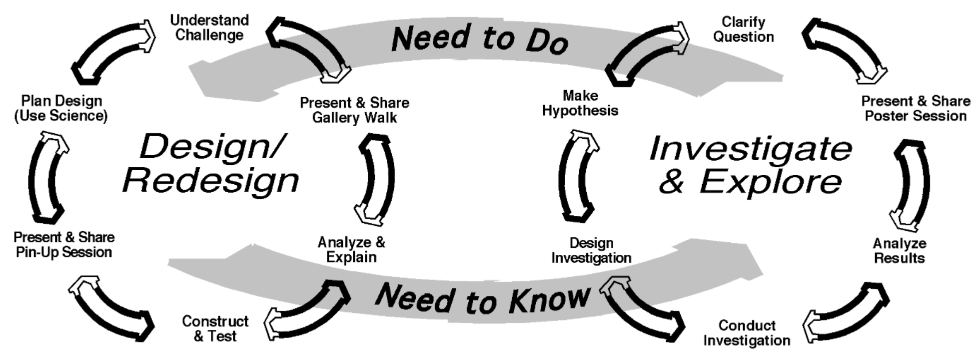

Figure 1.1 The connection between the research and design cycles (Kolodner et al., 2003a), reprinted with permission of the authors

Limited research is available on how teachers could teach or facilitate the connection between research and design in STEM education. Teaching STEM often already has its challenges for teachers, since it is a relatively new field of education (Stohlmann et al., 2012), and because teachers have often only received education in one discipline (Honey et al., 2014). Furthermore, teaching for the connection between research and design within STEM can pose problems for teachers, as teachers of STEM subjects often have no background or experience in design, and in combining design activities with research (c.f. Love & Wells, 2018; Banilower et al., 2013). Since teachers have the biggest influence on whether new educational approaches are implemented successfully into practice (Van Driel et al., 2001; Van Driel et al., 2005), and also influence students' knowledge and attitude development (Denessen et al., 2015), there is a need to study teachers' knowledge on and conceptions about teaching the connection between research and design.

For students, connecting research and design activities in STEM projects also can be difficult to achieve. Studies have shown for example fewer than 3% of participating students took a 'designerly stance towards inquiry', meaning that students did not automatically justify design choices with research (Hjorth et al., 2015; Christensen et al., 2016). Students' unwillingness to connect research activities to a design project could be related to ignorance of the ill-structured nature of design problems (Simmonds, 1980; Portillo & Dohr, 1989), inability to recognize the functions of research for design, a lack of perceived value of this way of working (Brophy, 1987), or negative attitudes towards doing research or design activities, as we know that students' attitudes towards science in general often decline as they proceed through Grade levels (Greenfield, 1997; Barmby et al., 2008). Therefore, there is also a need to better understand students' conceptions about applying the connection between research and design within STEM projects they carry out at school.

1.4 International relevance of the context

International education policies acknowledge the importance of research and design in K-12 science and engineering education (NRC, 2012; NGSS, 2013). The NRC Framework (2012) describes eight core practices in science and engineering education (1) Asking questions (for science) and defining problems (for engineering); (2) Developing and using models; (3) Planning and carrying out investigations; (4) Analysing and interpreting data; (5) Using mathematics and computational thinking; (6) Constructing explanations (for science) and designing solutions (for engineering); (7) Engaging in argument from evidence; (8) Obtaining, evaluating, and communicating information. Research and design are often embedded in STEM curricula in the form of short-term projects (Van Breukelen, de Vries & Schure, 2017; Johnson, 2013). Longer-lasting programs do exist, such as Sloyd in Finland (Metsärinne & Kallio, 2016) or Design and Technology in the UK (UK Department for Education, 2015), but these subjects are more crafts or technology oriented and do not include much science, or scientific inquiry. Internationally, attention for integrated science and engineering learning is increasing (Moore et al. 2014a; Moore et al. 2014b).

The studies in this dissertation are unique in the sense that they have been carried out in the context of two fairly recently introduced long-term STEM subjects in Dutch secondary education: O&O (Dutch abbreviation for 'onderzoeken & ontwerpen', that is: 'research & design') and NLT (nature, life and technology). The subject O&O was first introduced in 2004 in a few local Dutch secondary schools as a bottom-up initiative by parents and educators, and is now taught at a little less than a hundred certified, so called 'Technasium' schools. The main aims of O&O are to (1) acquaint students with professions related to STEM, and (2) stimulate students to develop skills as competent researchers and designers by letting them handle up-to-date and authentic questions in the science and engineering sector (SLO, 2014). O&O is an elective subject that is taught 4-6 hours a week in Grades 7 to 12 (ages 12-18) of Technasium schools. It is a subject that is entirely project-based: students conduct authentic research and design projects based on real world science or STEM related problems from companies and clients in the schools' area. For example, students write a research report which advises the local client on how to optimize an algae reactor, or students design a game or an app for families that are visiting a local petting zoo. Teachers of all subjects can become certified O&O teachers by completing six courses provided by the Technasium foundation: (1) Introduction to O&O; (2) Writing an O&O project; (3) Supervising project management; (4) Supervising and coaching of students; (5) Assessment and evaluation; (6) Contact with companies and stakeholders.

The subject NLT was introduced in The Netherlands in 2007 as a government initiative. At the moment, about 220 schools provide the subject NLT. The main aims of NLT are (1) increasing attractiveness of STEM education in order to increase the flow on to higher STEM education, and (2) increase the coherence of the separate STEM subjects (Krüger & Eijkelhof, 2010). NLT is only taught in upper secondary education in Grades 10 to 12 (ages 16-18), sometimes mandatory but often as an elective subject, for about 3-4 hours a week. NLT is entirely based on modules of 8-10 weeks that are related to different STEM disciplines. For example, students design tools to solve problems in the area of biomedical science, or do research on the technical aspects of clean water supply. Only teachers who are qualified in one of the single science subjects (physics, mathematics, chemistry, biology and geography) can become NLT teachers. Although there is no separate teacher education course for NLT, universities can offer short courses embedded in their regular teacher education curricula, and teachers can attend the annual NLT convention. Chapter 3 provides more extensive information on the subjects O&O and NLT, and also on their most important similarities and differences.

1.5 Dissertation outline

This dissertation focusses on how facilitating and conducting research and design activities, and the connection between them, are perceived by teachers and students in secondary STEM education. Quantitative and qualitative methods were used to obtain data about students' and teachers' experiences and thoughts. Figure 1.2 provides a schematic overview of the following chapters. To answer the main research question, four studies were performed in which (1) an overview of student and teacher attitudes towards research and design activities is provided (chapters 2 and 3); (2) the knowledge development of teachers in a professional learning community aimed at connecting research and design is described (chapter 4); and (3) the perceptions of students and teachers on the functions of research activities within a design-oriented STEM module are examined (chapter 5).

Chapter 2 describes a quantitative study with the main research question: What are the attitudes of secondary school students towards *doing* research and design activities? Unlike many previous studies, we used a questionnaire applying active formulation by using verbs (like 'conducting a design', or 'doing a research project'), rather than using the well-researched, passive nouns 'science' and 'technology'. Multilevel analyses were employed, based on 1625 returned questionnaires of students from the 8^{th} (ages 13-14) and 11^{th} Grade (ages 16-17). To answer the main research question, the following sub questions were formulated: (1) What are the attitudes of secondary school students towards doing research and design activities in general?; (2) Are there differences in student attitudes between doing research activities and doing design activities?; (3) Are there differences in attitudes between students taking the subject O&O and students who do not take this subject?; (4) Are there differences in student attitudes between lower (8th Grade) and upper (11th Grade) grades in secondary school, as attitudes have been known to decline when students proceed in secondary school (Barmby et al., 2008)?; and (5) Are there differences in student attitudes between boys and girls, as technology and science related careers are still more often pursued by men than by women (van Langen & Dekkers, 2005; Corbett & Hill, 2015)?

In *Chapter 3*, the focus moves from student attitudes to teacher attitudes. The main research question was: What are STEM teachers' attitudes towards *supervising* research and design activities? Since teachers are expected to facilitate or supervise (these terms are used interchangeably in this study) both research and design activities in STEM, and often have little experience in doing so, it is relevant to know their attitudes towards facilitating these kind of projects. The following sub questions were asked: (1) What are the general attitudes of STEM teachers towards supervising research activities and towards supervising design activities?; (2) What are the differences in attitude between and within two different types of STEM teacher populations, that is, teachers of O&O and teachers of NLT?; and (3) What are the differences in attitude between and within O&O teachers with different disciplinary backgrounds (science versus non-science)? Teachers of the Dutch STEM subjects O&O and NLT responded, and questionnaires were analysed using Multilevel analyses and t-tests.

Chapter 4 examines the knowledge development of six STEM teachers who participated in a professional learning community (PLC) aimed at connecting research and design, by using interviews and qualitative conventional content analysis. Not all STEM teachers are familiar with facilitating research or design projects, and even less teachers thus have experience combining research and design activities. Research questions were: (1) How can the development of teachers' personal PCK and beliefs about connecting research and design be characterised before and after a PLC?; and (2) How do teachers collectively give meaning to the connection between research and design during a PLC?

Chapter 5 investigates whether and how teachers and students recognized functions of research within design during a design-oriented STEM module. The main research question of this study was: What are students' and teachers' perceptions on the functions of research within design? The aim of this study was twofold: (1) examine whether and how students recognize and value the functions of research within a design process; and (2) examine whether and how teachers recognize and facilitate the functions of research within a design process in the context of a design-oriented STEM module. Using in vivo coding, combining inductive and deductive methods, teacher interviews and student focus groups were analysed. A case study approach was adopted, as there were four cases of a teacher (or two teachers, as in one school, the module was co-taught) and their class, employing this particular STEM module at their school.

Chapter 6 provides a summary of the main findings of chapters 2 to 5, a general discussion about the results, limitations and practical implications of these studies.

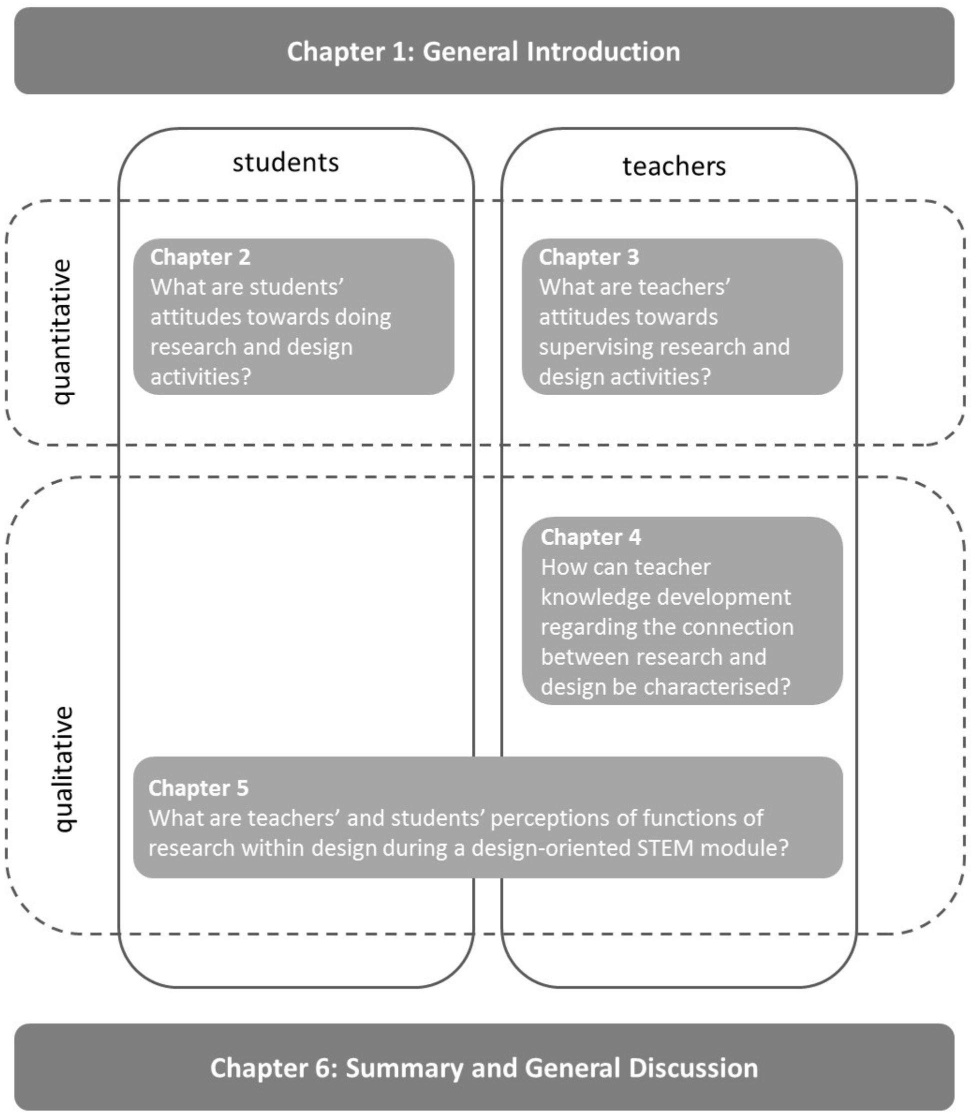

Figure 1.2 Overview of the studies reported on in this dissertation.

Chapter 2

Attitudes of secondary school students towards doing research and design activities

This chapter is based on:

Vossen, T. E., Henze, I., Rippe, R. C. A., Van Driel, J. H., & De Vries, M. J. (2018). Attitudes of secondary school students towards doing research and design activities. *International Journal of Science Education, 40*(13), 1629-1652.

Abstract

Research and design activities are often employed in STEM (Science, Technology, Engineering & Mathematics) education. This study aims to examine students' attitudes towards doing research and design activities in secondary school, among two groups of students: (1) students that take the quite recently introduced Dutch subject O&O (research & design), in which students perform authentic research and design projects related to STEM disciplines; and (2) students that do not take O&O. The subject O&O is only taught at a limited number of certified, so called 'Technasium', schools. A questionnaire, developed by the authors, was completed by 1625 students from Grades 8 and 11. Unlike previous studies on student attitudes, which usually use abstract concepts like 'science' or 'technology', the questionnaire used in this study contains active verbs to characterise research and design activities . The results showed that, in general, students who took the subject O&O had more positive attitudes towards doing research and design activities than regular students. Both student groups appeared to find doing research activities more relevant than doing design activities. The results of this study provide useful information for teachers as well as teacher educators about the existing attitudes of students, for example their preference for design projects over research projects.

2.1 Introduction

Teaching and learning about research and design have become important focus points in international science curricula (NGSS, 2013; NRC, 2012). Learning to conduct research and design activities can increase student knowledge, skills and awareness about science and engineering practices, enhancing their worldview on possible future professions as well as understanding the development of science and the links between research and design (NRC, 2012).

In this study, student attitudes towards doing research and design activities are investigated, instead of students' attitudes towards science in general, which has already often been the focus of previous research (Osborne, Simon & Collins, 2003). For instance, these studies have shown that students perceive the science domain as irrelevant, boring, too hard, and disconnected from the 'real world' (Aschbacher, Li & Roth, 2010; Barmby, Kind & Jones, 2008; Lyons, 2006; Potvin & Hasni, 2014). It has even been reported that students might view high-level science as one of the most useless things they learn in school (Kadlec, Friedman & Ott, 2007). When using the active verb 'engineering', students' attitudes have been found to be fairly positive (Ara, Chunawala & Natarajan, 2011). One's attitude informs one's behavioural intention, and consequently, can positively or negatively influence one's behaviour (Ajzen & Fishbein, 2005), for example, making a certain career or study choice.

Usually, research and design projects are embedded in traditional science subjects as short-term projects. A rather unique initiative is the relatively new course O&O (Dutch abbreviation for 'onderzoeken en ontwerpen', that is, 'research and design') in The Netherlands. This subject consists of research and design projects in STEM fields, and is taught 4-6 hours a week to all grades in secondary education at so-called Technasium schools. O&O includes different fields of STEM (such as industrial engineering, ecology, etc.), is entirely project-based and student-centered, and focuses on authentic research and design tasks which are negotiated by real local companies and carried out in groups of students. The subject O&O provides an interesting and rather unique case in which students are continuously involved in research and design projects in STEM throughout their secondary school education. This provides us with the opportunity to determine whether students who take a subject completely dedicated to research and design projects in STEM have different attitudes than students who do not take this subject.

2.2 Research questions

With this research, we aim to answer the following questions:

1) What are the attitudes of secondary school students towards doing research and design activities in general?

2) Are there differences in student attitudes between doing research activities and doing design activities?
3) Are there differences in attitudes between students taking the subject O&O and students who do not take this subject?
4) Are there differences in student attitudes between lower (8th Grade) and upper (11th Grade) grades in secondary school, as attitudes have been known to decline when students proceed in secondary school (Barmby et al., 2008)?
5) Are there differences in student attitudes between boys and girls, as technology and science related careers are still more often pursued by men than by women (van Langen & Dekkers, 2005; Corbett & Hill, 2015)?

2.3 Theoretical framework

2.3.1 Characteristics of research and design activities

Research and design often go hand in hand, yet can still be seen as two separate practices with separate goals and histories (Williams, Eames, Hume & Lockley, 2012). Research is often employed to explain, explore or compare certain situations by collecting and analysing data (Creswell, 2008). Design activities are used for developing or improving products or services (De Vries, 2005). Research and design have in common that they both are concerned with challenging, ill-structured problems or questions (Hathcock, Dickerson, Eckhoff & Katsioloudis, 2015), and both are iterative practices. While many models are described in literature (for example see Kolodner, Gray & Fasse, 2003a; Willison & O'Regan, 2008), the research process generally consists of these phases: orientation on research question; generate hypotheses; plan research; collect data; organize and analyse data; conclude and discuss; communicate and present. The design process too can be captured in different models (Kolodner et al., 2003a; Mehalik, Doppelt & Schuun, 2008), however, it generally consists of the following phases: clarify problem; assemble program of requirements; plan design; construct prototype; test prototype; repeat steps to optimize prototype; analyse product; communicate and present. Teachers often employ versions of these models when their students conduct research or design projects.

In educational policy documents like the NRC Framework (2012) and NGSS (2013), research and design activities are mentioned as important focal points in K-12 science and engineering education. These research and design practices are described as (1) Asking questions (for science) and defining problems (for engineering); (2) Developing and using models; (3) Planning and carrying out investigations; (4) Analyzing and interpreting data; (5) Using mathematics and computational thinking; (6) Constructing explanations (for science) and designing solutions (for engineering); (7) Engaging in argument from evidence; (8) Obtaining, evaluating, and communicating information (NRC, 2012). It is noteworthy that in this summary, science and engineering practices do not have their own separate process descriptions but have similar phases. However, the authors distinguish between science and engineering as two different practices with different goals: answering questions for science, and solving problems for engineering. The objectives for research and design activities in NRC (2012) and NGSS (2013) are similar to the learning goals of the subject O&O, which forms the context of our study.

2.3.2 Context: research and design in The Netherlands

The subject O&O was introduced in The Netherlands in 2004 and is taught at so-called Technasium certified schools. In September 2017, there are 92 certified Technasium schools in The Netherlands. Local companies usually act as 'clients' for projects, providing students with real research and design problems. For example, in one project a local company asked students to optimize an algae reactor, with a list of factors that influence algae growth, and a plan for upscaling the company's reactor. At the start of 8th Grade, students will have actively decided whether or not to take the subject O&O. In some schools, this decision is already made at the start of Grade 7. After this decision, students take the subject up to 9th Grade, after which they make a choice for a so-called Nature-profile or a Society-profile. Students with a Nature profile often choose O&O as an elective (and in some schools, this is mandatory), but sometimes Society-profile students can choose O&O as well. This means that in 11th Grade, some students have chosen to take O&O themselves, and some students are obliged to take the subject (this depends on individual school rules). Then, they take this subject until they graduate. An O&O teacher acts as a coach rather than a content specialist, and helps students to develop skills like planning, teamwork and perseverance. The main aims of O&O are (1) to acquaint students with STEM professions, and (2) to let students handle up-to-date and authentic STEM questions, in order to stimulate them to develop skills as competent researchers and designers (SLO, 2014).

O&O is a STEM course that uses different teaching approaches than traditional science subjects and has not yet been extensively researched. As O&O only consists of authentic projects and students can take this subject for multiple years, the subject thus provides students with repeated authentic learning experiences. The format of the subject O&O is unique, but the project based nature of the subject and the focus on research and design activities can also be found in other STEM projects or subjects around the world. Therefore, O&O forms an interesting context to study whether students taking this subject hold different attitudes towards doing research and design tasks.

2.3.3 Attitudes towards doing research and design activities

In this chapter we focus on students' attitudes towards doing research and design activities.

Attitude includes one's knowledge, values, feelings, motivation and self-esteem shaping an individual's personal outlook on a certain subject (Kind, Jones & Barmby, 2007; Van Aalderen-Smeets, Walma van der Molen & Asma, 2012) and can be described within three components: a cognitive, an affective and a behavioural component (Eagly & Chaiken, 1993). For example, one's attitude towards science includes: one's knowledge about what science actually involves (cognition), how one feels about science (affect), and how one would be willing to display certain behaviour towards science (for example: taking a science course, or becoming a member of a science club).

Van Aalderen-Smeets et al. (2012) constructed a framework to define attitude towards science in the context of primary school teachers. They adapted the traditional, tripartite model of attitude that includes a cognitive, an affective and a behavioural component (Eagly & Chaiken, 1993) and added a new component: that of perceived control, with subcategories self-efficacy and context dependency (Fig. 2.1). Their review of existing studies on attitude showed that, apart from cognition, affect and behaviour, the belief that one can succeed in doing a particular task (self-efficacy; Bandura, 1997) and the influence of context factors such as availability of teaching material and time (context dependency) also played a role in the construction of teachers' attitudes towards teaching science.

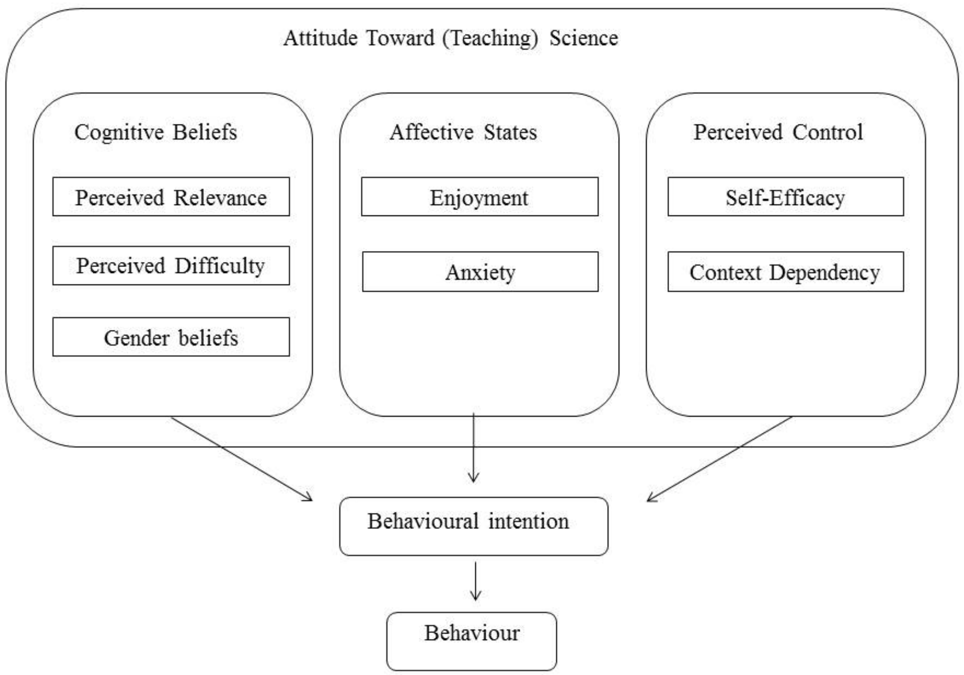

Figure 2.1 Theoretical framework for attitude toward (teaching) science. Adopted from Van Aalderen-Smeets, Walma van der Molen and Asma (2012, p. 176).

In this study, we use the attitude model of Van Aalderen-Smeets et al. (2012) in the context of secondary school students' attitudes towards doing research and design activities. This model fitted the goals of our study, because of the inclusion of one's self-efficacy in this model. Self-efficacy is the belief that one can succeed in doing a particular task (Bandura, 1997). Previous research on the subject of mathematics has shown that students' self-efficacy influences their attitude (Marchis, 2011). It has been shown that self-efficacy can be an important mediator in career choice (Pajares, 1997); students with a low self-efficacy regarding a subject will be less likely to pursue courses or a career related to this subject. High self-efficacy has also been related to higher academic achievement (Pajares & Schunk, 2001). Inquiry based contexts in science have been shown to act as a possible catalyst for students' self-efficacy (Ketelhut, 2007). Apart from one's self-efficacy, the cognitive and affective component of the attitude model can also influence student career or study choices. For example perceived difficulty, the subcategory that refers to the beliefs of students regarding the general difficulty of a subject (in our case, doing research or design activities), has been shown to be a predictor to most behavioural intentions and behaviour (Trafimow, Sheeran, Conner & Finlay, 2002), and therefore has a major influence on students' subject choice (Havard, 1996).

Previous studies have often focused on students' attitudes towards science and technology in general, rather than on doing research and design activities. These studies showed that students' attitudes towards science tend to become more negative during secondary school (Barmby et al., 2008; Crawford, 2014; Potvin & Hasni, 2014). A similar trend was found for students' attitudes towards technology – these declined from the first to the second year of secondary school, despite some students taking additional hours in the subject technology (Ardies, De Maeyer, Gijbels & Van Keulen, 2015). Another study found that technology-oriented company visits for primary school children also did not lead to an increased positive attitude towards technology (Post & Walma van der Molen, 2014). Students' attitudes towards design and engineering on the other hand, tend to be fairly positive (Ara et al., 2011; Kőycű & De Vries, 2016). This could indicate that students hold different attitudes towards the abstract topics of technology or science, compared to doing technology or science related activities (like engineering and doing research). Thus, our study aims to elicit students' attitudes towards doing research and design activities, using a questionnaire applying active formulation by using verbs (like 'conducting a design', 'doing a research project', 'engineering', etc.), rather than using the abstract, passive nouns 'science' and 'technology'. For an overview of the detailed research aims, please see paragraph 2.2.

2.4 Methods

2.4.1 *Participants*

Students from secondary schools from 8th Grade (ages 13-14) and 11th Grade (ages 16-17) participated in our study, so we could compare student attitudes in lower and upper secondary education. For this purpose, teachers of several Technasium schools (randomly selected from a list of schools available on the Technasium website) and regular schools were approached by email. The questionnaires were distributed as hardcopies by post, to be received by the teacher who acted as our contact person. Passive informed consent was obtained from the teachers of the students, and students themselves were informed via an instruction letter. The authors had no influence on the selection of students; as the partaking in this study was voluntarily, the teachers themselves selected the 8th or 11th grade classes that participated. Ethical approval was obtained from the ethics committee of Leiden University Graduate School of Teaching. For this study, 1315 questionnaires were sent to 22 Technasium schools offering the subject O&O, and 1164 questionnaires to the 16 schools without the subject O&O. In total, 1864 questionnaires were returned from 34 schools (22 Technasium schools and 12 regular schools), a response rate of 75%., The schools were situated all over The Netherlands, although the spread of Technasium schools over different provinces was greater. This was due to the fact that at the moment of this study, a limited number of Technasium schools taught the subject O&O at 11th Grade level. Therefore, we had to approach more schools to get a better sample of this group of students. Information on demography or curricular orientations of the schools was not collected. The aim was to compare O&O schools to non-O&O schools in general, and therefore our main criterion to select regular schools was that they did not offer O&O (other curricular activities were thus not taken into account). All students who did not take the subject O&O came from the regular schools that did not offer O&O as a subject.

After manually excluding questionnaires that were accidentally filled in by grades other than Grades 8 and 11 and questionnaires that were filled in without serious intention, 1788 questionnaires remained. These were scanned into the computer and further examined in an SPSS file. We decided to include partly incomplete questionnaires, because most students only left relatively few items unanswered. As a consequence, analyses were based on slightly different numbers of individual questionnaires, as students incidentally left a few items unanswered in the questionnaire. Students with missing grade were excluded (n = 10), as well as 11th Grade students that were not enrolled in the Nature profiles we selected for in our research (n = 18). Some 8th Graders were excluded due to inconsistency (n = 93): they stated they took a specific science subject that is officially only taught in higher secondary education (from 10th Grade and up). Students that did not indicate whether or not they (had) taken the subject O&O, were also excluded (n = 42). In total, 1625 students were included in further analyses. Table 2.1 shows the number of boys and girls in the sample population, the number of students per grade level and the mean age of the students per grade level.

Table 2.1 Basic characteristics of participants.

Categories		Total (*n*)	O&O students (*n*)	Non-O&O students (*n*)
Number of students		1625	924	701
Gender	Boy	947	589	358
	Girl	672	330	342
	Missing	6	5	1
Grade	8th Grade	945	608	337
	11th Grade	680	316	364
Age mean (sd)	8th Grade	13.18 (0.60)	13.16 (0.63)	13.21 (0.54)
	n (missing)	943 (2)	608 (0)	335 (2)
	11th Grade	16.36 (0.75)	16.27 (0.76)	16.44 (0.73)
	n (missing)	680 (0)	316 (0)	364 (0)

2.4.2 *Design of the questionnaire*

To construct our Attitudes towards Doing Research And Design Activities (ADRADA) questionnaire, we used the framework for attitudes towards (teaching) science (by Van Aalderen-Smeets et al., 2012; see Fig. 2.1). Van Aalderen-Smeets and Walma van der Molen (2013) developed their own questionnaire based on this theoretical model: the Dimensions of Attitude towards Science (DAS) questionnaire, which they used in the context of elementary school teachers teaching science. We adapted the items of DAS to the context of students in secondary school, and their attitudes towards doing research and design activities, instead of science.

The DAS consists of seven subcategories: Relevance, Difficulty, Gender, Enjoyment, Anxiety, Self-Efficacy and Context Dependency. We used all subcategories except for Gender. Items in the Gender subcategory were focused on whether students think researching or designing are activities more suited for boys than girls (or vice versa). Our fifth research question focusses on differences in attitude between boys and girls, and not on if they think research or design activities are more suitable for boys. We thus excluded this subcategory as it was not among our main interests. We also included items on intended behaviour, regarding the future of the students (e.g., choice of study or occupation), to explore whether students attitudes coincide with certain behavioural intentions. These items were not adapted from DAS, but from another questionnaire on student attitudes by Post and Walma van der Molen (2014). Items were scored on a 1-5 Likert scale, where 1 = strongly disagree

2

and 5 = strongly agree. The complete ADRADA questionnaire was constructed in Dutch and is available upon request.

2.4.3 Analyses

We determined the internal consistency for all subcategories in the attitude scales by calculating Cronbach's alpha (α) (Table 2.2). Because we decided to include questionnaires with incidental missing items, calculations for each category were based on a different number of individual questionnaires. Problematic items that lowered the Cronbach's alpha were removed from further analyses. The final ADRADA questionnaire therefore consisted of 57 items: 24 items on attitude towards doing research activities, 24 items on attitudes towards doing design activities, and 9 items on personal variables. Most subcategories showed satisfactory reliability of 0.7 or higher, even though the scales were based on small numbers of items. Subcategories with a Cronbach's alpha lower than 0.7 (Anxiety, Self-efficacy and Context Dependency in the research component of the questionnaire, and Context Dependency in the design component of the questionnaire) were still included in further analyses for continuity, as we aimed to explore the data according to the theoretical model of seven subcategories. However, since their internal consistency was not ideal, we approached differences on these dimensions and implications based thereon with caution.

We used Exploratory Factor Analyses to examine whether the questionnaire items sufficiently clustered according to the intended seven subcategories in the ADRADA: Difficulty, Relevance, Anxiety, Enjoyment, Self-efficacy, Context dependency and Future. Principal Component Analysis (PCA) with a Varimax rotation for both the research and design components of the ADRADA showed that the items indeed clustered within 7 categories (see Appendix 1). However, two negatively formulated items of Anxiety clustered together, while two positively (reversely) formulated items of Anxiety clustered along with the items of Enjoyment. We suspect this happened because of the reverse formulation of the items. To further assess the generalizability of the factors of the intended model, we also used a Confirmatory Factor Analysis on the items of the research component of the ADRADA, to illustrate the fit of the model onto the component with the most problematic subcategories according to the Cronbach's alpha scores. We used robust standard errors through clustering to account for the multilevel structure of the data, as students were nested within schools, subject conditions (O&O versus non-O&O), and within the two Grade levels. These analyses showed a reasonable to good fit in the research component of the ADRADA in the seven subcategories. Further suggestions for model stability are derived from the exploratory component analysis, which yields minimal deviations from the theoretical model, with only slightly higher fit when assessed through CFA. As the design components of the ADRADA showed higher scores on internal consistency compared to research, we expect similar or even better results for this component. The

2

PCA and CFA analyses thus indicate that we can keep the subcategories as described in the theoretical model, and remain consistent with literature and with the original intentions of the ADRADA.

Multilevel analyses for all subcategories in de ADRADA questionnaire were applied to the data to determine any differences between groups. Differences between students taking O&O and students not taking O&O were calculated, as well as differences between 8th and 11th Grade, and differences between boys and girls. A paired samples t-test was used to determine whether any difference existed between the attitudes towards doing research activities and the attitudes towards doing design activities. All analyses were performed with IBM SPSS Statistics version 22.

Table 2.2 Cronbach's alpha for the scales for student attitudes towards doing research and design activities.

	Research						
Main category	Sub category	Number of items	α	*M*	SD	SE	Number of students
Cognition	Relevance	4	0.72	3.65	2.70	0.07	1415
	Difficulty	3	0.75	3.16	2.22	0.06	1324
Affection	Enjoyment	3	0.82	3.10	2.60	0.07	1521
	Anxiety	4	0.68	2.45	2.74	0.07	1413
Perceived Control	Self-efficacy	4	0.64	3.27	2.52	0.07	1430
	Context dependency	3	0.59	3.34	2.20	0.06	1511
Behaviour	Future	3	0.83	2.98	2.92	0.08	1422
Average			0.72				
	Design						
Main category	Sub category	Number of items	α	*M*	SD	SE	Number of students
Cognition	Relevance	4	0.76	3.36	2.94	0.08	1371
	Difficulty	3	0.76	2.94	2.22	0.06	1345
Affection	Enjoyment	3	0.86	3.47	2.81	0.07	1480
	Anxiety	4	0.74	2.32	2.84	0.07	1484
Perceived Control	Self-efficacy	4	0.74	3.48	2.69	0.07	1429
	Context dependency	3	0.63	3.39	2.18	0.06	1472
Behaviour	Future	3	0.90	3.24	3.16	0.08	1444
Average			0.77				

Notes: Total number of students was n=1625. α = Cronbach's alpha, M = mean, SD = standard deviation, SE = standard error. Note that due to the algorithm for Cronbach's alpha, all students with missing values were excluded from the analysis of each subcategory (unlike our forthcoming analyses, where we do include students with missing values).

2.5 Results

The subheadings in this section correspond to the research questions of this study. A detailed overview of all aims and research questions was mentioned in paragraph 2.2.

2

2.5.1 General attitude towards doing research and design activities

In the research component of the ADRADA questionnaire, students scored highest on the 1-5 Likert scale on items in the subcategories Relevance, Context and Self-efficacy (Table 2.3). This means students see doing research as a relevant activity to learn at school, and they find themselves reasonably capable to complete such tasks. The lowest scoring subcategories were Anxiety, indicating students do not feel all that anxious when performing a research task, and Future, which indicates students are not overly enthusiastic to continue in a research career.

For attitudes towards doing design activities, students scored highest on the subcategories Self-efficacy and Enjoyment (Table 2.3) on the 1-5 Likert scale. This indicates students enjoy doing design projects and find themselves capable to carry out design projects. The lowest scoring subcategories are Anxiety and Difficulty, meaning students do not find design tasks that hard to do and are not so anxious while doing them.

Table 2.3 General attitude towards doing research and design activities.

		Research			Design		
Main category	Sub category	Mean	SD	N	Mean	SD	N
Cognition	Relevance	3.62	0.70	1611	3.32	0.75	1574
	Difficulty	3.14	0.75	1542	2.93	0.74	1496
Affection	Enjoyment	3.10	0.87	1606	3.45	0.94	1588
	Anxiety	2.48	0.70	1608	2.34	0.72	1571
Control	Self-efficacy	3.25	0.65	1613	3.46	0.68	1580
	Context	3.33	0.74	1607	3.37	0.74	1585
Behaviour	Future	2.97	0.98	1567	3.22	1.05	1551

Notes: Total $n = 1625$, however due to incidental missings n is different for every category, varying between 1496 and 1613.

When calculating the differences between the students' general attitude towards doing research activities and their attitude towards doing design activities, all categories differ significantly ($p<0.029$). In general, students had a significantly more positive attitude towards doing design activities than towards doing research activities, and experienced less anxiety and difficulty when performing design tasks. However, on the subcategory Relevance, students on average scored significantly higher on Relevance of doing research activities.

2.5.2 Difference between O&O and non-O&O students

Students taking the subject O&O in Technasium schools scored significantly higher on the subcategories Relevance of doing research activities, Self-efficacy when performing research projects and Context that enables them to do research, than students who did not attend Technasium schools and who did not take the O&O course (Table 2.4). O&O students furthermore showed significantly less anxiety towards doing research tasks than non-O&O students. When we look at the attitudes towards design, all categories differ significantly from each other (Table 2.4). O&O students generally had a more positive attitude towards design, experienced less anxiety and found designing less difficult to do. Students taking the subject O&O scored highest on the subcategories Enjoyment (mean = 3.66, SD = 0.87) and Self-efficacy (mean = 3.61, SD =0.64), with scores over 3.5 on a 5-point Likert scale.

In the last two columns of Table 2.4, we calculated the differences between the students' attitudes towards doing research activities and their attitudes towards doing design activities within the O&O group and the non-O&O group. This shows that students who took the subject O&O had a significantly more positive attitude towards doing design activities than towards doing research activities, except on the subcategory Relevance (Table 2.4). Students who did not take the O&O subject only showed significant differences between their attitudes towards doing research activities and towards doing design activities on the subcategories Relevance, Difficulty and Self-efficacy (Table 2.4). This means that non-O&O students, like O&O students, scored items on Relevance of doing research activities higher than Relevance of doing design activities, found doing research activities more difficult that design activities, and scored higher on Self-efficacy towards doing design activities.

2.5.3 Difference between lower and upper secondary education

When we look at the complete group of participating students, 945 students were in lower secondary education (Grade 8) and 680 students were in upper secondary education (Grade 11). Students in the 11th Grade scored significantly higher ($p =0.001$) on difficulty of doing research activities (mean = 3.21, SD = 0.71, n= 661) than students in the 8th Grade (mean =3.09, SD = 0.77, n= 881). Students in 11th Grade scored significantly lower ($p < 0.001$) on items within the component of Context – factors enabling them to do research activities at school (such as sufficient time and materials). Also, students in upper secondary education scored higher ($p < 0.001$) on future aspirations regarding doing research (mean = 3.09, SD = 0.95, n= 665). In students' attitudes towards doing design activities, significant differences between Grade levels were present in the subcategories Enjoyment ($p= 0.024$) and Context ($p < 0.001$). Students in lower secondary education scored higher on the Enjoyment component (mean = 3.50, SD = 0.94, n= 925) than 11th Grade students (mean = 3.39, SD = 0.93, n= 63) and the lower grade students also scored higher on enabling context factors when designing in class (mean = 3.46, SD = 0.73, n= 926).

2

Table 2.4 Differences between students who take the subject O&O and students who do not in attitudes towards doing research and design activities, and differences between attitudes towards doing research and design activities within both student groups.

		Differences between O&O and non-O&O students' attitudes towards doing research activities					Differences between O&O and non-O&O students' attitudes towards doing design activities					Differences between attitudes towards research and design	
Main category	Sub category	O&O students (n_{tot}=924)		Non-O&O students (n_{tot}=701)		Sign.	O&O students (n_{tot}=924)		Non-O&O students (n_{tot}=701)		Sign.	Within O&O students	Within non-O&O students
		Mean	SD	Mean	SD	p	Mean	SD	Mean	SD	p	p	p
Cognition	Relevance	3.67	0.71	3.56	0.68	**0.001**	3.44	0.73	3.17	0.74	**0.000**	**0.000**	**0.000**
	Difficulty	3.15	0.73	3.13	0.77	0.645	2.88	0.75	3.00	0.72	**0.004**	**0.000**	**0.000**
Affection	Enjoyment	3.07	0.88	3.14	0.86	0.092	3.66	0.87	3.18	0.95	**0.000**	**0.000**	0.298
	Anxiety	2.44	0.67	2.53	0.75	**0.009**	2.24	0.68	2.47	0.75	**0.000**	**0.000**	0.051
Control	Self-efficacy	3.35	0.63	3.12	0.65	**0.000**	3.61	0.64	3.26	0.68	**0.000**	**0.000**	**0.000**
	Context	3.42	0.73	3.22	0.74	**0.000**	3.48	0.73	3.22	0.74	**0.000**	**0.004**	0.831
Behaviour	Future	2.97	0.96	2.97	1.00	0.966	3.46	0.98	2.92	1.06	**0.000**	**0.000**	0.277

Notes: For O&O students, total n = 924, and for non O&O students, total n = 701, however due to incidental missings n is different for every category or comparison. Significant p-values are indicated in **bold**.

Table 2.5 Differences in attitudes towards doing research activities between 8th and 11th Grade in O&O and non-O&O students.

		O&O students					Non-O&O students				
Main category	Sub category	8th Grade (n_{tot}=608)		11th Grade (n_{tot}=316)		Sign.	8th Grade (n_{tot}=337)		11th Grade (n_{tot}=364)		Sign.
		Mean	SD	Mean	SD	p	Mean	SD	Mean	SD	p
Cognition	Relevance	3.65	0.73	3.73	0.66	0.090	3.48	0.72	3.63	0.63	**0.004**
	Difficulty	3.11	0.75	3.22	0.69	**0.042**	3.04	0.82	3.21	0.72	**0.005**
Affection	Enjoyment	3.07	0.91	3.05	0.83	0.745	3.18	0.88	3.10	0.84	0.283
	Anxiety	2.46	0.70	2.39	0.62	0.143	2.43	0.74	2.62	0.74	**0.000**
Control	Self-efficacy	3.29	0.65	3.46	0.57	**0.000**	3.10	0.66	3.13	0.63	0.578
	Context	3.47	0.74	3.30	0.70	**0.001**	3.29	0.75	3.15	0.73	**0.013**
Behaviour	Future	2.95	0.97	3.01	0.94	0.336	2.78	1.00	3.15	0.96	**0.000**

Notes: The actual number of students included per category can differ slightly from n_{tot} due to incidental missings in the data. Significant p-values are indicated in **bold**.

Table 2.6 Differences in attitudes towards doing design activities between 8th and 11th Grade in O&O and non-O&O students.

		O&O students					Non-O&O students				
Main category	Sub category	8th Grade (n_{tot}=608)		11th Grade (n_{tot}=316)		Sign.	8th Grade (n_{tot}=337)		11th Grade (n_{tot}=364)		Sign.
		Mean	SD	Mean	SD	p	Mean	SD	Mean	SD	p
Cognition	Relevance	3.42	0.74	3.47	0.71	0.285	3.13	0.75	3.20	0.74	0.239
	Difficulty	2.90	0.77	2.86	0.72	0.531	2.94	0.71	3.04	0.72	0.072
Affection	Enjoyment	3.63	0.90	3.72	0.81	0.126	3.26	0.96	3.10	0.93	**0.031**
	Anxiety	2.26	0.70	2.20	0.65	0.201	2.40	0.74	2.53	0.75	**0.025**
Control	Self-efficacy	3.58	0.66	3.67	0.61	**0.043**	3.30	0.73	3.22	0.64	0.157
	Context	3.51	0.75	3.44	0.68	0.166	3.37	0.70	3.08	0.75	**0.000**
Behaviour	Future	3.43	1.00	3.50	0.95	0.365	2.89	1.07	2.94	1.05	0.577

Notes: The actual number of students included per category can differ slightly from n_{tot} due to incidental missings in the data. Significant p-values are indicated in **bold**.

When we split up the complete group of students in O&O and non-O&O students again, we see some differences between lower and upper secondary education in the O&O group versus lower and upper secondary education in the non-O&O group. O&O students in upper secondary education scored significantly higher on items in the Self-efficacy component for both doing research and design activities than students in lower secondary education, unlike students who did not take the O&O course (Table 2.5 and 2.6). In both groups of students (O&O and non-O&O), 11th graders scored higher on the subcategory Difficulty of doing research activities, and lower on the Context component of doing research activities than 8th graders. Furthermore, in the non-O&O group, students in upper secondary education scored significantly higher on the subcategories Relevance of doing research activities and Future intentions to pursue in a research related study or career, unlike the O&O group. Also unlike the O&O group, upper secondary students of the non-O&O group scored higher on the Anxiety component than students in the lower secondary grade. In the non-O&O group, 11th graders scored significantly higher on Anxiety towards designing, and lower on the components Enjoyment and Context. It would seem that regular students' anxiety towards doing research and design activities increases from 8th to 11th Grade, while in students taking O&O, this is not the case.

2.5.4 Difference between boys and girls

In the complete group of participating students, 947 boys filled in the questionnaire, and 672 girls. When looking at all boys and girls in general, we see that in both attitude towards doing research activities and attitude towards doing design activities, boys scored items within the main category Control (Self-efficacy and Context) significantly higher than girls (Table 2.7). Girls scored significantly higher on the Anxiety component in attitude towards doing research activities, and significantly lower on items in the components Relevance and Future of doing design activities.

When we split up this complete group of students in an O&O and a non-O&O group again (Table 2.8), we see some differences. In both O&O and non-O&O students, boys scored significantly higher on the subcategory Self-efficacy of doing research activities, and also on the main category of Control within attitude towards doing design activities. Girls within the non-O&O group scored significantly higher on Anxiety and Difficulty in doing research activities than boys. When calculating the differences between the students' attitudes towards doing research activities and their attitudes towards doing design activities (see the last two columns in Table 2.8), we see that students who took the subject O&O, both boys and girls, had a significantly more positive attitude towards doing design activities than towards doing research activities, except on the subcategory Relevance. Students who did not take the O&O subject also seemed to have a somewhat more positive attitude towards

design compared to research as both boys and girls scored significantly higher on Difficulty regarding research activities, and higher on Self-efficacy for doing design activities.

Table 2.7 Attitudes towards doing research and design activities: differences between boys and girls in general.

		Research					Design				
Main category	Sub category	Boys (n_{tot}=947)		Girls (n_{tot}=672)		Sign.	Boys (n_{tot}=947)		Girls (n_{tot}=672)		Sign.
		Mean	SD	Mean	SD	p	Mean	SD	Mean	SD	p
Cognition	Relevance	3.62	0.70	3.63	0.68	0.833	3.36	0.74	3.28	0.74	**0.030**
	Difficulty	3.11	0.74	3.18	0.76	0.079	2.93	0.76	2.94	0.70	0.757
Affection	Enjoyment	3.11	0.88	3.09	0.86	0.657	3.45	0.92	3.45	0.96	0.939
	Anxiety	2.43	0.69	2.54	0.72	**0.002**	2.32	0.72	2.36	0.72	0.264
Control	Self-efficacy	3.35	0.62	3.11	0.65	**0.000**	3.53	0.66	3.37	0.69	**0.000**
	Context	3.37	0.76	3.28	0.71	**0.014**	3.43	0.75	3.29	0.73	**0.000**
Behaviour	Future	3.00	0.96	2.93	1.01	0.136	3.28	1.03	3.14	1.07	**0.010**

Notes: The actual number of students included per category can differ slightly from ntot due to incidental missings in the data. Significant p-values are indicated in **bold**.

Table 2.8 Attitudes towards doing research and design activities: differences between boys and girls within the O&O and non-O&O student groups, and differences between the attitudes towards doing research and design activities within boys and girls.

		O&O students											
		Research					Design					Differences between attitudes towards research and design	
Main category	Sub category	Boys (n_{tot}=589)		Girls (n_{tot}=330)		Sign.	Boys (n_{tot}=589)		Girls (n_{tot}=330)		Sign.	Within boys	Within girls
		Mean	SD	Mean	SD	p	Mean	SD	Mean	SD	p	p	p
Cognition	Relevance	3.66	0.71	3.70	0.69	0.404	3.47	0.28	3.40	0.73	0.196	**0.000**	**0.000**
	Difficulty	3.14	0.72	3.16	0.74	0.683	2.91	0.77	2.83	0.70	0.102	**0.000**	**0.000**
Affection	Enjoyment	3.07	0.89	3.06	0.86	0.946	3.64	0.87	3.70	0.889	0.327	**0.000**	**0.000**
	Anxiety	2.44	0.67	2.43	0.66	0.893	2.25	0.69	2.23	0.67	0.688	**0.000**	**0.000**
Control	Self-efficacy	3.42	0.61	3.23	0.64	**0.000**	3.65	0.62	3.54	0.67	**0.009**	**0.000**	**0.000**
	Context	3.45	0.75	3.36	0.70	0.077	3.52	0.73	3.42	0.73	**0.040**	**0.024**	0.069
Behaviour	Future	2.99	0.94	2.94	1.00	0.478	3.49	0.97	3.40	1.00	0.156	**0.000**	**0.000**
		Non-O&O students											
		Research					Design					Differences between attitudes towards research and design	
Main category	Sub category	Boys (n_{tot}=358)		Girls (n_{tot}=342)		Sign.	Boys (n_{tot}=358)		Girls (n_{tot}=342)		Sign.	Within boys	Within girls
		Mean	SD	Mean	SD	p	Mean	SD	Mean	SD	p	p	p
Cognition	Relevance	3.56	0.68	3.56	0.67	0.952	3.18	0.73	3.16	0.76	0.698	**0.000**	**0.000**
	Difficulty	3.07	0.76	3.20	0.78	**0.025**	2.95	0.74	3.04	0.69	0.085	**0.009**	**0.001**
Affection	Enjoyment	3.17	0.85	3.11	0.87	0.341	3.14	0.93	3.21	0.97	0.349	0.857	0.134
	Anxiety	2.42	0.72	2.64	0.75	**0.000**	2.44	0.76	2.49	0.74	0.430	0.397	**0.001**
Control	Self-efficacy	3.24	0.63	3.00	0.64	**0.000**	3.31	0.68	3.20	0.68	**0.030**	**0.018**	**0.000**
	Context	3.24	0.77	3.20	0.71	0.475	3.28	0.76	3.16	0.71	**0.043**	0.323	0.388
Behaviour	Future	3.02	0.98	2.91	1.02	0.152	2.93	1.03	2.90	1.09	0.725	0.205	0.718

Notes: The actual number of students included per category can differ slightly from n_{tot} due to incidental missings in the data. Significant p-values are indicated in **bold**.

2.6 Conclusion & Discussion

Like the Results section, the subheadings in this section correspond to the research questions of this study.

2.6.1 General attitudes of secondary school students towards doing research and design activities

On the basis of our results in respect to the first research question, we can conclude that students in secondary education had neutral to slightly positive attitudes towards doing research activities and somewhat more positive attitudes towards doing design activities, which on average, they viewed as less difficult. Students viewed doing research activities as more relevant and important to know about than designing. The positive attitude found towards doing design activities is similar to findings on students' positive attitudes towards engineering (Ara et al., 2011; Kőycű & De Vries, 2016), which is, like designing, another technology and science related activity. It should be noted, however, that while they have similar translations in Dutch, this may not be the case for all languages or cultures, and therefore designing and engineering cannot be regarded as exactly the same. It is also interesting to note that students found doing research activities more relevant or important than learning to do design activities, however they also found doing research activities more difficult. A study of Kadlec et al. (2007) showed that students and their parents indeed acknowledged science as being important, while at the same time however they saw a disconnect between math, science and technology education and their personal lives. A possible explanation for why students find research projects more difficult, could be that students associate research (in science) with looking for fixed, "right" answers that are already known by the teacher (Millar, 2004), while design activities could lead to multiple and new solutions. A qualitative follow-up study could give more insight in students' images on doing research and design tasks.

2.6.2 Differences between attitudes of students taking the subject O&O and students who do not take this course

Results of this study show that students taking the subject O&O had significantly more positive attitudes towards doing design activities than non-O&O students on all components, and on some components towards doing research activities. O&O students found doing research activities significantly more relevant than non-O&O students. They experienced less anxiety towards doing research tasks, and also scored significantly higher on positive self-efficacy and enabling context factors while doing research activities, although these results should be interpreted carefully as these scales had the lowest internal consistency in the ADRADA. Students taking the subject O&O also scored significantly higher on the subcategories Enjoyment, Context and Future aspirations to pursue a design related study or career than a career in research, whereas within the non-O&O group, no significant differences between their attitudes towards doing research activities and towards doing design activities were found for these subcategories.. This could be explained by the fact that only O&O students have extensive experiences with doing design activities in school. Follow-up studies could provide more information on whether O&O students actually choose STEM studies or occupations more often than regular students later in life.

A possible explanation for the differences in attitude between O&O and non-O&O students could also be the nature of the subject O&O, which is project- and context-based and uses inquiry, design and project based learning practices. A meta-analysis by Savelsbergh et al. (2016) showed that approaches such as Inquiry Based Learning (gaining knowledge through inquiry to solve a puzzling situation- Woolfolk, 2004) in science subjects indeed appear to have a positive influence on student attitudes. Other studies found that Problem Based Learning positively influenced students' attitudes (Lou, Shih, Diez & Tseng, 2011; Tandogan & Orhan, 2007).

As O&O is mostly an elective subject, students who take O&O as a subject could already have more positive attitudes towards doing research and design projects, because they show interest by actually choosing O&O. We could not correct for this possible influence on students' attitudes. However, the strong significant differences between O&O and non-O&O students, even up in 11th Grade where all students have chosen Nature profiles and thus have shown their interest in science, strongly suggest that the subject O&O has the potential to influence students' attitudes. More research is needed to provide empirical evidence, for example though effect studies.

2.6.3 Differences between attitudes of students in lower and upper secondary education

Results on the third research question show that students in lower secondary education scored higher on context factors, this might suggest that they experienced sufficient time, recourses and help when conducting research and design projects. Students in the upper secondary grade scored higher on difficulty of doing research activities, meaning they find doing research projects more difficult than lower grade students. As students proceed in their education, school projects often indeed become more difficult and complicated in higher grades. Despite viewing research activities as more difficult, 11th Grade students scored higher on future aspirations to do something with research than 8th Grade students.

Students who took the subject O&O showed higher self-efficacy in 11th Grade than in 8th Grade. This may suggest students become more confident in their abilities to conduct research and design tasks as they progress in education. The increased self-efficacy of O&O students could possibly be attributed to more mastery experiences and chances to interpret previous performances, important factors in creating self-efficacy beliefs (Britner & Pajares, 2006). Students who did not take the O&O course did not show this increase in self-efficacy from 8th to 11th Grade. In 11th Grade they even scored higher on the Anxiety components both towards doing research and design activities, suggesting that regular students' anxiety towards doing research and design tasks might increase from 8th to 11th Grade. The interpretation of these results is carefully formulated as the Self-efficacy and Anxiety scales showed lower internal consistency.

2.6.4 Differences between attitudes of boys and girls

In general, boys scored higher on the control component of attitude towards doing research and design activities, indicating that boys seem more confident and feel better enabled than girls to conduct research and design projects. Girls showed significantly lower self-efficacy on doing research activities than boys, although these results should be interpreted carefully as this scale had a lower internal consistency. Boys seemed to value design activities as more relevant and as a more interesting study or career path than girls, however, this difference is not found anymore when we look separately at students in the O&O group and students in the non-O&O group. These results contrast with findings of Britner and Pajares (2006), who found that girls scored higher on self-efficacy in science than boys. Jovanovic and King (1998), however, found that for girls, even after one year of hands-on performance-based science lessons, there was a decrease in science ability perceptions. Previous studies have shown that boys are more likely to be encouraged by teachers in participation in science than girls (AAUW, 1992; M. Sadker & Sadker, 1995). M. Sadker and Sadker (1995) argued that teachers might view boys as more difficult to handle and find it harder to keep their attention, hence making teachers try harder to keep them involved than girls. This teacher behaviour could result in making boys feel more confident in doing science than girls.

However, boys and girls in general did not differ on the subcategories Difficulty and Enjoyment, meaning both groups found research and design activities equally difficult and enjoyable. This is not the case anymore when we look at non-O&O students only; there, girls scored significantly higher on the perceived difficulty of doing research tasks. Furthermore, girls in this group also scored higher on Anxiety towards doing research. There were no differences in anxiety towards doing research between boys and girls within the group of O&O students, which could indicate that taking the subject O&O helps girls feel more empowered to do research projects.

This study differs from other studies in two profound ways. Firstly, we measured the attitudes of students who had taken the subject O&O weekly for 2 or 5 years. In other studies, interventions to enhance positive attitudes are often much shorter. In these studies, an increased positive attitude is often not found (Post & Walma van der Molen, 2014). Secondly, instead of looking at students' attitudes towards static concepts as 'science' or ‘technology’, our questionnaire focused on the performance of research and design activities. It is possible that, by using activating verbs like ‘doing research at school’, research and design activities are placed into a more realistic context for them, therefore possible leading to more positive attitude scores in the questionnaire.

Different types of factor analyses showed that the ADRADA questionnaire clustered according to the seven subcategories, indicating that the outcomes of the analyses are stable. Should future studies seek for improvement of this instrument, they could take into consideration the outcomes of the PCA model and group the positively formulated Anxiety items in the subcategory Enjoyment, or look carefully at the formulation of the items. The internal consistency of the Anxiety, Self-efficacy, and Context Dependency scales could also be improved by looking at the formulation of the items. On the other hand, lower internal consistency could also be inherent to the fuzzy nature of (some of) the measured concepts. For example, within the subcategory Context dependency, items on sufficient time could have been scored low, while items on available resources could have been scored high by the students.

In conclusion, this study shows that students taking the subject O&O - a context-based, student-centered subject with applied research and design tasks - had more positive attitudes towards doing research and design activities than students in regular classes. The results of this study strongly suggest that a project and context based subject like O&O could possibly enhance students’ attitudes towards doing research and design activities.

The results of this study provide implications for teachers as well as teacher educators. Teachers can use the information of this study to become more aware of the existing attitudes of students. Teachers as well as researchers could explore how to enhance students’ self-efficacy or general attitudes in research projects. Also, science teachers at non-O&O schools could benefit from knowing that students’ anxiety appears to increase from 8th to 11th Grade, so they can take appropriate measures to enhance students’ confidence and self-efficacy, for example by letting their students gain more experience in conducting authentic research and design projects.

This study provides encouraging results which are worthy to follow up on. For example, a study on the attitudes of teachers towards guiding research and design projects has been conducted by the authors to gain more insight in the existing attitudes of teachers towards this subject (Vossen et al., 2019a). International STEM subjects could possibly also use the ADRADA questionnaire to elicit attitudes towards doing research and design activities in students who are enrolled in different STEM subjects.

Chapter 3

Attitudes of secondary school STEM teachers towards supervising research and design activities

This chapter is based on:
Vossen, T. E., Henze, I., Rippe, R. C. A., Van Driel, J. H., & De Vries, M. J. (2019). Attitudes of secondary school STEM teachers towards supervising research and design activities. *Research in Science Education*.

Abstract

Research and design activities are important focus points in international policies for secondary Science, Technology, Engineering and Mathematics (STEM) education. It is up to school teachers to implement and supervise these activities in the STEM classroom. However, not much is known about the attitudes teachers hold towards supervising research activities or design activities. In this study, a questionnaire to measure teacher attitudes towards supervising research activities and design activities in secondary school was completed by 130 Dutch teachers who taught the relatively new Dutch STEM subjects O&O (research and design) and NLT (nature, life and technology). These integrated STEM subjects are context based, and are taught in a limited number of schools. Important differences between these integrated STEM subjects are their student and teacher populations: NLT is taught in grades 10-12 by teachers with a qualification in a science subject, while O&O is taught in grades 7-12 and can be given by any teacher in secondary school. The results showed that on average, both O&O and NLT teachers had high self-efficacy scores on supervising research and design activities even when they had received no special education in doing so. Furthermore, the teachers in general viewed supervising research activities as a more relevant activity than supervising design. Since research and design activities are becoming more important in (inter)national curriculum standards, STEM teacher education and subsequent professional development should not only familiarize teachers with supervising research projects, but with design projects as well.

3.1 Introduction

In several educational documents, research and design activities are identified as important focus points in K12 Science, Technology, Engineering and Mathematics (STEM) education (NRC Framework 2012; NGSS 2013; Platform Onderwijs2032 2016). Two integrated STEM subjects that focus on research and design skills were introduced in The Netherlands: O&O (the Dutch abbreviation for 'Onderzoeken en Ontwerpen', that is, 'Research and Design') in 2004, and NLT (nature, life and technology) in 2007. Both subjects are elective and entirely project or module-based. O&O is taught 4-6 hours a week in grades 7-12 (ages 12-18); the projects take about 10 weeks in the lower grades, and in the upper grades students choose projects themselves which last for 20 or 40 weeks. NLT is taught 3-4 hours a week in grades 10-12 (ages 16-18), and each module takes about 8-10 weeks. The subjects' main difference is that NLT is more research and science oriented, and O&O has an equal amount of research projects and design projects. Each project revolves around two or more STEM domains connected in authentic real-world contexts and bound by STEM practices, characteristics that fit the description of integrated STEM education (Kelley and Knowles 2016). O&O and NLT are unique types of subjects that employ research and design activities in STEM all year through, instead of embedding these activities in the regular science curriculum in the form of short-term projects (Johnson 2013; Van Breukelen et al. 2017).

Teachers play a big part in shaping such new subjects in the curriculum – they are the biggest influence on whether the new approach is implemented successfully into practice (Van Driel et al. 2001; Van Driel et al. 2005). However, teachers of integrated STEM subjects are not specifically educated to teach all the different kinds of STEM projects the subjects entail (Honey et al. 2014). Teachers of NLT are qualified to teach one single science subject (biology, physics, chemistry, mathematics or geography), and do not participate in professional learning for NLT specifically. O&O teachers can be teachers of any subject (from physics to history to languages). They receive basic education of six units on how to supervise interdisciplinary research projects and design projects, on how to assess these projects, and on how to develop projects in collaboration with local companies using authentic problems. Thus, it is often the case that O&O and NLT teachers are not content experts in every project, but rather act as coaches who supervise students who conduct these integrated STEM projects.

In this chapter, the term STEM teachers refers to teachers of integrated STEM subjects (like O&O and NLT). Most STEM teachers are not specifically educated to supervise research and design in multiple contexts, and not much is yet known of these teachers' outlook and feelings of competence when doing research activities and design activities with their students. To understand their outlook on supervising research activities and design activities in the classroom, we investigated the attitudes present in two different populations of STEM teachers (O&O and NLT teachers) who supervise research activities and design activities conducted by their students. Teachers' variables, like a teacher's attitude, are important in shaping student attitudes and in determining whether the introduction of new integrated STEM subjects will be successful (Denessen et al. 2015; Osborne et al. 2003; Van Driel et al. 2001). Results from this study may uncover possible problems that teachers experience when supervising research or design, and may show differences between the two different STEM teacher populations.

Our research questions are:

1. What are the general attitudes of STEM teachers towards supervising research activities and towards supervising design activities?
2. What are the differences in attitude between and within two different types of STEM teacher populations, that is, teachers of O&O and teachers of NLT?
3. What are the differences in attitude between and within O&O teachers with different disciplinary backgrounds (science versus non-science)?

3.2 Theoretical framework

3.2.1 Teaching STEM

Educational policies like the Next Generation Science Standards (NGSS 2013) place emphasis on providing stronger connections between STEM disciplines because "most global challenges concerning energy, health, and the environment (e.g., climate change, sustainability) require an interdisciplinary (and frequently, international) perspective involving mathematics, science, and technology" (Shernoff et al. 2017 p. 2). With integrated STEM, educators try to combine science, technology, engineering and mathematics disciplines into one subject. It should be clarified that STEM can involve multiple subjects, and these need not involve all four STEM disciplines (Stohlmann et al. 2012). However, limited research is available on how teachers could instruct integrated STEM since it is a relatively new field of education (Stohlmann et al. 2012), and few teachers are specifically trained to teach integrated STEM as most Dutch secondary school teachers have only received education in one discipline (Honey et al. 2014). Shernoff et al. (2017) state that this causes concern over the quality of education and teacher skills in STEM. Thus, the existing literature implies a need for greater teacher education in relation to teaching integrated STEM subjects.

Asking teachers to teach in STEM areas other than their own discipline creates new challenges and knowledge gaps (Stinson et al. 2009). Shernoff et al. (2017) found that teachers stated that "they did not know how to effectively integrate the STEM areas", and that "their lack of understanding of how to teach in integrated ways was strongly related to students' lack of understanding or lack of motivation to learn in different ways" (p. 8). Teachers expressed that a shift in mindset was needed: teachers and students needed to get used to the idea that the teacher's role was not to give the students the correct answer to the given tasks (Shernoff et al. 2017). Teachers of integrated STEM also emphasize the importance of support in areas outside their expertise, time to prepare, implement and evaluate a project, or to work with colleagues and resources (Eijkelhof and Krüger 2009; Shernoff et al. 2017).

Over the last few decades, the technology and engineering components of STEM have been given little attention in schools compared to science and mathematics (Hoachlander and Yanofsky 2011). This seems to be changing slowly. The engineering design process, in which students solve a problem by developing products or services in a systematic and iterative way (De Vries 2005), is becoming more important in STEM education curricula because it has the potential to enhance problem solving in real world science and mathematics problems (Shernoff et al. 2017; Stohlmann et al. 2012) and can act as the 'glue' that meaningfully integrates STEM disciplines in K-12 education (Moore et al. 2014a; Moore et al. 2014b). However, very few K-12 teachers are actually trained to teach the engineering design process.

Previous studies provide empirical evidence for the effectiveness of the design process in facilitating the integration of concepts from multiple STEM areas (Estapa and Tank 2017; Guzey, Moore, Harwell and Moreno 2016), and for the influence of design activities on positive attitudes towards STEM careers and skills like problem solving, creativity, communication and teamwork (e.g., Glancy et al. 2014; Guzey et al. 2016; Moore et al. 2014b). These findings also touch upon the discussion whether integrated STEM should focus on the learning of scientific concepts, the learning of skills to be able to engage in scientific and engineering processes, or both. In their definition of STEM education, Kelley and Knowles (2016) place emphasis on content learning in two or more STEM areas and on the importance of enhancing student concept learning. Johnson (2013) describes integrated STEM as "an instructional approach, which integrates the teaching of science and mathematics disciplines through the infusion of the practices of scientific inquiry, technological and engineering design, mathematical analysis, and 21st century interdisciplinary themes and skills (www.p21.org)". She seems to place emphasis on the inquiry process, the engineering design process and 21st century skills like critical thinking, problem solving, collaboration and information literacy to teach science and mathematics. Bybee (2010) describes STEM literacy as "the conceptual understandings and procedural skills and abilities for individuals to address STEM-related personal, social, and global issues", placing emphasis on both conceptual knowledge and procedural skills, like inquiry. Educational documents, moreover, often place emphasis on increasing student knowledge about career opportunities in STEM (NRC 2012). It seems that ideally, teaching integrated STEM results in both student learning of scientific concepts and student skill development in scientific and engineering processes. The focus on conceptual knowledge versus skills has implications for teachers: a strong focus on student knowledge acquisition might imply that teachers actually need to *teach* or explain content to their students in relation to a STEM project. A strong focus on student skill development asks for a more student-centered approach, like *guiding and supervising* students (Henze et al. 2007) who engage in research or engineering processes in STEM projects. It remains debatable how skill-focused approaches ensure that students contextualise these skills and that students acquire the underlying conceptual knowledge required to understand the STEM disciplines.

3

3.2.2 Teacher attitudes

As described above, most integrated STEM teachers are originally educated to teach subjects in single disciplines. Implementing a new integrated STEM subject as part of curriculum innovation poses challenges for teachers who are not used to teaching these subjects. They are not yet used to the content of the new subject, as it differs from the content of the subjects teachers usually teach (Stohlmann et al. 2012). Also, they have to get used to other, often project-based and student-centered teaching methods and pedagogical approaches, , instead of letting students complete workbook questions after a teachers' explanation (Henze et al. 2007). This makes new integrated STEM subjects, like the Dutch subjects O&O and NLT, potentially more difficult subjects to teach. Research indeed shows that teachers from the separate disciplines of science, technology and mathematics all felt uncomfortable at some point while implementing a new integrated STEM subject (Stohlmann et al. 2012). The degree to which teachers were passionate to continue to develop as a teacher of a new integrated STEM subject decreased their discomfort (Stohlmann et al. 2012). From previous research, we know that teachers react differently towards curriculum innovations and develop different types of knowledge for teaching (for example content-oriented versus skills-oriented) (Cohen and Yarden 2009; Henze et al. 2008). Instructionally effective teachers are often more positive and receptive towards curriculum innovations than less effective teachers, possibly because highly efficient teachers have high personal self-efficacy, feel confident about their teaching abilities and like teaching (Guskey 1988). The attitudes of teachers will shape their interpretations of newly introduced subjects in the curriculum (Jones and Legon 2014).

Teachers' attitudes, whether positive or negative, can influence student attitudes (Denessen et al. 2015). Measuring teacher attitude is important because students' attitudes towards a subject are shaped by observing teachers' comments and enjoyment when teaching about a topic (Frenzel et al. 2009). By attitude, we mean the personal outlook of an individual on a certain subject, which is shaped by one's knowledge, values, feelings,

motivation and self-esteem (Kind et al. 2007; Van Aalderen-Smeets et al. 2012). Teachers' attitudes are known to be related to teaching effectiveness and choice of instructional strategies (Ernest 1989; Guskey 1988; Jones and Legon 2014), and thus influence the classroom practice of a subject. When teachers hold negative attitudes or anxiety towards the subject they teach, for example math anxiety, they can pass this anxiety on to their students (Geist 2010). Conversely, positive teacher attitudes towards mathematics relate to positive student attitudes and student performance in mathematics (Mensah et al. 2013). Hence, research shows that the teacher variables, such as attitude, are the most significant factor determining student attitude towards a subject, instead of curriculum variables (Osborne et al. 2003).

3

Attitude has been described as having three components: a cognitive, an affective and a behavioural component (Eagly and Chaiken 1993). A distinction can be made between one's *personal* and one's *professional* attitude (Van Aalderen_Smeets et al. 2012). A personal attitude, for example towards science, refers to the attitude of the individual, independent of their profession, and includes for example one's interest in reading science magazines in their spare time. A professional attitude, in the case of this study, of secondary school STEM teachers, involves beliefs and feelings they have towards teaching STEM projects within the school context. Van Aalderen-Smeets and Walma van der Molen (2013) constructed a Dimensions of Attitude towards Science (DAS) questionnaire based on their framework for attitude (Van Aalderen-Smeets et al. 2012).The DAS was developed in the context of Dutch elementary school teachers teaching science, including questions about teachers' personal and professional attitude. As we are interested only in STEM teachers' attitudes towards supervising research and design activities in a school context, we adopted the framework of Van Aalderen-Smeets et al. (2012) and based our questionnaire on the professional attitude section in the DAS and on the corresponding theoretical model. Another reason for the choice of this model is its inclusion of the construct of self-efficacy.

Van Aalderen Smeets et al. (2012) adapted the traditional tripartite attitude model consisting of the components cognition, affect and behaviour (Eagly and Chaiken 1993). They added the component of perceived control (see Fig. 2.1 in chapter 2), consisting of the subcategories Self-efficacy and Context Dependency. Self-efficacy is the belief in one's capabilities to perform on a certain task (in our case supervising research and design activities) and is informed by one's prior experiences such as successes and failures, and by feedback (Bandura 1997; Jones and Legon 2014). Self-efficacy has been shown to be correlated with teachers' attitudes, among other factors as prior knowledge and experiences (Jones and Legon 2014), and is also a predictor for teacher behaviour and the success of educational reform (Jones and Legon 2014). Context Dependency is the beliefs and feelings teachers have about the influence of external factors on their teaching, for example the influence of available time, support and teaching materials on their lessons (Van Aalderen-Smeets et al. 2012).

Van Aalderen-Smeets et al. (2012) also divide the cognitive and affective components of the attitude model into different subcategories. The Cognitive Beliefs component consists of the subcategories perceived relevance, perceived difficulty, and gender beliefs. In the context of professional attitude, perceived relevance refers to the importance that a teacher assigns to teaching a topic, stating for example "It is important that students learn to carry out research and design activities". Perceived difficulty refers to one's belief regarding the general difficulty of a topic (in our case, supervising research or design activities), and is a predictor to most behavioural intentions and behaviour (Trafimow et al. 2002). Gender beliefs refers to the beliefs that teachers have about the role of gender in teaching or learning a certain topic. The Affective States component consists of the subcategories enjoyment and anxiety Enjoyment refers to positive emotions, for example, enthusiasm, when teaching a topic (in our case, supervising research or design activities). Anxiety refers to negative emotions, for example, feeling nervous, when supervising research or design activities.

3.2.3 Research goal

This study aims to examine the attitudes of two different STEM teacher populations (from the subjects O&O and NLT) towards supervising research and design activities. This study differs from other studies that primarily focus on teachers' attitudes towards single science subjects, especially mathematics (Ernest 1989; Mensah et al. 2013), or science and technology in general, especially in primary school (Palmer 2004; Tosun 2000; Van Aalderen-Smeets and Walma van der Molen 2013). The subject O&O can in some cases differ substantially from teachers' original subjects because teachers in languages, art or history can also supervise projects in this STEM-oriented subject. Thus, O&O teachers of these non-science disciplines are perhaps comparable to primary school teachers who teach science. Primary school teachers often have negative attitudes and experience anxiety when teaching science (Van Aalderen-Smeets et al. 2012). We might expect that this could also be the case for the non-science teachers who teach O&O. However, O&O teachers often choose themselves to teach this subject, whereas primary school teachers are obliged to also teach science to their students. Teacher autonomy and opportunity to make choices themselves is positively associated with teacher engagement and job satisfaction (Skaalvik and Skaalvik 2014). Based on the study design and the theoretical background, we expected to find some differences between O&O and NLT teachers as these teacher populations vary. We expected O&O teachers to have more positive attitudes than NLT teachers supervising design activities, and NLT teachers to have more positive attitudes than O&O teachers supervising research activities. Overall, we expected quite positive attitudes in both groups of STEM teachers as they have mostly chosen to teach these subjects themselves.

3.3 Method

3.3.1 Context: the Dutch STEM subjects O&O and NLT

The subject O&O was introduced in The Netherlands in 2004 in so-called Technasium schools which are certified to teach this subject. The subject was first introduced in a few local schools as a bottom-up initiative by parents and educators. Fourteen years later, there are 94 certified Technasium schools all over The Netherlands. The subject O&O mainly aims to (1) acquaint students with professions related to STEM, and (2) stimulate students to develop skills as competent researchers and designers by letting them handle up-to-date and authentic questions in the science and engineering sector (SLO 2014). To reach these goals, groups of students conduct open research projects and design projects related to STEM. The project topics are provided by local companies and stakeholders who act as 'clients'. In the projects, often multiple STEM domains are involved, for example a combination of science and engineering, or technology and engineering. This, and the link to authentic practices, makes O&O an integrated STEM subject. In one example of an O&O project, a local petting zoo asks students to develop a game for visitors; in another , a local company asks students to optimize an algae reactor and identify factors that influence algae growth. O&O teachers are not content specialists regarding for example algae growth or game development, but rather act as coaches to help the students complete their projects and to help them acquire certain skills like teamwork and project management.

Each project takes about 10 weeks in grades 7-10 (ages 12-16); in grades 11-12 (ages 16-18) students choose projects themselves which last for 20 or 40 weeks. In the lower grades, teachers have written material available to provide their students with steps to complete the project, for example by partial assignments like 'the client wants to see five detailed sketches'. In the upper grades, students can choose their projects themselves, and eventually approach clients and stakeholders themselves to create their own project. During the subject O&O, students are assessed on their process (50%) and their product (50%). There are no standardized knowledge tests involved as skill development is the main goal of O&O. Students are expected to integrate conceptual knowledge they learned in other subjects in their projects. Teachers assess student skills through written project reports, portfolios, meetings with the student groups, presentations and the final product. Sometimes, when students need information about a certain topic or skill, the teacher can decide to give a workshop, but mostly, the teachers just supervise and coach the students during their projects without giving lectures. Teachers of all subjects can become certified O&O teachers by completing six courses provided by the Technasium foundation: (1) Introduction to O&O; (2) Writing an O&O project; (3) Supervising project management; (4) Supervising and coaching of students; (5) Assessment and evaluation; and (6) Contact with companies and stakeholders. Teachers also have to write and teach an O&O project themselves before getting their certificate. Every year, the Technasium foundation provides a week of additional schooling to help teachers become advanced O&O teachers.

The subject NLT (Dutch abbreviation for Nature, Life and Technology) was introduced in The Netherlands in 2007 as a government initiative. About 220 schools are registered as NLT-schools, and 165 schools were members of the NLT association in August 2017. The main aims of NLT are (1) increasing attractiveness of STEM education to increase the flow on to higher STEM education, and (2) increase the coherence of the separate STEM subjects (Krüger and Eijkelhof 2010). NLT differs from the traditional single disciplinary subjects such as geography, biology, chemistry, physics and mathematics in four ways: (1) NLT is interdisciplinary; (2) NLT has a stronger emphasis on career orientation in science and technology fields; (3) NLT integrates technology and science; and (4) NLT shows how mathematics is used within science and technology topics (SLO 2012). Like O&O, NLT is a context based subject that also often employs projects. Students participate in structured modules of 8-10 weeks each related to STEM, such as designing tools related to the biomedical sciences, or researching the technical aspects of clean water supply. Usually, a NLT module includes some kind of research activity or project for the students. Unlike O&O, NLT has a stronger emphasis on developing science concept knowledge as well, in addition to development of skills. Therefore, the subject NLT sometimes includes knowledge tests to assess students, in addition to their written project reports, portfolios, products and presentations. NLT is interdisciplinary in the sense that the problems in the modules lie 'in between' disciplines of science (such as physics, chemistry, biology, mathematics, computer science and earth science), for example problems in fields of climate, environment, and ICT (Eijkelhof and Krüger 2009). NLT is an integrated STEM subject as technology and mathematics also play an important role in these interdisciplinary problems, and because students participate in modules linked to authentic contexts. NLT teachers are teachers who are qualified in single science subjects: physics, mathematics, chemistry, biology and geography. There is no official teacher education or qualification for NLT, but teachers can attend an annual NLT convention which offers short lectures and workshops for overseeing modules. Also, NLT teachers can attend general science teacher professional development courses.

O&O is mainly an elective subject that is taught 4-6 hours a week in all grades 7 to 12 (ages 12-18) of Technasium schools. Unlike O&O, NLT is only taught in grades 10 to 12 (ages 16-18), sometimes mandatory but often as an elective subject, for about 3-4 hours a week. In both NLT and O&O, students conduct research and design activities. Design activities are more common in O&O than in NLT. In general, teachers have more experience in supervising research activities than in supervising design activities because science and inquiry-based methods often receive more attention in schools than the engineering design process (Hoachlander and Yanofsky 2011). Because teachers can often choose voluntarily to teach the subjects O&O and NLT, it is likely that they also have affinity with supervising research and design activities in integrated STEM, suggesting a default positive attitude. However, if schools face a shortage of O&O or NLT teachers, teachers will be appointed to teach O&O or NLT by the school management.

3.3.2 *Participants*

We approached O&O and NLT schools for this study by selecting schools from databases on the Technasium and NLT subject websites. We invited O&O and NLT teachers to participate in our study by emailing the section heads of departments. Teachers who replied, distributed the questionnaires to other teachers in their O&O or NLT department. In total, 234 questionnaires were sent to O&O and NLT teachers; distributed as hardcopies by post to be received by the teacher who acted as our contact person. In total, 147 questionnaires were returned from 55 schools situated all over The Netherlands. We approached a larger number of NLT-schools than Technasium schools because in NLT-schools, often only 1 or 2 teachers taught NLT, whereas in Technasium schools, O&O teacher teams were generally larger. We obtained passive informed consent from the teachers via an instruction letter. Ethical approval was obtained from the ethics committee of Leiden University Graduate School of Teaching.

Questionnaires that were less than half completed were excluded from the analysis. We also excluded teachers who taught both the subjects O&O and NLT at the moment of filling in the questionnaire to prevent ambiguity in the results as we aimed to compare O&O and NLT teachers. In total, 78 O&O teachers and 52 NLT teachers were included in further analyses (Table 3.1). Most NLT teachers had an academic (University) degree in science; this is also one of the requirements for NLT teachers. O&O teachers had various educational degrees, mostly in Higher Vocational Education, which entails more practice oriented studies (including teacher education), and university. This means that they could have some experience with studying science; however as we do not know which studies the teachers attended, we cannot make any statements about that. Almost all teachers taught different subjects besides teaching O&O or NLT. All NLT teachers also taught science subjects, mostly physics, chemistry and biology. Two NLT teachers also taught history, but always combined with NLT and another science subject. Of the O&O teachers, 12 only taught the subject O&O. Two teachers taught another, unspecified subject in addition to O&O, while nine teachers taught a science and a non-science subject in addition to O&O. Forty teachers exclusively taught science subjects in addition to O&O: physics, biology, mathematics, chemistry, public understanding of science and geography. Because geography teachers are also allowed to teach NLT, in this chapter, we characterise geography as a science subject to control the comparison between O&O and NLT teachers. Fifteen O&O teachers exclusively taught non-science subjects besides O&O: history, languages, philosophy and management

Table 3.1 Basic characteristics of participants.

Categories		Total (*n*)	O&O teachers (*n*)	NLT teachers (*n*)
Nr. of teachers		130	78	52
Gender	Male	82 *63%*	49 *63%*	33 *63%*
	Female	48 *37%*	29 *37%*	19 *37%*
Age groups (freq.)	18-25 years	3 *2%*	3 *4%*	0 *0%*
	26-35 years	37 *28%*	27 *35%*	10 *19%*
	36-45 years	31 *24%*	16 *20.5%*	15 *29%*
	46-55 years	28 *22%*	16 *20.5%*	12 *23%*
	56 years and up	30 *23%*	15 *19%*	15 *29%*
	Missing	1 *1%*	1 *1%*	0 *0%*
Teaching experience (freq.) in total	Less than 2 years	5 *4%*	4 *5%*	1 *2%*
	2-5 years	15 *12%*	13 *17%*	2 *4%*
	6-10 years	37 *28%*	22 *28%*	15 *29%*
	11-15 years	29 *22%*	16 *21%*	13 *25%*
	16 years and up	44 *34%*	23 *29%*	21 *40%*
Teaching experience (freq.) in O&O or NLT	Less than 1 year	6 *4.5%*	5 *6%*	1 *2%*
	1-2 years	19 *14.5%*	10 *13%*	9 *17%*
	3-5 years	39 *30%*	29 *37%*	10 *19%*
	6 years And up	66 *51%*	34 *44%*	32 *62%*
Highest educational degree	Lower vocational	4 *3%*	3 *4%*	1 *2%*
	Higher vocational	48 *37%*	43 *55%*	5 *10%*
	University	64 *49%*	28 *36%*	36 *69%*
	PhD	14 *11%*	4 *5%*	10 *19%*
Experience with doing research	Yes, during my study	106 *82%*	61 *78%*	45 *87%*
	Yes, during a former job	49 *38%*	26 *33%*	23 *44%*
	Yes, during a job I perform in addition to teaching	7 *5%*	6 *8%*	1 *2%*
	No, never	4 *3%*	4 *5%*	0 *0%*
Experience with conducting a design	Yes, during my study	60 *46%*	39 *50%*	21 *40%*
	Yes, during a former job	35 *27%*	23 *29%*	12 *23%*
	Yes, during a job I perform in addition to teaching	6 *4.5%*	3 *4%*	3 *6%*
	No, never	44 *34%*	23 *29%*	21 *40%*

and organization. We compared these last two groups of O&O teachers to explore possible differences between teachers with an exclusive science background and teachers with an exclusive non-science background.

3.3.3 Design of the questionnaire

Our Attitudes towards Supervising Research And Design Activities (ASRADA) questionnaire was based on the Dimensions of Attitude towards Science (DAS) questionnaire (Van Aalderen-Smeets and Walma van der Molen 2013), which has been used in the context of elementary school teachers teaching science. As this questionnaire was already constructed in Dutch, there were no translation issues. We adapted the items of DAS to the context of teachers in secondary school, and their attitudes towards *supervising research and design activities*, instead of *science*. For the ASRADA questionnaire, we used the attitude components of Van Aalderen-Smeets et al. (2012) (see Fig. 2.1 in chapter 2): Relevance, Difficulty, Enjoyment, Anxiety, Self-Efficacy, Context Dependency, and Behavioural Intention. The subcategory Gender beliefs was excluded as gender beliefs were not within the scope of this study. The Behavioural Intention component included items on whether teachers intended to attend professional development courses to learn more about supervising research and design activities, instead of asking them whether they intended to supervise *more* research and design activities within the subject O&O or NLT because these subjects already solely consist of research and design assignments. The questions in every component were asked twice: once for the topic of supervising research activities, and once for supervising design activities. The wording of the items was checked by several teacher educators for clarity and consistency. Items were scored on a 1-5 Likert scale, where 1 = strongly disagree and 5 = strongly agree. The complete ASRADA questionnaire was constructed in Dutch and is available upon request (for example items, see Appendix 2).

3.3.4 Analyses

The questionnaires were scanned into the computer and data were converted to an SPSS file. We included partly incomplete questionnaires because some teachers only left a few items unanswered. As a consequence, questionnaires with missing values in a certain category were excluded from analyses regarding that category, causing slightly different numbers of individual questionnaires per analysis.

The ASRADA questionnaire was constructed to include 27 items on attitude towards supervising research activities and 27 items on attitudes towards doing design activities. After exclusion of items that lowered Cronbach's alpha (α), the ASRADA consisted of 51 items in total: 20 items on attitude towards supervising research activities, 22 items on attitudes towards doing design activities, and 9 items on personal variables. The internal consistency for all sub-categories in the attitude scale was determined by calculating

Cronbach's alpha (α) (Table 3.2). The Cronbach's alpha for the research component of the attitude scale was 0.76, and 0.85 for the design component, making the instrument of sufficient reliability. Calculations for each category were based on slightly different numbers of individual questionnaires as we decided to include questionnaires with some missing values. Exploratory principal component analyses (PCA) showed that the items sufficiently clustered according to the seven subcategories of the attitude model. An instrument very similar to the ASRADA from a previous study on attitudes of secondary school students towards *doing* research and design activities (Vossen et al. 2018), which was also based on the DAS, showed a similar clustering of all attitude components with even more participants [*n*=1625] and in additional confirmatory factor analyses, suggesting that the categories in the questionnaire are quite stable.

3

Table 3.2 Cronbach's alpha for the scales for teacher attitudes towards supervising research and design activities.

	Supervising research activities						
Main category	Sub category	Number of items	α	*M*	SD	SE	Number of teachers
Cognition	Relevance	3	0.75	4.10	1.88	0.17	127
	Difficulty	3	0.73	3.29	1.96	0.18	121
Affection	Enjoyment	3	0.87	4.06	2.23	0.20	129
	Anxiety	4	0.79	1.70	2.43	0.21	129
Perceived Control	Self-efficacy	3	0.77	4.06	1.74	0.15	128
	Context dependency	2	0.74	3.41	1.71	0.15	129
Behaviour	Intention	2	0.68	3.17	1.97	0.17	128
Average			0.76				
	Supervising design activities						
Main category	Sub category	*N* items	α	*M*	SD	SE	*N* teachers
Cognition	Relevance	4	0.83	3.77	2.96	0.26	128
	Difficulty	2	0.80	3.05	1.57	0.14	123
Affection	Enjoyment	3	0.92	4.08	2.33	0.21	125
	Anxiety	4	0.85	1.79	2.76	0.25	127
Perceived Control	Self-efficacy	4	0.90	3.84	3.03	0.27	127
	Context dependency	3	0.77	3.36	2.47	0.22	124
Behaviour	Intention	2	0.91	3.08	2.23	0.20	127
Average			0.85				

Notes: Total number of teachers was *n*=130. α = Cronbach's alpha, *M* = mean, SD = standard deviation, SE = standard error. Note that due to the algorithm for Cronbach's alpha, all teachers with missing values were excluded from the analysis of each subcategory.

We analysed differences *between* the O&O teacher group and the NLT teacher group by using a multilevel analyses approach that corrects for the extra variance in the data given that teachers in our sample all came from different schools. Multilevel analyses were also applied to the data to search for possible differences *between* O&O teachers with a science background and O&O teachers with a non-science background. To discover whether any differences between their attitudes towards supervising research or design activities existed *within* the O&O teacher group and *within* the NLT teacher group, paired samples *t*-tests were applied. All analyses were performed with IBM SPSS Statistics version 22.

3

3.4 Results

The subheadings in this section correspond to the research questions of this study as stated in the Introduction.

3.4.1 General attitudes of STEM teachers towards supervising research and design activities

The overall attitude towards supervising research and design activities of all STEM teachers in this study was fairly positive. Teachers scored highest on the subcategories Relevance [see Table 3.2; research: *M*=4.10 | design: *M*=3.77], Enjoyment [research: *M*=4.06 | design: *M*=4.08] and Self-Efficacy [research: *M*=4.06 | design: *M*=3.84] on both components (research and design) of the ASRADA. This means teachers found supervising research or design activities a relevant activity, they enjoyed supervising research and design activities and also perceived high self-efficacy while supervising students doing research or design activities. Relevance of supervising research activities was scored higher by the respondents than the Relevance of supervising design activities. The lowest scoring subcategory was Anxiety [research: *M*=1.70 | design: *M*=1.79], meaning teachers did not feel anxious while supervising student research or design activities. Teachers scored neutral to slightly positive on the subcategory of Behavioural Intention [research: *M*=3.17 | design: *M*=3.08], which means that on average, they showed no disinterest, but also no clear intention to participate in teacher professional development courses aimed at supervising research or design activities.

3.4.2 Differences between two different groups of STEM teachers (O&O and NLT)

In the multilevel analyses in which we compared the attitudes *between* O&O and NLT teachers, we found that attitudes towards supervising research activities were similar for both O&O and NLT teachers as we found no significant differences between the subcategories for research. It seemed like O&O teachers were somewhat more positive than

NLT teachers towards taking professional development courses in supervising research (Behavioural Intention) [O&O: *M*=3.31, SD=0.93 | NLT: *M*=2.98, SD=1.06], but this result was not significant [p=0.058]. However, some clear differences existed between O&O and NLT teachers regarding their attitudes towards supervising design activities. O&O teachers scored significantly higher [p<0.01] on the subcategories Enjoyment [*M*=4.26, SD=0.66], Self-Efficacy [*M*=3.97, SD=0.70], Context [*M*=3.68, SD=0.68] and Behavioural Intention [*M* =3.28, SD=1.11] than NLT teachers [respectively *M*=3.75, SD=0.88 | *M*=3.58, SD=0.81 | *M*=2.81, SD=0.78 | *M*=2.76, SD=1.08], meaning they enjoyed supervising design activities more, experienced more self-efficacy, experienced better enabling contexts to supervise design activities (like available materials) and were more positive towards participating in professional development courses aimed at supervising design activities than NLT teachers. NLT teachers scored significantly higher [p<0.01] on the subcategories Difficulty [NLT: *M* =3.33, SD=0.59 | O&O: *M*=2.95, SD=0.71] and Anxiety [NLT: *M* =1.99, SD=0.80 | O&O: *M*=1.66, SD=0.58], which means they saw supervising design activities as more difficult and experienced more anxiety while supervising design activities than O&O teachers.

Within the two teacher populations, there were also differences between teachers' attitudes towards supervising research activities and their attitudes towards supervising design activities (Table 3.3). Results from a paired samples *t*-test showed that O&O teachers scored significantly higher [p<0.001] on Difficulty towards supervising research activities [*M* =3.31, SD=0.63] compared to supervising design activities [*M* =2.95, SD=0.71], and significantly higher [p<0.05] on the subcategories Enjoyment [*M* =4.26, SD=0.66] and enabling Context [*M* =3.68, SD=0.68] for supervising design activities compared to supervising research activities [respectively *M*=4.03, SD=0.75 | *M*=3.49, SD=0.79]. There were no significant differences in the subcategories Anxiety, Self-efficacy and Behavioural Intention. Within the NLT group, teachers scored significantly higher [p<0.05] on the subcategories Enjoyment [research: *M*=4.09, SD=0.73 | design: *M*=3.75, SD=0.88], Self-efficacy [research: *M*=4.16, SD=0.63 | design: *M*=3.58, SD=0.81], Context [research: *M*=3.28, SD=0.95 | design: *M*=2.81, SD=0.78] and Behavioural Intention [research: *M*=2.98, SD=1.06 | design: *M*=2.76, SD=1.08] to attend professional development regarding supervising research activities, whereas they scored significantly higher on Anxiety towards supervising design activities [design: *M*=1.99, SD=0.80 | research: *M*=1.61, SD=0.58]. Teachers within both groups scored significantly higher on the subcategory Relevance [O&O: *M*=4.13, SD=0.66 | NLT: *M*=4.10, SD=0.60] regarding the supervision of research activities, in comparison to supervising design activities [O&O: *M*=3.83, SD=0.73 | NLT: *M*=3.62, SD=0.80].

Table 3.3 Differences in attitudes between supervising research and design activities *within* the O&O teacher group and *within* the NLT teacher group.

		O&O teachers (n_{tot}=78)					**NLT teachers (n_{tot}=52)**				
Main category	**Sub category**	**Research**		**Design**		**Sign.**	**Research**		**Design**		**Sign.**
		Mean	SD	Mean	SD	p	Mean	SD	Mean	SD	p
Cognition	Relevance	4.13	0.66	3.83	0.73	**<0.001**	4.10	0.60	3.62	0.80	**<0.001**
	Difficulty	3.31	0.63	2.95	0.71	**<0.001**	3.24	0.67	3.33	0.59	0.199
Affection	Enjoyment	4.03	0.75	4.26	0.66	**0.023**	4.09	0.73	3.75	0.88	**<0.001**
	Anxiety	1.76	0.62	1.66	0.58	0.249	1.61	0.58	1.99	0.80	**<0.001**
Control	Self-efficacy	4.00	0.54	3.97	0.70	0.789	4.16	0.63	3.58	0.81	**<0.001**
	Context	3.49	0.79	3.68	0.68	**0.023**	3.28	0.95	2.81	0.78	**0.001**
Behaviour	Intention	3.31	0.93	3.28	1.11	0.698	2.98	1.06	2.76	1.08	**0.021**

Notes: Due to individual missing values *n* is different for every category. For O&O teachers *n* varies between 75 and 78. For NLT teachers *n* varies between 50 and 52. Significant p-values are indicated in **bold**.

3.4.3 Differences between science and non-science O&O teachers

Within the group of O&O teachers, there are teachers who, besides O&O, exclusively taught science subjects [*n*=40], and teachers who exclusively taught non-science subjects (like history and languages) [*n*=15]. When comparing differences *between* these two teacher groups with multilevel analyses, we found a significant difference in the subcategory of Behavioural Intention, despite the low sample sizes. Non-science teachers scored significantly higher [P<0.05] than science teachers on items stating they would consider joining teacher professional development opportunities in supervising research [non-science: *M*=3.77, SD=0.78 | science: *M*=3.09, SD=0.91] or design [non-science: *M*=3.80, SD=1.00 | science: *M*=3.03, SD=1.07].

Paired samples *t*-tests showed that *within* the O&O teachers with a science background, teachers scored items on Relevance [*M*=4.08, SD=0.67] and Difficulty [*M*=3.32, SD=0.70] of supervising research activities significantly higher [P<0.01] compared to Relevance [*M*=3.76, SD=0.73] and Difficulty [*M*=2.93, SD=0.79] of supervising design activities (Table 3.4). This means that the science teachers viewed supervising research activities as more relevant than design activities, but also thought that supervising research activities is more difficult for teachers in general than supervising design activities. Non-science O&O teachers also scored significantly higher on the Difficulty scale for supervising research [research: *M*=3.24, SD=0.68 | design: *M*=2.91, SD=0.66], but the difference between the relevance of supervising research activities [*M*=4.09, SD=0.71] versus supervising design activities [*M*=3.88, SD=0.81] was not significant [p=0.228].

Table 3.4 Differences in attitudes towards doing research and design activities *within* O&O teachers with a science background and *within* O&O teachers with a non-science background.

		Science teachers (n_{tot}=40)					Non-science teachers (n_{tot}=15)				
Main category	**Sub category**	**Research**		**Design**		**Sign.**	**Research**		**Design**		**Sign.**
		Mean	SD	Mean	SD	p	Mean	SD	Mean	SD	p
Cognition	Relevance	4.08	0.67	3.76	0.73	**0.004**	4.09	0.71	3.88	0.81	0.228
	Difficulty	3.32	0.70	2.93	0.79	**0.009**	3.24	0.68	2.91	0.66	**0.046**
Affection	Enjoyment	4.07	0.78	4.19	0.73	0.358	4.07	0.67	4.36	0.64	0.183
	Anxiety	1.65	0.52	1.68	0.58	0.747	1.80	0.75	1.53	0.50	0.205
Control	Self-efficacy	4.05	0.47	3.96	0.65	0.391	3.87	0.57	3.80	0.72	0.704
	Context	3.47	0.73	3.71	0.65	0.066	3.50	0.73	3.52	0.74	0.849
Behaviour	Intention	3.09	0.91	3.03	1.07	0.554	3.77	0.78	3.80	1.00	0.849

Notes: For science teachers, total n = 40, however due to individual missing values n is different for every category, varying between 37 and 40. Significant p-values are indicated in **bold**.

3.5 Discussion

Teacher experiences, attitudes and beliefs in integrated STEM subjects have not yet been studied extensively. This study aims to contribute to decreasing this knowledge gap in literature. The subjects O&O and NLT provide us with a unique situation in which we can study two types of STEM-based subjects, instead of shorter STEM-based projects. The instrument that was developed for this study could also contribute to further, international, studies into teachers' attitudes in delivery of STEM subjects. The subheadings in this section correspond to the research questions of this study as stated in the Introduction.

3.5.1 General attitudes of STEM teachers towards supervising research and design activities

Overall, we found that the responding STEM teachers held fairly positive attitudes towards supervising research activities and design activities (research question 1). Previous studies also show that both teachers and students hold positive attitudes towards contemporary teaching methods like inquiry and design based learning (Ara et al. 2011; Damnjanovic 1999; Savelsbergh et al. 2016). Teachers in The Netherlands can mostly choose whether they would like to teach O&O or NLT, and such voluntary choices and degree of autonomy are positively related to engagement, job satisfaction (Skaalvik and Skaalvik 2014), and perhaps also to attitude.

In general, teachers viewed supervising research activities as a more relevant activity than supervising design. This indicates that teachers in general find it more important that students learn how to do research than how to conduct a design. A previous study found that students in general also rate the relevance of doing research activities higher than doing design activities (Vossen et al. 2018). We know that inquiry, or doing research, has long been a desirable skill for students to acquire (Welch et al. 1981; Crawford 2014), and Hoachlander and Yanofsky (2011) have found that engineering components of STEM (such as design) have been given less attention than science components (like doing research). Another remarkable outcome of this study was that all teachers scored rather high on self-efficacy. The teachers in this study thus had high feelings of competence even though they were not extensively trained to teach STEM subjects. One might expect a lower self-efficacy in teachers who teach a fairly innovative subject, especially in O&O teachers who supervise design activities as not many of them have a background in design themselves. However, this was not the case. Previous research also found that teachers may hold exaggeratedly positive self-efficacy towards teaching science even if they had no experience (Settlage et al. 2009). Other studies have found that low performing people often hold overly favourable views of their abilities, while high performing people tend to slightly underestimate their abilities; the so-called Dunning-Kruger effect (Dunning 2011; Kruger and Dunning 1999; Schlösser et al. 2013). As Tschannen-Moran and Hoy (2007, p.5) mention: "It is important to note that self-efficacy is a motivational construct based on self-perception of competence rather than actual level of competence.". Reviewing the correlations in our data between the ASRADA subcategories, the categories Self-efficacy and Enjoyment had the highest correlation. Rather than actual competences, the teachers' high self-efficacy could also be related to high feelings of enthusiasm as literature shows that teacher attitude has only very loose correlations to actual teacher knowledge (Allum et al. 2008).

3.5.2 Differences between two different groups of STEM teachers (O&O and NLT)

When comparing attitudes towards supervising research activities and supervising design activities *between* O&O and NLT teachers, we found no significant difference in their attitudes towards supervising research activities. However, in comparison to O&O teachers, NLT teachers perceived more difficulty when supervising design activities. When comparing the attitudes towards supervising research activities and supervising design activities *within* O&O and NLT teachers, we found that O&O teachers were somewhat more positive towards supervising design activities than towards supervising research activities (except on the subcategory Relevance), and NLT teachers were more positive about supervising research activities than about supervising design activities. It seems that teachers tend to rely on their own backgrounds: NLT teachers are qualified teachers of science subjects, and thus they are more used to teaching scientific research methods instead of supervising design. O&O teachers, on the other hand, are a more diverse group of teachers with experience in both supervising research and design activities because about half of the projects in O&O are design-based, and about half are research-based. O&O teachers, like O&O students

3

in an earlier study (Vossen et al. 2018), appear to find supervising or conducting design activities significantly more enjoyable than research activities. It is possible that teachers and students of O&O perceive designing as an activity that has less to do with content knowledge, and therefore finding it 'easier' and more enjoyable. Because most teachers can voluntarily choose to teach O&O or NLT, the subjects might attract different types of teachers. It is also possible that because of their lack of experience with design projects, NLT teachers are more negative about supervising design activities than O&O teachers.

3.5.3 Differences between science and non-science O&O teachers

The group of non-science O&O teachers could in a way be compared to primary school teachers as both of these groups have no specific prior experience in teaching STEM. However, in contrast to the low self-efficacy for teaching science in primary school teachers (Tosun 2000), the non-science O&O teachers surprisingly also had high feelings of self-efficacy towards supervising research activities and design activities, not significantly different from the science teachers. These feelings of high self-efficacy could be related to teacher autonomy: primary school teachers are often obliged to teach science somewhere in their curriculum, and most O&O teachers are free to choose whether they want to teach this subject. Even though their self-efficacy was high, the non-science O&O teachers had significantly more interest in attending professional development courses than the science O&O teachers. This could indicate that although they already feel competent and enthusiastic, they acknowledge that their competence could grow by acquiring more knowledge and skills for supervising research activities and design activities. They might also be aware of their non-science background. Interestingly, the science O&O teachers and the NLT teachers scored neutral on their intentions to take professional development courses. Because of their background in science, science O&O teachers may think they do not need further professionalization. In contrast, they might feel there are already enough suitable courses available for them as there are many options for science teacher professionalization in The Netherlands.

3.5.4 Limitations & Implications

As ours was a quantitative study with a closed questionnaire, it would be interesting to include more information about teachers' backgrounds and teaching practices in qualitative follow-up studies. In this study, we only had limited information on the teachers' prior education and their experience with conducting research and design themselves. It would be worth discovering the nature of these teaching and learning experiences, and their influence on the development of teacher attitude and the enacted pedagogies during their O&O or NLT lessons. It could be that the more experience teachers have doing research or design tasks themselves, the more positive their attitudes. As we had no information on which teachers had more in-depth experiences in doing research or design than other teachers, we cannot answer this question. Qualitative follow-up studies should also consider student views on the way they are supervised during these research and design activities. Gender beliefs were not within the scope of this study; however, they can influence the way in which teachers approach students (Shepardson and Pizzini 1992). Therefore, additional research on gender beliefs regarding the execution and supervision of research and design problems would be desirable to give more insight into gender beliefs within STEM teachers and students.

Further research is needed to explore why STEM teachers had such high-self-efficacy scores about supervising research and design activities even when they had received no special education in doing so. Their high self-efficacy might not be related to actual competence (Tschannen-Moran and Hoy 2007), but to high levels of enjoyment. It would be interesting to examine these relations between self-efficacy, enjoyment, and actual competences further in future research, for example by triangulating teachers' own self-efficacy with other measures of their effectiveness (such as classroom observations, student outcomes and student perceptions of the quality of teacher supervision), and examining the exact correlation between Enjoyment and Self-efficacy scores. It is, however, a promising result that these STEM teachers have high feelings of self-efficacy as this has been shown to be positively related to teacher perseverance (Bandura 1997; Palmer 2006) and student performance (Ashton and Webb 1986). Teachers' satisfaction with their choice of profession can also relate to high feelings of self-efficacy (Caprara et al. 2006), and O&O and NLT teachers can indeed mostly choose voluntarily whether they want to teach STEM.

3

3.6 Conclusion

The teachers in this study generally found supervising research activities significantly more relevant than supervising design activities. The explanation for this finding should be examined further. National and international curricula already emphasize the importance of the engineering design process (NGSS 2013; SLO 2015); however, the implementation of design activities in schools might not reflect this. The integration of research and design activities are common practice in some university programs and in the professional world (Sanders and Stappers 2008). STEM teacher education should therefore not only familiarize teachers with supervising research activities, but with design activities as well.

The results of this study indicate that there is a need for additional STEM teacher professional learning development, especially for non-science teachers who are beginning to teach in STEM subjects as well. Since STEM teachers have different backgrounds, it is important that ample time, support and professional development courses are provided to them (Stohlmann et al. 2012). Teacher professional development is often aimed at the *content* of STEM projects, but for learning to supervise research and design processes, the *pedagogy* for supervising such projects should also be emphasized. Also, teachers might need first-hand experiences in carrying out research and design activities themselves as not all O&O and NLT teachers necessarily have done this before during their education or career. Instead of already existing courses for single subjects, courses specifically aimed at integrated STEM could attract more STEM teachers and could enhance their willingness to attend such professional development opportunities.

Chapter 4

Finding the connection between research and design: the knowledge development of STEM teachers in a professional learning community

This chapter is based on:
Vossen, T. E., Henze, I., De Vries, M. J., & Van Driel, J. H. (2019). Finding the connection between research and design: the knowledge development of STEM teachers in a professional learning community. *International Journal of Technology and Design Education*, 1-26.

Abstract

Research and design activities are becoming more important in Science, Technology, Engineering and Mathematics (STEM) and D&T (design and technology) education. Research and design are often taught separately from each other, while in professional STEM practices, many projects are neither 'research only' or 'design only' – they are both. In this study, we aimed to provide insights in teachers' personal and shared knowledge on how research and design can be connected. To this end, we examined the development of pedagogical content knowledge (PCK) and beliefs of six teachers of the Dutch STEM subject O&O (research and design), who participated in a professional learning community (PLC) aimed at connecting research and design within this subject. Results of pre and post-PLC interviews showed that teachers' personal PCK was very diverse, probably due to their different beliefs, backgrounds and teaching contexts. Through jointly designing instructional strategies for connecting research and design, teachers contributed to a collective knowledge base. The results of this study indicate that a professional learning community in which teachers with varying backgrounds construct knowledge and instructional strategies together, can be a powerful method to enhance personal PCK and collective knowledge. These are promising outcomes in the light of shaping professional development activities for STEM and D&T teachers, which in turn aims to provide students with a holistic and realistic view on current professional STEM fields.

4.1 Introduction

Research and design activities are considered core processes in STEM (Science, Technology, Engineering and Mathematics) and D&T (Design & Technology) education (NGSS, 2013; NRC Framework, 2012; ITEA, 2007). Research and design activities are often implemented in STEM education as short-term projects, and often these projects specifically focus on researching or designing only. In reality, however, research and design activities overlap and connect within STEM professions (Sanders and Stappers 2008). Seeing the link between research and design and developing a view of the professional world in STEM are key learning goals mentioned in the NRC framework (2012 p. 42): "Engaging in the practices of engineering likewise helps students understand the work of engineers, as well as the links between engineering and science." Still, the practice of connecting science and engineering, or research and design, is not self-evident in education (Kolodner et al. 2003a; Van Breukelen et al. 2016). This gap between policy ("students should learn that research and design are connected in reality") and educational practice ("students conduct research projects and design projects separately") is to be bridged by the teacher. Often, D&T teachers or science teachers are expected to teach these integrated STEM practices, however virtually none of these teachers have a background or experience in combining research/science with design/engineering (c.f. Love and Wells 2018). Furthermore, like design and technology, combining research and design activities is a less established practice in education, when compared for example to inquiry in science education, and does not have a well-established epistemology (De Vries 2006; Doyle et al. 2019). It is unexplored what STEM teachers' knowledge is about connecting research and design in the classroom. It is therefore of interest to understand teachers' (often implicitly held) beliefs about the connection between research and design (Doyle et al. 2019), and how they develop pedagogical content knowledge (PCK), or 'knowledge and beliefs' (Van Driel et al. 1998), about this practice (De Vries 2015; Engelbrecht and Ankiewicz 2016).

In this chapter, we studied the knowledge development of teachers of the Dutch secondary school subject O&O (the abbreviation for 'onderzoeken en ontwerpen', which is Dutch for 'research and design'), a STEM oriented subject that consists of authentic research and design projects in STEM fields provided by local companies, within a professional learning community (PLC) aimed at connecting research and design. The subject O&O is a form of STEM education because it combines research projects (related to the Science component of STEM) and design projects (related to the Technology and Engineering components of STEM), and because the O&O projects all have STEM-related contexts (for example in the fields of architecture, industrial design or biology). As O&O is a relatively new and innovative subject, it is important to know the perceptions of teachers of the practices related to research and design, because teachers are the biggest influence on successfully implementing a new curriculum (Van Driel et al. 2001). While there are several studies trying to connect science and engineering (Apedoe et al. 2008), or science content to design activities (van Breukelen et al. 2016), studies on teacher knowledge about connecting research and design activities are scarce. With this study, we aimed to conduct a qualitative exploration of what teachers' personal PCK and beliefs on connecting research and design are, and how they develop over the course of a PLC. Several studies have stretched the importance of arranging professional development in the form of "communities of learning", where the expertise of teachers and experts meet to support meaningful shifts of practice (Butler et al. 2004; Hultén and Björkholm 2016). The notion that teachers construct their knowledge partly based on their existing knowledge and beliefs, and partly based on their participation in a learning community where they develop shared meanings, is consistent with constructivist learning theory (Borko et al. 1997). By bringing together teachers with varying backgrounds, we attempted to better understand their collective meaning making of the connection between research and design, through analyzing shared products they developed together. Therefore, our research questions are:

1. How can the development of teachers' personal PCK and beliefs about connecting research and design be characterised before and after a PLC?
2. How did teachers collectively give meaning to the connection between research and design during the PLC?

4.2 Theoretical framework

Research and design are often connected to each other, however both activities have separate goals and histories (Williams et al. 2012). Research is conducted by collecting and analysing data, to explore, explain or compare certain conditions (Creswell 2008). The goal of design activities is to develop or improve products or services (De Vries 2005). Many models of the research process and the design process have been described in literature (for example see Kolodner et al. 2003a; Mehalik et al. 2008; Van Dooren et al. 2014; Willison and O'Regan 2008). As researching and designing are dynamic practices, they have no fully agreed upon consensus models within the community (Vezino 2018). It is not the purpose of this chapter to give unambiguous definitions of research and design practices; however, we can mention a number of core elements for each activity. The research process generally consists of articulating a research question; generating hypotheses; planning the research; collecting data; organizing and analysing data; conclusions and discussion; and presenting the findings. The design process generally consists of clarifying the problem; assembling a program of requirements; planning the design; constructing a prototype; testing the prototype; optimizing the prototype; analysing the product; presenting the product to the client or target group. Research and design activities have thus quite similar structures and are both concerned with challenging, ill-structured problems or questions (Hathcock et al. 2015). Both processes are systematic, purposeful, tentative and both processes can inform each other (Vezino 2018). In the subject O&O (Dutch abbreviation for 'Research and Design'), which forms the context of this study, learning outcomes of research projects are specified as: the candidate can, within contexts, analyse questions, use relevant concepts and theory, develop a discipline specific research, choose a suitable research method, conduct the research, and draw conclusions from the results while using relevant knowledge, consistent reasoning and relevant mathematical skills (SLO 2014). Learning outcomes of design projects within the subject O&O are specified as: the candidate can, within contexts, expand a question into a design problem, choose a design method based on this problem, prepare, conduct, test and evaluate a technological design while using relevant concepts, theory, skills and valid and consistent reasoning (SLO 2014). As one of the aims of O&O is to give students a realistic idea of what research and design projects look like within real STEM professions, it is important that students not only learn to conduct research and design projects separately, but also that these activities have similarities and can be connected to each other. Furthermore, it is necessary for students to include research activities within their design projects to enhance the quality of their designed decisions and rise above a trial-and-error approach (Burghardt and Hacker 2004; Crismond and Adams 2012).

Research and design activities can be connected and intertwined, enhancing and informing one another. For example, doing research and thereby gaining knowledge is part of, and even necessary for designing (Downton 2003; Frankel and Racine 2010; Sanders and Stappers 2008). De Jong and Van der Voordt (2002) view research and design as activities on a gliding scale between art and science, in which design activities without research activities are a form of 'intuitive design' and can almost be labelled as art. In the overlapping area between research and design, the connection between these two activities can take multiple forms. Frankel and Racine (2010) describe three mechanisms: research for design, research through design, and research about design. Research *for* design can be explained as research to enable design, such as using qualitative and quantitative methods to find characteristics of materials used for the product, establish regulations and standards, obtain data on human physical characteristics and understand human behaviour (Downton 2003), but also user and usability testing. In research *through* design, the emphasis is on the research objective of creating design knowledge, not the project solution (Frankel and Racine 2010). In this case, the design itself helps to provide knew knowledge in a broader context. In research *about* design, one studies the design process – for example the history of design, design theory, and the analysis of design activity (Schneider 2007). Design activities can also play their part in a research process, for example, when designing a device to take measurements, or when designing experiments (Fallman 2003). In an educational context, the importance of conducting (scientific) research integrated within design projects has been mentioned in numerous studies (Apedoe et al. 2008; Kolodner et al. 2003b; Mehalik et al. 2008). Doing research or scientific inquiry is related to, and can be enhanced by the design process (Shernoff et al. 2017; Stohlmann et al. 2012). In her paper, Gunckel (2010) describes the application of the experiences-patterns-explanations (EPE) triangle (Anderson 2003), in which students must find patterns in their experiences with phenomena, and then attempt to explain those patterns. In the EPE triangle, doing research to discover patterns and theories is followed by application, for example by design. The cycles of research and design have a back and forth relationship in an integrated research and design lesson (Vezino 2018). Kolodner et al. (2003a) argue that this back and forth movement enhances students' learning of science through research and design activities.

In their approach to science education, called Learning By Design (LBD), Kolodner et al. (2003b) visualize this relationship between investigation (research) and design within STEM education (see Fig. 1.1 in chapter 1). They state that learning in the LBD cycle takes place through activities specific to investigating and designing. Whenever there is a 'need to know' during the design cycle, an investigation, or research, is conducted, in which students need to figure out which knowledge they need to complete the design challenge. The 'need to do', according to Kolodner et al. (2003a) consists of applying what students have learned through investigation in their design. In our study, we even take the interpretation of these two cycles one step further: students can move back and forth between the research and design cycle during the project, regardless whether the main focus of the project is researching or designing. Whenever students experience a 'need to know' – for example the need to know more about the topic of the design challenge, or about the users or target group – they move from the design cycle into the research cycle. Vice versa, whenever students experience a 'need to do'- the need to construct a measuring method, or the need to give practical recommendations that inform a product or service – they move from the research cycle into the design cycle.

Teachers need to be able to facilitate students in connecting the research and design cycles to each other. For that, they need specific knowledge and skills for guiding students in this practice, for which we will use the construct of pedagogical content knowledge (PCK). Shulman (1987) described this as: "that special amalgam of content and pedagogy that is uniquely the province of teachers, their own special form of professional understanding" (p. 8). The construct of PCK is often employed in topic-specific teaching contexts, for example: knowledge about chemical equilibrium in chemistry (Van Driel et al. 1998), or knowledge about photosynthesis in biology (Käpylä et al. 2009). However, PCK also applies to broader educational contexts, such as PCK about the practice of modelling (Henze et al. 2007; Justi and Van Driel 2005) or PCK about the Nature of Science (NOS) (Faikhamta 2013; Wahbeh and Abd-El-Khalick 2014). It is thus acknowledged in literature that PCK can be broad or narrow, and topic, discipline, or practice specific. In this study, we use the construct of PCK in a broad sense, meaning that the contents of PCK in our case are scientific practices (e.g. 'researching' and 'designing'). Content knowledge is a knowledge base essential for PCK (Gess-Newsome 2015). The teachers in our sample were expected to collectively possess basic content knowledge about research and design processes, as some of them had specific design backgrounds or experience with researching. In our study, the content of PCK is thus formed by the research and design processes, and we investigated teachers' knowledge about the teaching and learning of the connection between these research and design activities.

In the 2015 Consensus Model for PCK (Gess-Newsome 2015), PCK is influenced by other knowledge bases: the generic Teacher Professional Knowledge Bases (TPKB), like pedagogical knowledge and content knowledge, and Topic Specific Professional Knowledge (TSPK), which is dynamic and canonical knowledge constructed by experts and generated by research or best practice. In our study, the content of this knowledge base would be the research and design processes. These knowledge bases influence a teachers' personal PCK (pPCK), which is described as the knowledge of and reasoning behind teaching particular content, in a particular way, for a particular purpose, to particular students (Gess-Newsome 2015). pPCK is the teachers' unique and personal knowledge about teaching, informed by his/her beliefs and experiences, educational background, and interactions with others (Gess-Newsome 2015). Since the teachers in this study were interviewed about their personal knowledge before and after a PLC, we consider pPCK as a suitable construct to examine their knowledge. Furthermore, we were interested in the development of a shared, collective knowledge base of the O&O teachers as a group. During the PLC, the teachers constructed several products together. We already know from other studies that such activities can lead to enhanced teacher PCK (Coenders et al. 2010), and can also contribute to the development of a shared, collective knowledge base (Gess-Newsome 2015).

4

To examine individual teachers' pPCK, we adopted four domains of PCK as described by Magnusson et al. (1999): teacher knowledge about goals and objectives (M1); teacher knowledge about students (M2); teacher knowledge about instructional strategies (M3); and teacher knowledge about assessment (M4). Domain M1 includes teachers' knowledge of the goals and objectives for students and why it is important that students reach these learning goals (Barendsen and Henze, 2017; Magnusson et al. 1999). Domain M2 includes knowledge of student requirements for learning specific science concepts, and areas of science that students find difficult (Magnusson et al. 1999). Domain M3 includes knowledge of teaching procedures and methods to teach a certain concept. Magnusson et al. (1999) describe this knowledge to be subject-specific or topic-specific, however in our case, the knowledge about instructional strategies related to the connection between research and design is rather domain-specific to STEM or practice-specific. Domain M4 includes knowledge of the dimensions that are important to assess, and knowledge of the methods by which that learning can be assessed (Magnusson et al. 1999), and why these methods are suitable.

Another, overarching domain is that of orientations and beliefs, which shapes other components of PCK and thereby influences teacher PCK and teacher practice (Magnusson et al. 1999). Beliefs are not a well-defined construct (Jones and Legon 2014), and scholars have adopted contrasting representations of beliefs and knowledge (Veal 2004); knowledge has been described as a component of beliefs (Rokeach 1968), and beliefs have been described as a special form of personal, tacit knowledge (Kagan 1990). The difference between knowledge and beliefs is hard to describe, but in general, beliefs are regarded as less linked to cognition (as knowledge is), but more to affect and evaluation (Jones and Legon 2014; Pajares 1992). Beliefs have also been defined as "understandings, premises or propositions about the world that are felt to be true" (Richardson 1996, p. 103). These premises can arise from a number of sources: believing an authority, deductive logic, the experience of the senses, the emotion of feeling that something is true or right, rational intuition, and personal use of the scientific method (Lewis 1990). Beliefs can differ in intensity and are linked to one another; the more a certain belief is connected to and influences other beliefs, the more central this belief (Rokeach 1968). Beliefs strongly affect behaviour (Pajares 1992): beliefs influence for example how teachers make decisions for implementing instructional strategies (Veal, 2004) and which knowledge teachers choose to draw upon (Leinhardt and Greeno 1986). Beliefs and knowledge are thus tightly interwoven (Gess-Newsome 1999; Pajares, 1992), and it is highly likely that upon eliciting teacher knowledge like pPCK, we will also get insight in teacher's beliefs about the connection between research and design.

4.3 Method

To examine teacher knowledge development on connecting research and design, we did a qualitative, explorative, multi-case study, in which we made in-depth descriptions of the personal PCK development of 6 O&O teachers, and in-depth descriptions of the products that the teachers developed collectively during the PLC.

4.3.1 Context

The context of this study is the Dutch subject O&O (Dutch abbreviation for 'Research and Design'), which was introduced in 2004 and is now taught at 98 certified, so called 'Technasium' secondary schools in The Netherlands from 7th to 12th Grade. O&O is a project-based, elective subject where students conduct authentic research and design projects based on real world science or STEM related problems from companies and clients in the schools' area. In an O&O project for example, students write a research report with advices to the local client for the optimization of an algae reactor. Another example is that of a project in which students design a game or an app for a local petting zoo, considering its target group. One of the main goals of the subject O&O is to make students familiar with research and design practices in the professional world. However, projects in O&O are labelled as a research project *or* as a design project in the project database founded by the Technasium foundation. In reality, many O&O projects include both research and design activities because they are based on authentic problems, but whether this relation between research and design is clear and visible to both teachers and students, is uncertain.

4.3.2 Participants

Seven O&O teachers participated in the PLC, of whom six completed the study (see Table 4.1). The teachers that were approached were in schools that had already showed interest in previous research about the subject O&O by the authors. The teachers were approached individually by email, in which information about the PLC meetings and about the study were given. Some of the approached teachers recommended the PLC to colleagues, of which some also enrolled for the PLC and the corresponding study. All teacher names used in this study are pseudonyms, to ensure anonymity.

Table 4.1. Teacher characteristics.

Teacher	Gender	Age (at start of PLC)	Background	Years of teaching experience (total)	Years of teaching experience (in O&O)
Will[a]	M	47	Studied science teaching for lower secondary education, University- level physics, and physics teaching for upper secondary education. Has educational degrees in physics, Public Understanding of Science (see Henze et al., 2007), O&O, mathematics, chemistry and ICT. Teaches at the same school as Dan. Design experience: through his experience as a technology and O&O teacher. Research experience: through scientific research during his studies at university concerning physics, and supervision of students' final research projects (in 11th and 12th Grade).	20	7
Dan	M	28	Bachelor: Civil Engineering. Master: Civil Engineering & Management. Master: Science Education: O&O. Has educational degrees in physics and mathematics in lower secondary education, and O&O in upper secondary education. Teaches at the same school as Will. Design experience: through his study Civil Engineering, with for example assignments like 'design an airport on a platform in the sea'. He tries to stay updated on his discipline through trade magazines. Research experience: through scientific research during his studies at university concerning engineering.	3	3
Kate[a,b]	F	28	Bachelor: Industrial Design. Master: Integrated Product Design. Master: Science Education: O&O. Is still enrolled in teacher education for mathematics in lower secondary education, and O&O in upper secondary education. Works at this moment as science communicator at a university. Design experience: through her studies and her previous work as a product designer, where she worked on improving a device that measures rainfall. Research experience: through scientific research during her studies at university concerning product design.	1	0.5
Sean	M	52	Polytech: Technical Physics and Control Technology. Has educational degrees in physics and Nature Life and Technology, upper secondary education. Design experience: through his previous work as a technician designing electrical installations at energy companies, through teaching O&O, and through design in his private life, for example designing a website, or a new bedroom. Research experience: through scientific research during his studies at university concerning physics, and concerning educational practice.	15	3
Jill	F	45	Royal Art Academy. Polytech: art teaching for upper secondary education. Has educational degrees in art education and O&O. Teaches at the same school as Sue. Design experience: through her previous work as a teacher at the Art Academy, through the architectural aspects of her studies, through family members that were technicians, and through personal interest in building things throughout her life. Research experience: through the architectural aspects during her studies.	12	5
Sue	F	30	Studied mathematics teaching for lower and upper secondary education. Has educational degrees in mathematics and O&O. Teaches at the same school as Jill. Did not attend first PLC meeting due to illness. Design experience: through design of educational materials. Research experience: through research projects during her studies.	8	3

[a]The first author knew teachers Will and Kate through her network.
[b]Kate was still enrolled in teacher education at the moment of this study, however, she already was paid to teach a few hours of O&O each week at her internship school. Therefore, we indicated her teaching experience in O&O with 0.5 years.

4

4.3.3 The Professional Learning Community

The main aims of the PLC were to increase teacher knowledge about the ways in which research and design can be connected, and how they can communicate this connection to their students through instructional strategies (for all intended learning outcomes of the PLC, see Appendix 3). We wanted teachers to learn that research and design can be connected in many different ways (for example: doing research is necessary for design, and after doing research, one can make recommendations for a design to apply the results), and how to facilitate this connection in their classrooms (for example by developing short instructional strategies, or adapting existing projects). So, the focus of the PLC was mainly within domains M1 and M3 of Magnusson et al. (1999): knowledge about goals and objectives and knowledge about instructional strategies related to the connection between research and design. Four PLC meetings of 3 hours each took place in October 2016, November 2016, January 2017 and February 2017. All PLC meetings were facilitated by the first author of this study, to whom we will refer as F in tables and quotations. Below, we will provide rich descriptions of the content of each PLC meeting.

In the first PLC meeting, the facilitator presented the outline of the PLC. A big part of the first meeting was dedicated to an expert lecture about research and design that was given by an experienced O&O teacher educator (to whom we will refer as TE in tables and quotations) from a nearby university. Teachers discussed their views on research and design, and the connectedness of the two. As the first lecture was slightly more design focused, a second short lecture on specifying research questions was given by the facilitator of the PLC (F).

In the second PLC meeting, consensus on the common goals of the PLC was reached: learning about the connection between research and design (and corresponding instructional strategies), learning about research and design separately, and opportunities to connect with the other teachers in the PLC for professional gain. Then, teachers were asked to jointly construct a Content Representation (CoRe): 'an overview of how teachers approach the teaching of the whole of a topic and the reasons for that approach - what content is taught and how and why' (Mulhall et al. 2003 p.6). First, the teachers formulated an overarching statement (a so-called 'big idea'): "Within a research and design project, you have to be able to choose certain methods and justify them". Then, they discussed the several aspects of this big idea (related to the four domains of Magnusson et al. 1999): what were the learning goals attached to this idea, why was it important that students knew about this, how would they give instruction to students regarding this big idea, etc. They produced a CoRe table as a group in a discussion structured by the facilitator. Teachers were also asked to develop short instructional strategies (so-called plug-ins) in groups of 2-3 after a brainstorm session. Plug-ins are short, low cost instructional strategies that have ready-made material and can be implemented in any O&O project without too much preparation time. The intended learning outcomes of the plug-ins developed in this PLC were to make the connection between research and design explicit for students. After presenting their plug-ins to each other, the facilitator encouraged the teachers to try out the plug-ins in their classes before the next meeting.

In the third meeting, teachers were asked to share their experiences with testing the plug-ins. As teachers participated in the PLC voluntarily and the testing of the plug-ins in their own classrooms was not mandatory, not all teachers had tested their plug-ins. In that case, they were asked to describe an experience in which research and design were connected in a successful way in their class. Then, the teachers adapted the plug-ins based on each others' comments. The teachers were also asked to adapt an example O&O project in pairs according to the outcomes of the CoRe they constructed during the previous meeting. They formulated principles for redesigning the projects to include a connection between research and design, for example: "The different parts of the project have to match up with different research and design methods". After one hour, teachers presented the adaptations they made to each other.

In the fourth and last meeting, the facilitator started with a short recap of the previous meetings and asked teachers to evaluate the plug-ins one last time after some teachers had tried them. Then, teachers worked on adapting O&O projects of their own schools, so that these included clear links between research and design components. Finally, teachers discussed tools they would like to see developed in the future, and evaluated the PLC as a whole.

4.3.4 Data collection

To elicit teachers' pPCK and beliefs regarding connecting research and design in the classroom (research question 1), semi-structured interviews were conducted by F before the first meeting and after the last meeting of the PLC. The questions were loosely based on Content Representations (Loughran et al. 2006), and strongly on the PCK model of Magnusson et al. (1999), including the four domains: (M1) knowledge of goals and objectives; (M2) knowledge of students; (M3) knowledge of instructional strategies; (M4) knowledge of assessment. As teachers' knowledge is informed by their belief systems (Gess-Newsome 1999), we aimed to elicit teachers' beliefs from these interviews as well. The interviews were audio recorded and transcribed in verbatim. The PLC meetings were recorded on audio and video, and group work during the meetings was recorded on audio. Of all teachers, active consent was obtained. Ethical approval was obtained from the Ethics Committee at the Leiden University Graduate School of Teaching.

To examine how the teachers collectively gave meaning to the connection between research and design, we examined the products that teachers co-constructed during the PLC. It has been shown that developing educational products together enhances shared teacher knowledge (Coenders et al. 2010). In our case, these were the plug-ins (short, instructional strategies) that teachers developed. We collected the plug-in instruction manuals that the teachers wrote, and asked them to reflect on the plug-ins collectively during the PLC, and individually during the post-PLC interviews. Also, the teachers constructed a CoRe together; a representation of how a community of teachers thinks about the knowledge needed to teach a particular topic (Gess-Newsome 2015). We summarized the outcomes of the CoRe to elicit salient issues within our teacher group.

4.3.5 Analysis

To elicit the individual teachers' pPCK and beliefs (research question 1), the pre-PLC and post-PLC interview transcripts were used as the main data source. The recordings of the PLC were used as supporting data. The analysis of the interview transcripts was based on the four domains of the PCK model of Magnusson et al. (1999). First, the interview transcripts were read thoroughly several times. The first and second author analysed the interviews with a conventional content analysis approach (Hsieh and Shannon 2005) guided by the four domains of Magnusson in Atlas.ti version 7.5.6. A teacher's answer to each interview question or follow-up question was coded as a separate segment, unless the answer on the follow-up question (or follow-up remark) was a clear continuation of the previous statement, or if the additional information was needed in order to understand what the teacher exactly meant by his/her previous statement. After coding all segments, we removed codes that represented teachers' statements about the subject O&O in general, as we wanted to explicitly explore their PCK about the connection between research and design. We then revised all codes, and made an analysis of themes (Creswell 2007) by only coding explicit statements on the connection between research and design, statements on research and design when they were mentioned in combination with each other, separate statements on research, and separate statements on design. This resulted in a list of codes for each individual teacher. After revising these lists, small adaptations to some codes were made to make them more comprehensible. Consensus on difficult text segments and remaining codes was reached between the first and second author by revisiting the transcripts of the teacher interviews.

We grouped all single codes under meaningful bigger categories within the domains of Magnusson et al. (1999). We constructed in-depth, explorative descriptions for all teacher cases, to characterise his/her knowledge development by comparing codes from the pre-PLC and post-PLC interviews, because each teacher case was different and unique. We selected the richest and most meaningful quotes from each teacher, regarding salient issues in their knowledge development, or central beliefs to which their development was related. We also compared teachers' PCK to the intended learning outcomes of the PLC (see Appendix 3).

The collective knowledge construction of the teachers (research question 2) was informed by the Content Representation (Mulhall et al. 2004) they constructed together in the second PLC meeting. We looked for salient issues in the table of outcomes they developed during their discussion on the several CoRe elements. We also analysed the two main plug-ins the teachers designed in groups, and teachers' reflections on these instruments during the PLC and during their individual post-PLC interviews to characterise these instructional strategies. Out of the in-depth descriptions of the plug-ins, we could extract information about the types of instructional strategy that the teachers as a group preferred and about which learning goals they had attributed to these activities.

4.4 Results

The results are structured according to the order of the research questions. Data on the first research question about teachers' pPCK and beliefs is structured according to each teacher case. Data on the second research question is structured according to the three products that teachers constructed (the CoRe and two plug-ins).

4.4.1 Teachers' personal PCK and beliefs development: pre and post PLC

4.4.1.1 Will

In domain M1, knowledge about goals and objectives, Will's starting position was that he could, after probes by the interviewer, already mention different learning goals for students about the connection between research and design which were also intended learning outcomes of the PLC. In the post-PLC interview, Will actually mentioned less of the different M1 learning goals when compared to his starting position. Instead, he seemed to focus on the learning goals related to his central belief that it is a prerequisite that students see the utility of research within design. This was a salient issue in his reasoning after the PLC in domains M1 ('students need to know that doing research is needed to conduct a design'), M2 ('students see the relevance of a project through using research within their design') and M3 ('I stimulate students in the importance of doing orientation research'). He indicated that the PLC enhanced his ideas about the importance of this issue:

"I think that, it was in my head before the PLC: 'You cannot do one without the other [research or design], it is just connected'. That was implicit at first, but I think I am more explicit now, I indicate more clearly: 'Why do we do research for our design? What is the importance of doing this orientation research?'"

Making the connection between research and design explicit to students (M3: knowledge of instructional strategies) was one of the intended learning outcomes of the PLC. In the pre-PLC interview, Will struggled whether or not he should do this. When asked about which instructional strategies he wanted to use, he answered:

“I do not really have an answer to that… I think it [the connection] is already hidden within the project description itself.”

In his post-PLC interview, Will made more sophisticated statements about strategies for instruction, using more specific wording:

“I would indicate in the project description, within the material we offer students, indicate more clearly and explicitly whether a part within the project is about doing research, or whether a part within the project is about designing, for example research, research, design, really indicate per part: ‘This is what you are doing now’.”

4.4.1.2 Dan

Dan, like Will, could already in his pre-PLC interview mention different learning goals for students about the connection between research and design in domain M1, knowledge about goals and objectives. After the PLC, Dan mentioned less different intended learning outcomes related to learning goals for students (M1), but he did mention different goals than he did in his pre-PLC interview. This indicates that he adopted new knowledge of domain M1 during the PLC: for example that students should know that looking up information is not the same as doing research, a topic that was discussed during the first meeting.

In his pre-PLC interview, a central belief of Dan was that students’ in general disfavour doing research. Among his most mentioned codes in M2 (knowledge about students) were ‘students find doing research boring and stupid’ and ‘students do not see the need of doing research within design’. He did not make specific statements about students in relation to the connection between research and design yet. In his post-PLC interview, Dan made relatively less negative statements about students, and he mainly mentioned difficulties students had when connecting research and design, for example when students do not test or improve their design:

“At this moment, it [the connection] is not obvious for the students yet”… “They like designing, they do the design cycle just once. They are really rigid, to my surprise, they say very quickly: ‘This is our design’. And then I try to change their minds, or let them think about: ‘But why? Can’t it be better?’ But students are very rigid: ‘This is our design, can we build it now?’”

In domain M3, knowledge about instructional strategies, it is surprising that Dan, in his pre-PLC interview, mentioned that adapting the project description could be an approach to make clear the connection between research and design, while after the PLC, which also had this principle as an intended learning outcome, Dan did not mention this anymore. He seemed to focus more on his idea of addressing the connection within workshops, providing students with open projects, and on evaluating the plug-ins the teachers made in the PLC, although he had not used one of the plug-ins yet. He also mentioned again that he wanted to show students that doing research is not the same as looking up information, which was consistent with his statements in domain M1.

4.4.1.3 Kate

Post-PLC, Kate mentioned that research and design request different skills, and that when research is used within design, it becomes less of an art project, which means she has adapted some of the intended learning outcomes of the PLC (see Appendix 3), although not excessively. At the start of the PLC, Kate said she wanted students to recognize the connection between research and design (which relates to student knowledge), however after the PLC, she stated she found it more important for students to be able to actively apply the connection within their projects (which relates to student skills):

“… but if you think: Is it really important that they [students] know all the descriptions of the concepts and get them right, or is it more important that they can carry out the process in the right way? Then I think the latter is much more important.”

In both her pre-PLC and post-PLC interview, Kate showed the central belief that all ideas, even misconceptions of students should be able to exist, in order for them to get the chance to discover for themselves whether a research or design idea works or not. In her post-PLC interview she mentioned that students are used to pleasing the teacher and doing as he/she says, but that it is an eye-opener for them if they realize they can choose any approach to a project, as there is not one correct answer:

“… they [students] were asking me what the best answer was. And then I said I was really happy with their discussion, because that made them real designers. Because, if they choose to go in one direction for a certain reason, and if they can explain this reason to the client, or they can go in another direction, that’s both fine, as long as they explain their choices. So they had to decide on the answer, not me. And this was an eye-opener for them I think.”

In her pre-PLC interview, Kate mentioned a lot of strategies she could use as a teacher to support students’ design projects. This variety of strategies were probably implied by her background as a designer and science communicator, she mentioned. In her post-PLC interview, Kate mentioned relatively less different instructional strategies when compared to her starting interview, however, she talked a lot about one instructional strategy she had recently used to make user research prior to a design project more appealing to students. She let her students sort questionnaires within different typologies of users, instead of letting them analyse the questionnaires quantitatively on the computer. She found this a successful experience in connecting research to a design project, because her students actually used research to inform their design after this exercise.

4.4.1.4 Sean

In his starting interview Sean mentioned less different goals and objectives (M1) than after the PLC, indicating he had developed his knowledge and adopted some of the intended learning outcomes of the PLC. For example, he mentioned that research and testing is important for design, otherwise it becomes art (one of the intended learning outcomes as stated in Appendix 3). Also, after the PLC, Sean was more convinced of the importance of letting students test their design:

"And persuade students they have to do something. That they make a design, but test it and certainly need a second and third design, at the end of the project, it is important to mention that. They are often slow, and at the end of the project they are stressed and don't have time to test anymore. So I say: 'Just go make something and we will adapt it, just do it'. I am guiding them more directly, so to say. Before I think we mentioned it: 'hey, shouldn't you test this'. But now I think: if you did not test [your design], then it will certainly not be sufficient, so I am more coercive in what they have to do."

This quotation also relates to domain M3, knowledge of instructional strategies, as Sean also pointed out he wants to stimulate students to test their design. Sean appeared to be ambivalent at the start of the PLC on whether or not to make the connection between research and design explicit to students. In the pre-PLC interview, he gave mixed answers about the importance of making explicit this connection or not. In his post-PLC interview, Sean said that he would make the connection explicit, but rather communicate this to students during group work than in a plenary fashion:

"Naming it [the connection] constantly in conversations. [talking about connection] Plenary, it does not make much sense I think, in the sense of talking about it at the beginning of the lesson, but rather in short workshops"…

Sean also tried one of the plug-ins he designed with his students, contrary to Will, Dan and Kate. He mentioned some restrictions however, which we will discuss in the next paragraph when we analyse the plug-ins the teachers made. Sean clearly had a desire to implement practical instructional approaches in his lessons. Perhaps this motivation stemmed from his background as a technician.

A central belief of Sean, in both his pre and post interview, is that he found justification of student statements really important. He wanted students to justify their choices and claims within the research and design projects. It became obvious that this was a really important issue for him.

4.4.1.5 Jill

At the start of the PLC, Jill mentioned little variety of goals and objectives regarding the connection between research and design (M1). A salient issue in all knowledge domains in her pre-PLC interview was a role division strategy, in which students fulfilled and switched between certain roles within an O&O project: the planner, the researcher, the designer, and the chair. It became clear that she believed this was one of the best ways to let students see the connection between research and design. Jill also stated in her pre-PLC interview that she would not make the connection between research and design explicit to her students, because she believed her students already saw this connection:

"I don't know, making it explicit, it is so logical, you don't build a house without doing research on materials, so in any case, orientation knowledge is necessary for a design. I think that when you ask a student, they would say: 'That's logical, isn't it?'"

After Jill's post-PLC interview, she had formulated more and clearer learning goals she wanted her students to achieve, for example, she wanted them to see there that the interaction between research and design allows them to make a good product, and she wanted students to think about differences between research and design. There was more variation in her knowledge of goals and objectives (M1) compared to her starting position, and she did not mention her role division method as much as before. Contrary to her opinion in the starting interview, she stated after the PLC that the connection between research and design is something that should be named:

"What was striking to me, and it is just true, you have to make it [the connection] visible for them [the students], so putting up posters in the classroom, denominating it real often, show pictures. Like you made that link clear to us: 'Where are you in the cycle? Where does the connection lie?' Then you can name it and put your finger on it, and those considerations you do make in your head, but it is good to always make it visible."

In M3, knowledge about instructional strategies, Jill showed a lot of initiative by having tried one of the designed plug-ins in her lesson, and by having designed another instructional method by herself. She elaborately talked about the latter, a method called 'mythbusters' (referring to the well-known television program), in which she let students check a statement given to them on a card. Students got a box of materials with which they could design an experiment, and test whether this statement could be true. She stated that students were enthusiastic:

"The students were instantly enthusiastic about being allowed to do research, immediately getting to work with the materials, to see if the facts were true."

4.4.1.6 Sue

Sue missed the first PLC meeting due to illness, so she missed information about the PLC's intended learning outcomes in M1, knowledge of goals and objectives, which were mainly treated in the first meeting. We saw indeed that post-PLC, Sue mainly made general statements about M1, like 'doing research (gaining knowledge) is part of, and necessary for, designing'. However, for some other teachers, this is also the case, as after the PLC they have specific learning goals in mind (for example Will). Before the PLC, Sue stated that students have to recognize the connection between research and design. However, after the PLC, she stated she was in doubt about this learning goal for students she mentioned at the start. This is illustrated in this quotation from her post-PLC interview:

F: "Is it important that students know something about the connection?"

Sue: "I'm in doubt."

F: “What is it that makes you doubt this?”

Sue: “If it just feels right for them. It’s so logical that you switch between [research and design]. And if it feels logical for them and they just understand that before they are going to do something, they need to know something first. Then to me it doesn’t matter whether they put it under the term research or design. If they just, I’m in doubt.”

F: “So if they are working nicely in the process, so to say?”

Sue: “Yes. They have to know what they are doing, and that you need the one for the other, but if that one’s name is either research or design [is not important].”

It seems that after the PLC, Sue believed it is more important that students are able to carry out the process of connecting research and design, rather than students being able to name this connection. A similar statement was made by Kate in her post-PLC interview. At the start of the PLC, Sue’s most mentioned code in M1 was ‘students must recognize the connection between research and design’, whereas after the PLC, Sue mentioned the statement that ‘the connection must feel logical for students’ more.

In domain M3, knowledge of instructional strategies, Sue had some ideas about methods in her pre-PLC interview, like dividing students into research and design specialists, or letting students sort cards with all the parts of the project under the headings ‘research’ and ‘design’. One of the plug-ins loosely resembled the latter, and Sue also tried this plug-in with her students. Like Jill, Sue also thought in her post-PLC interview that students found the connection between research and design logical, and like Sean she wanted to make the connection explicit during group work instead of plenary. In her pre and post interview it was Sue’s belief that it was important to structure the projects clearly for her students. In her post-PLC interview, she added that projects also should not always follow the same structure, in order for students not to get bored.

4.4.2 *Teachers’ collective meaning making to the connection between research and design*

4.4.2.1 The Content Representation

During the construction of the CoRe, the teachers discussed which ‘big ideas’ about connecting research and design were important, what the related learning goals were for students and how to implement these in a project. Teachers discussed several big ideas and voted for the most important ones: ‘during research and design, you have to justify your choices’, and ‘research should be made “sexy” by connecting it to design’. Eventually, the main big idea was constructed on which we based the CoRe: ‘Within a project, you must be able to choose research methods and design methods, and justify them’.

It is remarkable that ‘choosing the right research and design method is important’ was a big idea that only one individual teacher voted for. It was during the group discussion prior to choosing the main big idea, that the ideas ‘you have to justify your choices’ and ‘choosing suitable research and design methods is important’ became merged. This showed that the O&O teachers collectively assigned importance to choosing the right methods, even when individual teachers did not mention this extensively during their pPCK interviews. The teachers even mentioned that they had a need for a canonical depository with a range of research and design methods they could consult for their projects. During the discussion, the teachers often switched from one big idea to another, as they saw everything as related to each other. This showed that they had some difficulty to break down the broad, practice-oriented issue of connecting research and design into smaller units or learning goals.

Cross-case analyses showed that several learning goals were adopted by all teachers after the PLC, for example ‘students should know that doing research is needed for their design’, ‘we should make the connection between research and design explicit (during group work)’ and ‘reasons why students need to be able to connect research and design’. Also, after the PLC, more teachers mentioned that ‘students need to justify their choices – a central belief of Sean, who might have transferred this to others. These collectively agreed upon learning goals are an indication of a shared knowledge base. All teachers also agreed that the group atmosphere in the PLC was very positive.

4.4.2.2 The plug-ins that teachers developed

Teachers developed their own short instructional strategies, or plug-ins, in teams, and reflected upon them collectively during the PLC and individually during the post-PLC interview. In the next two paragraphs, we will discuss and describe two of the designed plug-ins, as these were the most discussed by the group and tested by several teachers, and matched best with the PLC’s goal to connect research and design.

During the second PLC meeting, teachers Jill and Sue worked together on designing the plug-in ‘Flip over signs’. They designed a sign that students can place on their desk and flip over: one side of the sign reads ‘research’, the other one ‘design’. The sign reflects what the students are doing. While working on their project, students are supposed to flip over the sign according to whether what they think they are doing is research or design related. The teacher can initiate a discussion about the signs. The intended learning outcomes of this plug-in are to make students aware that they switch between research and design activities during the same project, and to engage students in a discussion with the teacher about the connectedness of research and design. The other teachers were positive about the idea of the flip-over signs:

Sean: “Because it’s so simple, children have to agree upon what they are going to do. Or divide them, within groups you can do something else, but you have to talk about it. So if there’s a sign you have to place, you gave to do something with it.”

Kate: “Groups can indicate whether they are doing things more design related or research related. I think that is a confirmation or awareness: research and design are not so black and white, it dissolves into each other more than I thought before”

Dan stated that he was sceptical, and that the plug-in did not appeal to him, although he admitted that it was probably because he did not walk by the teams of students so often, which was a requirement for this plug-in in order to start discussions about the flip-over signs.

Kate, Sean and Dan designed the plug-in 'Explain it!'. This plugin was a competitive game in which two teams of students try to convince each other that they made the best thinking steps within their project, and in which students can give each other feedback. The game consists of cards with different statements related to the project, for example: "Explain how you have used orientation research for your design project". The intended learning outcome of this plug-in is to engage students in a discussion on the justification of the research and design choices they made within their projects. Also, the set-up of having a discussion as a game also invites students to learn from each other's' successes and mistakes. The teachers were quite enthusiastic about this plug in because of the element of competition, although there were some practical restrictions.

Sean actually tried this plug-in with his students:

"The plug-in we made ourselves, with the cards where children could convince each other why they were really good at the research and design parts of the project. That is a nice plug-in, but there has to be enough time. There are few moments in which that [plug-in] is efficient. If they have not done anything yet, it had no use, and if they are done [with the project], then it's too late. So the timeframe in which to implement this is narrow."

When the O&O teachers designed instructional strategies together during the PLC, this could lead to the development of collective knowledge. The plug-ins show for example that the teachers still thought of research and design as more-or-less separate entities, as the flip-over signs read 'research' *or* 'design', and 'Explain it!' contained not only questions about the connection, but also questions aimed at research only or design only. For this reason, Dan even stated that he was sceptical whether the plug-ins even established the connection between research and design. However, both plug-ins were designed to start a conversation with or among students: letting students think and verbally reason about the possible link between research and design was clearly a shared learning goal of the O&O teachers. The importance to justify research and design choices, one of the components of the big idea that teachers chose for the CoRe, also featured in the plug-in 'Explain it!'. This game was primarily aimed at justifying research and/or design choices.

4.5 Discussion

The discussion is structured according to the order of the research questions, which are stated in the last paragraph of the theoretical framework.

4.5.1 Teachers' personal PCK and beliefs development

The results of this study showed that the pPCK of each teacher was different and developed in a different way. Some teachers broadened their knowledge about learning goals regarding the connection between research and design, however some teachers merely shifted to other ideas or narrowed their existing knowledge further. Thus, teachers did not cluster together in certain typologies, like those found in other studies on PCK (Henze et al. 2008). Research that uses individual teachers as the unit of analysis confirms that teacher learning can be unpredictable, and that some teachers change more than others during professional development (Borko 2004; Franke et al. 2001). Teachers from the same school (e.g. Jill and Sue), or with similar educational backgrounds (e.g. Kate and Dan), had different pPCK. This illustrates that all teachers had different experiences and qualifications regarding research and design, indicating they all had different independent knowledge of research and design at the start of the PLC. Combined with their different personal beliefs, this could have led to the variety in knowledge development. These findings also contribute to the notion of ambiguity in research and design pedagogy and epistemology. In follow-up research, it would be interesting to examine the epistemology of (the connection between) research and design along with teachers and other education specialists. It is likely that the teachers' attitudes, beliefs and personal, educational or professional experiences acted as amplifiers or filters on their knowledge development, thus contributing to teachers' varied pPCK (Gess-Newsome 2015). Every teacher viewed the pedagogy of connecting research and design differently and acted differently because of the variety in knowledge and beliefs - otherwise we would have found typologies. However, the teachers' thinking and verbal reasoning about the pedagogy of the connection between research and design did evolve during the PLC, as they made more explicit statements about this topic after the PLC when compared to their starting position.

Teachers' pPCK could have been strengthened further by repeatedly testing instructional strategies aimed at connecting research and design, like the plug-ins they developed, and reflecting on these actions in the classroom practice (Clarke and Hollingsworth 2002). However, the teachers in our sample did not extensively apply the plug-ins 'Flip-over signs' and 'Explain it!' in their classrooms during our study (which was strongly advised, but not mandatory). Possibly, this was related to a lack of skills for implementing these new strategies in the classroom (Gess-Newsome 2015), or to the issue that teachers' knowledge about teaching the connection between research and design was not strong enough yet to provoke significant changes in their behaviour in practice (Barendsen and Henze 2017; Park and Chen 2012). Literature shows that some elements of teachers' knowledge and practice are more easily changed than others, and changing instructional strategies is one of the harder elements to change (Borko 2004; Franke et al. 2001). It is also possible that some of the teachers in our sample applied the developed plug-ins in their classrooms in the period after the PLC, thus enhancing their pPCK development outside the scope of this study.

The teachers showed explicit and different beliefs during their interviews on pPCK. For example, a central belief of Sean was that students needed to justify their choices, and a central belief of Will was that students should first know how to do orientation research before they design. One of the central beliefs of Jill was that students should learn about citizenship, a goal that was not mentioned by the other teachers; perhaps this belief was implied by her background as an arts teacher. These central beliefs about some important learning goals were not changed after the PLC, whereas teachers' beliefs about the importance of teaching the connection between research and design did change (for example the belief that students should be able to *apply* their knowledge about connecting research and design, instead of merely *understand* its presence). Their central beliefs likely influenced teacher knowledge development during the PLC (Leinhardt and Greeno 1986). For example, Will shows a narrowing of his knowledge in his post-PLC interview. His central belief was that it was a prerequisite to understanding the connection between research and design, that students saw the necessity of orientation research before conducting a design. Attending the PLC might have enhanced this central belief for Will.

4.5.2 Teachers' collective meaning making to the connection between research and design

Although each individual teacher had different knowledge and beliefs, the results of this study also showed that teachers built a collective knowledge base during the PLC. During the construction of the CoRe, the teachers as a group adopted the idea of the importance of justifying research and design choices, and the importance of choosing suitable research and design methods. We saw that during the discussion on the CoRe, the teachers had difficulty to choose and stick to one particular big idea, as they saw all big ideas as connected to each other. Previous attempts to use the CoRe tool with D&T teachers provided similar results: in comparison to science educators, D&T teachers found it challenging to identify specific big ideas for lessons in D&T (Williams et al. 2012). Possibly this is due to the fact that there are no canonical schemas that are familiar to all D&T teachers, or because D&T, and in our case, research combined with design, do not have well-established epistemologies (Doyle et al. 2019).

After the PLC, all teachers understood the importance of the connection between research and design, and certain ways of connecting research and design were more appealing to the teachers as a group than others. For example, the need to do orientation research before conducting a design was mentioned multiple times by all participating teachers during the PLC, and in their post-PLC interviews. The need to justify choices within the project was also mentioned by more teachers in their post-PLC interviews, and during the development of the CoRe. During the course of the PLC, these topics were salient issues in the teacher conversations, and featured in the plug-ins. For example, 'Explain it!', was a game aimed at justifying research and/or design choices. The development of the plug-ins indicated that teachers wanted students to be engaged in a dialogue with the research or design process or product through justification and evaluation of choices. A reason for this could be that these topics were linked to some of the teachers' central beliefs: for example, the central belief of Sean, that students should justify choices, or the central belief of Will, that orientation research is critical to the further course of a design project. Through conversation and sharing, the central beliefs and pPCK of individual teachers could very well have contributed to the collective knowledge base of the teacher group. According to the new Refined Consensus Model on PCK, this could be seen as the development of a form of collective PCK: an amalgam of different educators' contributions, shaped through knowledge exchange during discussions and the collective development of instructional strategies, resulting in a shared knowledge base around a particular topic (Carlson and Daehler 2019).

4.6 Limitations and implications

Teachers' PCK about connecting research and design was quite tacit at the beginning of the PLC. After the PLC, teachers made more and clearer statements about the connection between research and design, but these were also not yet very sophisticated. The timespan of just four meetings is quite a short time to expect a large impact on teacher PCK development (Supovitz and Turner 2000), especially since this was the first time the teachers in this study explicitly thought and talked about connecting research and design. However, other research has shown that more short-term interventions with tightly focused topics can actually have a moderate positive effect on teacher knowledge development (Rollnick et al. 2017). In that sense, the PLC in this study was successful in letting teachers' think explicitly about the specific practice of the connection between research and design for the first time and framing their minds towards a more integrated practice of research and design. We recommend providing additional support in the form of PLC meetings/activities to STEM and D&T teachers who are expected to teach across different domains and activities, as teachers generally require additional education for linking the different STEM domains (Shernoff et al. 2017; Stohlmann et al. 2012).

In this study, teachers' knowledge, beliefs and backgrounds were all very diverse. Should we have included more teachers in our sample, it is likely that they would have again had different beliefs and different ways to develop their knowledge. To know whether a certain (personal, educational or professional) background leads to a certain pattern in teachers' knowledge development, more teacher groups with similar backgrounds should be included in follow-up research. As teacher's personal science backgrounds, peers and personal traits influence how they put their beliefs in practice (Veal 2004), these follow-up studies should also look into the interaction between teachers' backgrounds, beliefs and knowledge, to truly understand the reality of classroom practice (Doyle et al. 2019). This also implies that schools, wishing to establish STEM and D&T teacher teams, should pay attention to, and make explicit the different beliefs of teachers. Further research should look into how these groups of teachers can specify their central beliefs and learning goals, in order for them to be able to develop their knowledge and their lessons together.

4.7 Conclusion

In conclusion, despite the short time span of the PLC, teachers did become more aware of the connection between research and design in practice as well as in their classroom subject O&O. Teachers developed their own knowledge (pPCK), but also contributed to the shared knowledge of the group. The knowledge development of the teachers can be attributed to the discussions, lectures and activities provided during the PLC meetings, but also to the one-on-one interviews with the first author, which were in-depth conversations about their individual learning goals and classroom practices. Teacher Will even stated:

"The funny thing is, the most valuable for me is perhaps this conversation. Just because you can sort out your thoughts."

All teachers in our group reported very positively on the group atmosphere, and strong PLCs based on trust and good communication can foster teacher learning and instructional improvement (Borko 2004).

This study shows that a professional learning community in which teachers with varying backgrounds construct knowledge and instructional strategies together, as well as individual in-depth conversations with a facilitator aimed at teachers' PCK development, are powerful methods to enhance personal and collective PCK. These are promising outcomes in the light of shaping professional development activities for STEM and D&T teachers. To date, very little is known about how to connect research and design activities to each other in D&T and integrated STEM education. Connecting research and design in the classroom has the potential of providing students with a holistic and realistic view on current professional STEM fields, while studies on teacher knowledge and strategies about the connection of research and design activities are scarce. Our study provides valuable insights in teacher knowledge development about this practice.

Chapter 5

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

This chapter is based on:
Vossen, T. E., Tigelaar, D., Henze, I., De Vries, M. J., & Van Driel, J. H. (2019). Student and teacher perceptions of the functions of research in the context of a design-oriented STEM module. *International Journal of Technology and Design Education*.

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.

5.1 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 Dufy 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 analyse 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 chapter, 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 context-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.

5.2 Theoretical framework

The technological design process is often depicted in educational textbooks as a variation of a block diagram (for example, see Fig. 1.1 or 5.1) 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 analyse 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 analyse 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 this chapter, 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).

5.3 Research questions

In this chapter, 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?

5.4 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).

5.4.1 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 module-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. 5.1) 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 4). 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 (Fig. 5.1).

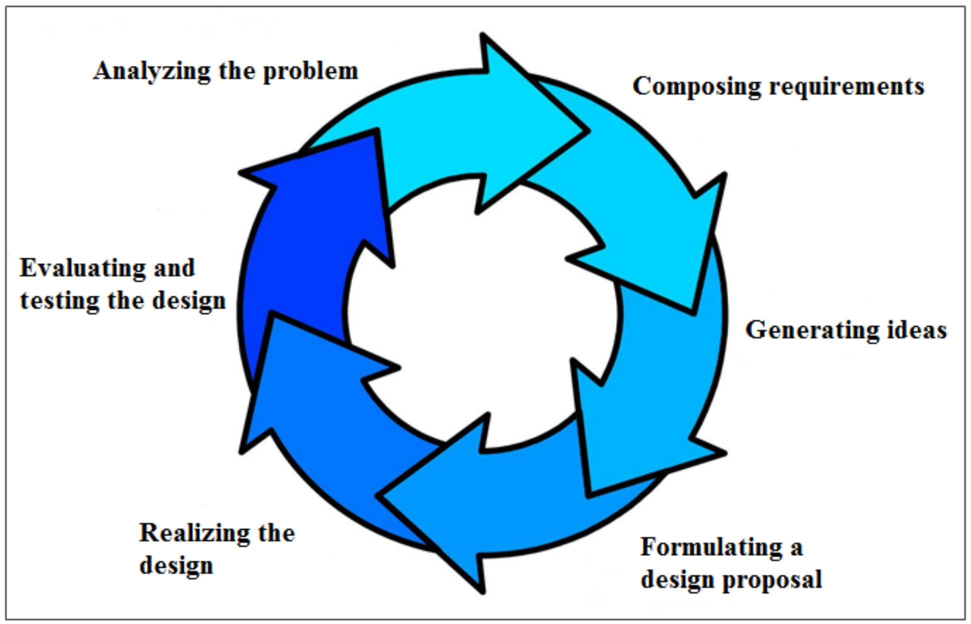

Figure 5.1 The design cycle as presented in the TDBT module. Adapted and reprinted from the Dutch course material with permission of the authors.

5.4.2 *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 in upper secondary school, the students that participated were either in 10th or 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 5.1.

5.4.3 *Data collection*

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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 5.

Data on teachers' recognition of the function of research within the design process were collected by individual, semi-structured interviews (Appendix 6). 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 6). 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.

Table 5.1. Background information on participating teachers and student focus groups. All teachers, except Mary and Mitchell, taught at different secondary schools situated between Amsterdam and The Hague, in The Netherlands.

	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 hours 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 hours 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 hours a week, Samuel gave this module 1 hour a week during half a school year. He included some extra exercises.	The module was taught for 3 hours a week during a period of a quarter of a school year. 1 hour 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
Nr. of focusgroups	3	3	4	4	See Mary
Nr. of boys | girls	5 | 4	1 | 7	4 | 8	7 | 5	See Mary
Ages of students	15-16	15-16	15-17	16-18	See Mary

5.4.4 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 familiarise ourselves with the data. Second, the answers from the teachers and students were summarised according to the questions of the interview protocols (Appendix 5 and 6) 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 analysed 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 7 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 design project themselves. The main code categories that emerged from the data are listed in Table 5.2. The first, second and third author agreed upon the merging, renaming or grouping of codes and the coding of difficult text segments (see Table 5.3). Consensus was reached by collectively revisiting the raw interview and focus group transcripts and by discussing the wording of codes. After consensus on the individual codes and the bigger code categories was reached, we performed a cross-case analysis (Miles and Huberman 1994) using large code tables (an adapted version of such a code table is shown in Appendix 7) 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 5.3).

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Table 5.2. 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 7.

Table 5.3. Coding examples of difficult text segments and the eventual consensus codes. The abbreviated codes are explained in Appendix 7.

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[a] FUN_DforR[b]	Because Mary talks about examining which methods to apply for the design of an installation, she mentions a function of research for design[a]. Also, she mentioned method design as a design step within the research process, therefore acknowledging that design can have a function for research too[b].

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5.5 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.

5.5.1 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: Behaviour). 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.

5.5.2 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.

5.5.3 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.

5.6 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.

5.6.1 Possible explanations for students skipping research activities in a design project

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, Vallarand and Blanchard 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 characterised design by sketching and building and therefore preferred to skip research and start building, while (2) other students instead characterised 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.

5.6.2 Teacher instructional strategies related to the functions of research within design

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.

5.7 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.

Chapter 6

Summary and General Discussion

6.1 Introduction

This dissertation intended to contribute to theoretical and practical knowledge on how to connect research and design activities in secondary STEM education. The main research question in this dissertation was: What do students and teachers in a STEM education context think about research, design and the connection between research and design? To answer this question, four studies were performed in which (1) an overview of student and teacher attitudes towards research and design activities is provided (chapters 2 and 3); (2) the knowledge development of teachers in a professional learning community aimed at connecting research and design is described (chapter 4); and (3) the perceptions of students and teachers on the functions of research activities within a design-oriented STEM module are examined (chapter 5). It is important to know more about the perceived connection between research and design, because one of the central aims of STEM education is to reflect professional practices in STEM fields, and in many STEM professions, research and design activities are connected and complement each other (Sanders & Stappers, 2008). Also, during designing, it is important to employ research activities to enhance the quality of design decisions and to rise above a mere trial-and-error approach (Burghardt & Hacker, 2004). All studies have been carried out in a Dutch secondary school context, involving in particular two fairly recently introduced STEM subjects: O&O (Dutch abbreviation for 'onderzoeken & ontwerpen', that is: 'research & design') and NLT (nature, life and technology).

This final chapter first summarizes the main findings of each study, followed by a discussion of the findings, limitations of this research, suggestions for further research and practical implications for teachers, teacher educators and policy makers.

6.2 Summary of the main findings

In ***Chapter 2****,* a questionnaire was developed to describe the attitudes of secondary school students towards *doing* research and design activities. The theoretical framework for attitude of Van Aalderen-Smeets, Walma van der Molen and Asma (2012) was used, including the components Cognition (relevance, difficulty), Affect (enjoyment, anxiety), Perceived Control (self-efficacy, context), and Intended future behaviour. Multilevel analyses were employed, based on 1625 returned questionnaires of students from the 8^{th} (ages 13-14) and 11^{th} Grade (ages 16-17). The research questions were: (1) What are the attitudes of secondary school students towards doing research and design activities in general?; (2) Are there differences in student attitudes between doing research activities and doing design activities?; (3) Are there differences in attitudes between students taking the subject O&O

and students who do not take this subject?; (4) Are there differences in student attitudes between lower (8th Grade) and upper (11th Grade) grades in secondary school?; and (5) Are there differences in student attitudes between boys and girls? Results showed that students in general had neutral to slightly positive attitudes towards doing research activities and somewhat more positive attitudes towards doing design activities. However, students in general considered doing research activities as more relevant and important to know about than design activities. Students taking the subject O&O had significantly more positive attitudes towards doing design activities than non-O&O students on all components, experienced less anxiety towards doing research tasks, and also scored significantly higher on positive self-efficacy and enabling context factors regarding research activities. It was also found that students who took the subject O&O showed higher self-efficacy in 11th Grade than in 8th Grade, while non-O&O students showed an increase in anxiety for both research and design activities from 8th to 11th Grade. The data showed that girls in general had lower self-efficacy than boys for doing research and design activities. In non-O&O students, girls scored significantly higher on the perceived difficulty and anxiety of doing research tasks than boys. The differences found between the O&O and non-O&O groups of students suggest that a project- and context-based subject like O&O could possibly enhance students' attitudes towards doing research and design activities. Furthermore, as students in general had less positive attitudes towards doing research projects when compared to design, it seems crucial for educators to explore how to make research projects more appealing for students.

An adapted version of the questionnaire in Chapter 2 was used in ***Chapter 3*** to uncover teacher attitudes towards *supervising* research and design activities. Teachers of two different context-based Dutch STEM subjects participated: 78 teachers of the subject O&O and 52 teachers of the subject NLT. Data were analysed using multilevel analyses and paired samples t-tests. The aim of this study was to examine (1) the general attitudes of STEM teachers towards supervising research activities and towards supervising design activities; (2) the differences in attitude between and within two different types of STEM teacher populations (O&O and NLT); and (3) the differences in attitude between and within O&O teachers with different disciplinary backgrounds (science versus non-science). Like the study in chapter 2, the questionnaire for teacher attitude was based on the framework for attitude of Van Aalderen-Smeets, Walma van der Molen and Asma (2012), and included the components Cognition (relevance, difficulty), Affect (enjoyment, anxiety), Perceived Control (self-efficacy, context), and Behavioural intention. Overall, this study found that the responding STEM teachers held fairly positive attitudes towards both supervising research activities and design activities. A result similar to that of the student population was that teachers perceived supervising research activities as a more relevant activity than supervising design. O&O teachers were in general more positive towards supervising design activities than towards supervising research activities, and for NLT teachers, the opposite was true. In comparison to O&O teachers, NLT teachers perceived more difficulty when supervising design activities. A remarkable outcome of this study was that all teachers, even O&O teachers without a science background, scored rather high on self-efficacy regarding the supervision of research and design activities. However, the non-science O&O teachers did show significantly more interest in attending professional development. It is well possible that the teachers' high self-efficacy was based on high feelings of enthusiasm for teaching STEM, rather than on actual competences, as literature shows that teacher attitude has only very loose correlations to actual teacher knowledge (Allum et al. 2008). Design activities are now given increased attention in educational policies, while this study shows that teachers in general evaluated supervising design activities as less relevant than research. Therefore, STEM teacher education should not only familiarize teachers with supervising research activities, but with design activities and their relation to research activities as well.

An example of such teacher professionalization is employed in ***Chapter 4***, in which the knowledge development was examined of six teachers of the subject O&O (Dutch abbreviation for 'research and design') in a professional learning community (PLC) aimed at connecting research and design. Individual teacher interviews were held before and after the PLC aimed to elicit the development of teachers' pedagogical content knowledge (PCK); a "special amalgam of content and pedagogy that is uniquely the province of teachers, their own special form of professional understanding" (Shulman, 1987, p. 8). This study aimed to (1) characterise the development of teachers' personal PCK and beliefs about connecting research and design before and after a PLC; and (2) examine how teachers collectively gave meaning to the connection between research and design during the PLC. Interviews were analysed according to five components of the PCK model of Magnusson et al. (1999): teacher beliefs; teacher knowledge about goals and objectives; teacher knowledge about students; teacher knowledge about instructional strategies; and teacher knowledge about assessment. Results from the interviews showed that the personal PCK of each teacher was different and developed in a different way. Some teachers broadened their knowledge about learning goals regarding the connection between research and design, while some teachers merely shifted to other ideas or narrowed their existing knowledge further. The teachers showed explicit and different central beliefs about teaching the connection between research and design, influencing their PCK development and sometimes this influenced the collective knowledge as well. The teachers collectively adopted the idea that it was important to do orientation research before starting a design, to justify research and design choices, and to choose suitable research and design methods. The PLC in this study was successful in letting teachers make their tacit thoughts about the specific practice of connecting research and design explicit for the first time, as connecting research and design does not have a well-established epistemology. This study shows that both professional learning communities in

6

which teachers with varying backgrounds construct knowledge and instructional strategies together, and individual in-depth conversations with a facilitator aimed at teachers' PCK development, are powerful methods to enhance personal and collective PCK.

Having explored the knowledge and beliefs of O&O teachers, we were also curious about the perceptions of NLT teachers and, equally important, the perceptions of students on the connection between research and design. ***Chapter 5*** investigates (1) in what ways students recognized and valued the functions of research within a design process in the context of a design-oriented STEM module; and (2) in what ways teachers recognized and facilitated these functions within this same STEM module. The particular STEM module was taught during the Dutch subject NLT (nature, life and technology), and aimed to familiarize students with the design process in the context of biomedical technology. An explorative case study approach was adopted, in which five teachers and their four classes of students participated in interviews and focus groups. Interviews were analysed using a list of different functions of research within design, informed by scientific literature. The way in which teachers reported to facilitate research activities in the design process was analysed using the principle of pedagogical content knowledge (PCK), with a special focus on teachers' use of different instructional strategies. This study found that teachers and students could recognize and name many different functions of research within the design process, implying that the use of a design-oriented STEM module is a good starting point for students to recognize functions of research within design. Although students recognized the value of doing research for design, both teachers and students reported that some students were reluctant to employ research activities and would rather start building. Teachers emphasized the importance of research for design by oral explanation, assessment requirements or by adding instructional strategies, such as a reverse designing strategy, to the module. Both teachers and students held the strong view that design should always be preceded by research steps, thereby tending to reduce the design cycle into a sequence of steps which all students must follow. This mismatches the notion that instruction should be differentiated to different students' preferred ways of learning (Hall, 2002). Therefore, follow-up research on differentiated instruction regarding design pedagogy in practice is needed.

6.3 General discussion

6.3.1 Contribution of this dissertation to research on integrated STEM education

Teaching and learning about research and design are important goals in international integrated STEM education (NGSS, 2013; NRC, 2012; ITEA, 2007). Integrated STEM is described as the combination of two or more disciplines in science, technology, engineering and mathematics disciplines into one subject (Stohlmann et al., 2012). The studies in this dissertation are an addition to existing literature because they examine students' and teachers' attitudes and perceptions on doing and supervising research and design activities, and the connection between these two practices. Integrated STEM education can take many forms, for example in short-term projects (Johnson, 2013; Van Breukelen et al., 2017), in extracurricular activities (Chacko et al., 2015) or in long-term STEM subjects (this dissertation). The Dutch subjects O&O and NLT are examples of such STEM subjects, but because these subjects solely consist of module- and project-based education, the findings of the studies in this dissertation could be translated to broader (international) contexts as well.

It is often up to the teacher to shape these new STEM subjects in the curriculum as teachers have been described as being the most important factor in successfully implementing new STEM approaches into practice (Van Driel et al., 2001; Van Driel et al., 2005). However, teachers of integrated STEM face many challenges. They are usually not specifically educated to teach all the different kinds of STEM projects the subjects entail (Honey et al., 2014). This could cause gaps in teacher knowledge (Stinson et al., 2009), and lead to teachers feeling uncomfortable about their teaching methods (Stohlmann et al., 2012), experiencing more anxiety and having more negative attitudes towards STEM teaching (Van Aalderen-Smeets et al., 2012). The studies in chapters 3, 4 and 5 of this dissertation however show that, in the case of O&O and NLT teachers, problems are not caused by negative attitudes and a lack of knowledge about the connection between research and design. In chapter 3, it was found that O&O and NLT teachers' attitudes and self-efficacy regarding the supervision of research and design activities were very positive, and chapters 4 and 5 showed that teachers could already in their starting interviews name ways in which research and design activities could be connected in STEM. The findings of chapters 4 and 5 indicate that the main challenge for teachers may not lie in attitude or knowledge development (although these are by no means unimportant), but in the application of successful pedagogies in their classrooms.

6

The teachers in chapters 4 and 5 all mentioned that they had great difficulty in persuading some students to include research activities within their design projects, for example to enhance justification of design choices (Crismond & Adams, 2012). These findings are congruent with studies stating that students, as novice designers, tend to skip research and pursue single, finalized solutions (Christensen et al., 2018; Moore et al., 1995). The results of chapters 2 and 5 both indicate that students, once they have some experience with design projects, have more positive attitudes towards design projects, like design activities better than research activities and would rather start building their design, resulting in the skipping of other important phases in the design process. The results in chapters 2 and 5 also show that this is not the result of students finding research activities irrelevant: chapter 2 shows that students rate the relevance of research activities even higher than that of design, and chapter 5 shows that students were able to name many different ways in which research activities can benefit the design process. The latter finding provides an important addition to current literature as the knowledge of students about connecting research and design is often underrepresented or estimated quite low (Christensen et al., 2018; Portillo & Dohr, 1989).

Based on the findings, it should be acknowledged that although students and teachers find the connection between research and design relevant and possess some knowledge about how research and design can benefit each other, this does not guarantee successful practical implementation of this connection in the classroom. Although in literature about integrated STEM, the design process has been mentioned as the 'glue' that meaningfully integrates STEM disciplines in K-12 education (Moore et al. 2014a; Moore et al. 2014b), the implementation of the design process in STEM projects does not automatically lead to concept learning (Van Breukelen et al., 2017). Likewise, merely implementing research and design activities in STEM projects does not ensure that students understand these processes deeply, or use the knowledge they have about conducting research and design within their projects. Chapter 5 shows that students with some knowledge about the functions of research for design, did not always apply that knowledge in practice. The results from chapters 4 and 5 imply that the teacher role, the curriculum, and a fruitful interaction between these two, are crucial to make integrated STEM education successful in terms of connecting research and design practices.

A possible solution for the challenge of applying successful pedagogies to connect research and design in STEM classrooms might lie in teacher professionalization, but also in letting students make the connection explicit themselves in conversations. It is a promising result that by simply talking about the connection and verbalizing thoughts, teacher and student knowledge is made explicit, which helps them to develop new insights about the connection between research and design (chapters 4 and 5). Chapter 4 shows that even a short intervention, in the form of a professional learning community in which teachers construct knowledge collectively as well as individually, can already have a big impact on teacher knowledge development.

6.3.2 Possible explanations for the findings

Students' and teachers' images of doing or facilitating research and design activities, yield possible explanations for the findings that both students and teachers found doing research more relevant than design, and that a proportion of students nonetheless seemed unwilling to conduct research within their STEM projects. By image, we mean the mental representation that first comes to mind when people think about research and design activities, skills and related professions. Students' images of STEM related professions have previously been measured by drawing assignments, such as Draw-A-Scientist (Finson, 2002; Schibeci, 2006) or Draw-An-Engineer (Knight & Cunningham, 2004). Related to the work on images students have of science and scientists, and engineering and engineers, is research on the views on the nature of science (NOS) (Lederman, 2013; Lederman et al., 2002; Ryan & Aikenhead, 1992), in which scholars examine students' views on the epistemology of science (e.g. 'what is scientific knowledge?' and 'how is scientific knowledge created?'). These views on science will certainly be influenced by students' images on science and vice versa, write Ryan and Aikenhead (1992).

It is plausible that students' images on scientific inquiry, or 'the research process' as it is called in this dissertation, will influence their beliefs about how to ideally conduct a research. Lederman (2013) described the research process as a combination of various scientific procedures like observing and inferring (which are already individually complex processes) used in a cyclical manner. To make the whole of scientific inquiry understandable, these complex processes are scaffolded through models: the research and design processes are indeed often displayed in educational materials as cycles, with double-ended arrows to emphasize the iterative nature of research or design (Mosborg et al., 2005). A possible problem with these depictions is that regardless of the double arrows, they often do suggest a certain order in which ideally to follow the phases of the research or design cycle. This can influence student and teacher images of what a research or design cycle *should* look like, leading students and teachers to believe there is only one "right" way of doing research or design. Other scholars also acknowledge the relationship between someone's image and attitude (Van Aalderen-Smeets & Walma van der Molen, 2013; Post & Van der Molen, 2014; Kőycű & De Vries, 2015).

Chapters 2 and 3 show that in general, both O&O and non-O&O students and O&O and NLT teachers rated doing or supervising research activities as more relevant than design activities. It is remarkable that although students and teachers of the subject O&O like design activities better than research activities, they rate doing research as more relevant to learn. Traditionally, science and inquiry-based methods have received more attention in schools than the engineering design process, and this could provoke students and teachers to think that research is more relevant than design (Hoachlander & Yanofsky, 2011). The superior attention to research could cause students and teachers to have clearer images of what doing research entails, compared to their image of design. This is illustrated by a study by Fralick et al. (2009), who showed through a drawing test that many middle school students had no image of engineering, and that some viewed engineers as working outdoors in manual labour, while students had clearer images of scientists. However, since students of the subject O&O have structural experiences with conducting design projects, their image of design might be just as well-developed as their image on research.

Another possible explanation for the finding that students and teachers rate learning to do research as more relevant than learning to design, could be that research is viewed as a more sophisticated or prestigious activity than designing. For example, in a survey held among 1000+ adults about which professions they deemed most prestigious (Taylor, 2001), scientists ranked third in a list of seventeen possible professions, while engineers ranked seventh. Chapter 2 shows that students also found doing research more difficult than designing, which perhaps causes them to view doing research as a more sophisticated and difficult activity in which you are looking for one "right" answer (Millar, 2004), whereas solving design problems could be viewed as "easier" as multiple answers are possible because the solution is unknown.

One of the main problems regarding the connection between research and design that was uncovered in chapters 4 and 5 of this dissertation was the unwillingness of some students to include research activities during design projects. Chapter 2 shows that O&O students are more positive towards design projects than to research activities, and in chapters 4 and 5 both teachers and students indicated that there is a large group of students that prefer to start building or sketching their design first, without doing precursory research. Results of chapters 4 and 5 suggest that even though some students and teachers were able to mention key ideas of design (for example, that a design cycle is an iterative and non-linear process), the same teachers and students also held the strong image that research and design should be conducted in a certain order, with research activities always preceding the sketching and design phases in a design process. The observation that teachers and students tend to act upon their image that the design cycle should be conducted in a certain order (chapter 5), suggests that affective components like images or beliefs are perhaps harder to influence than cognitive components like knowledge.

This firm image of what the design process should look like, may cause several problems in the classroom. For example, the O&O and NLT teachers in chapters 4 and 5 adapted their instructions according to the image that research should always precede design. This might cause students to perceive a lack of autonomy, because this specific design sequence that students and teachers have in mind does not leave much freedom for personal input. In chapter 4, some teachers mentioned that they needed to make clear the relevance of doing research for design for their students with their instructions. In chapter 5 however, we saw that students could already mention different reasons why doing research was relevant for their design project. According to the expectancy-value theory (Brophy, 1987), no effort will be invested in a task if the assumption that you can carry out a certain task is low, no matter how high the perceived relevance of the task. If students did see the relevance of research activities for their design projects, then why did they still not employ them?

The image that students have of research could also be a factor for their motivation. Findings from chapter 5 suggest that students generally see doing research as looking up information and writing reports, activities that most students regard as less enjoyable than design. This confirms the findings in chapter 2, in which students with some experience with design projects rate design activities as significantly more enjoyable than research activities. The images that students have about doing research or conducting a design may create certain expectations. For example, students often expect design to be a more tangible activity than research, while this is only partly true: the design process, like the research process, also contains many abstract phases. These expectations can lead to misunderstandings among students. The notion that research is difficult (as shown in chapter 2), could lead to students thinking they are not able to do innovative research during school projects. If students have the image that research can only lead to one, 'fixed' answer that is already known by the teacher (Millar, 2004), they might not feel the autonomy to experiment with different methods and bring up different solutions. Educational research on this matter is important because if teachers or curriculum developers do not take into account the images and perceptions of students, it becomes hard for deep learning to occur.

The firm image of what the design cycle should look like also poses a problem for students with different learning preferences. Felder and Silverman (1988) distinguished for example different preferences for learning strategies in engineering students. They found that the majority of engineering students were visual, sensing, inductive, and active learners. In contrast, most engineering education is tailored to auditory, abstract (intuitive), deductive, passive, and sequential learners. This study, like our study, indicates that there is a mismatch between the preferred learning strategies of the students and the educational approaches of design. As a consequence, students might perform less well, feel frustrated, and society might lose many potentially excellent engineers (Felder & Silverman, 1988). The results in chapter 5 already show an indication of different preferred research and design strategies, perhaps related to different images of what designing is. Some students for example saw the preparation phases of design as "the real designing", others viewed the sketching and building phases as the actual design activity and saw all the preceding steps as annoying, obligatory tasks.

The question remains where these images about research and design come from. Why do students and teachers think that ideally, research activities like looking up information and doing user research, should *always* precede the development of the design? Possible explanations for student images could be the way in which research and design are taught or assessed; actual personal experiences of students (in or outside school); also, images could be due to a myth, passed on from generation to generation of learners (Schulz, 2001). Tsai (2002) wrote that teachers' beliefs about the nature of science, learning and teaching are related and can be viewed as 'nested epistemologies'. Changing teachers' fixed ideas of teaching and learning science may be a prerequisite of changing their beliefs about science, or vice versa. The research and design cycles as depicted in STEM modules may serve as a useful heuristic for STEM teachers, but as there are just models of reality they should not be used too rigidly. A possible explanation for the rigid use of certain models is that

6

most STEM teachers do not have a lot of experience doing (combined) research and design projects themselves (Honey et al., 2014; Shernoff et al., 2017).

6.4 Limitations and future research

One of the strengths of the research in this dissertation was that it combines quantitative and qualitative studies. Starting the dissertation with two large scale, quantitative studies to provide an overview of the existing attitudes of students and teachers contributed to a good structure of the research project. In addition, two quantitative instruments were developed that can be used by other educational researchers. After exploring general attitudes among a large number of participants, the two qualitative studies ensure that the dissertation also includes more in-depth elaborations about student and teacher thinking. The context of this study (the two Dutch STEM subjects O&O and NLT) could be viewed as limited, however, these subjects are excellent examples of long-term, integrated STEM education, and as they are entirely module- or project-based they can also serve as examples for shorter STEM projects. Therefore, it is a strength that the subjects O&O and NLT are suited to inform both long-term subjects and short-term projects in an international context. However, the research in this dissertation also has some limitations, which provide suggestions for future research.

First, since O&O is an elective subject for students to take and for teachers to teach, their strong positive attitudes towards design (and somewhat positive attitudes towards research) could be caused by an a priori interest in both practices. The studies in this dissertation did not correct for this possible bias. However, other research has shown that despite an equal amount of a priori interest in two groups of students, students that were selected for and participated in an inquiry-based summer course still had more positive attitudes towards science than students who applied to the program but were not selected (Gibson & Chase, 2002). Another argument could be that students who already are high achievers in STEM choose STEM related subjects, because 'you tend to like what you are good at'. This is not necessarily the case as Schibeci and Riley (1986) found that their data supported a model that supports the notion that attitudes influence achievement, rather than the other way around. It is therefore likely that the subject O&O in which students gain experience in conducting authentic research and design projects influences their attitudes positively. It's important to know that students and teachers of the subject O&O hold such positive attitudes towards design, because a positive attitude could consequently influence behaviour positively (Ajzen & Fishbein, 2005). For example, the positive attitude of O&O students towards doing design activities could be an influencing factor in their study or career choices. The question whether taking a subject like O&O directly influences student

study choice is worthy of follow-up research, and is currently being studied by Korthals and Borghans (2018).

Second, the studies in this dissertation rely upon students' and teachers' self-reported attitudes, knowledge, beliefs and perceptions. These data provide very rich insides in what students and teachers think, which was the main aim of this dissertation. However, the findings in the studies are based on students' and teachers' self-reported thoughts, which does not necessarily reflect authentic classroom practices or actual student and teacher behaviour. To further study whether and how students' or teachers' perceptions influence STEM classroom practice, follow-up studies could include observation instruments to document actual student and teacher behaviour next to their own reported behaviour (Barendsen & Henze, 2017). It would be interesting for example to document teacher and student behaviour after teachers have participated in an intervention aimed at professionalization such as the PLC in chapter 4. Due to time limitations, it was not possible to include such a study in this dissertation.

As one of the main aims of this dissertation was to explore student and teacher thinking, all studies in this dissertation were primarily of a descriptive nature. Future research could employ explanatory methods, for example, to explain the origin of teachers' knowledge and beliefs and their effects on students, or to explain where student and teacher attitudes towards research and design come from. We recommend examining student and teacher images of research and design in follow-up research, because the studies in this dissertation indicate that the image that research is difficult, or the image that research should always precede design in the design process, can cause pedagogical problems. Research is needed to examine whether students for example view doing research as passive information processing activities, and whether this influences their willingness or motivation to engage in research activities. Gaining increased insight in students' and teachers' images of research and design, their origins and how to change them, seems valuable for further improving research and design education. This dissertation already indicates that it is essential to activate students' and teachers' pre-existing knowledge and beliefs, because the studies in chapters 4 and 5 show that simply the verbalization of thoughts on this matter can contribute to the knowledge development of teachers (chapter 4) and reveals that students and teachers actually know quite a lot about how research and design are linked to each other (chapter 5).

It would be interesting if future research also examines the influence of teachers' various backgrounds on their STEM teaching practice and their knowledge development. Teachers of STEM projects or subjects often have very different educational backgrounds. As is mentioned in chapter 3, teachers of the subject NLT all have different backgrounds in STEM related disciplines, but teachers of O&O can also have backgrounds in other subjects such as arts or languages. The findings of study 3 indicate that this last group of teachers without a STEM related educational background, express a greater need for teacher professionalization. The study in chapter 4 shows that next to having different backgrounds, teachers also seem to have individually different belief systems. As teachers' educational and personal backgrounds influence how they put their beliefs in practice (Veal, 2004), future studies could also look into the interaction between teachers' backgrounds, beliefs and knowledge, to better understand the reality of classroom practice (Doyle et al., 2019). A STEM teacher with a background in design presumptively has different images and beliefs on what a design process looks like than a STEM teacher with a background in mathematics or languages, and this in turn could also influence how their students perceive the design process.

Chapter 5 suggests that not all students have the same preferred ways of working with the design cycle, which could be related to 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). Therefore, future research should examine what differentiated instruction for design projects should look like, and whether a differentiated approach can also benefit the research process. Future studies could examine the use of new heuristics, or rules-of-thumb (Wieringa, Janssen & Van Driel, 2011), as it seems that often only single varieties of the research and design cycle are being used as a heuristic in current STEM education. An example of a heuristic suggested in earlier research is to focus on iterations of the research and design cycle towards student understanding of the process and related concepts, rather than to focus on iteration towards an end product (Kolodner et al., 2003b). The use of innovative instructional strategies mentioned by some of the teachers in chapters 4 and 5 (for example, the plug-ins) could help facilitate a differentiated approach. The effects of these instructional strategies on student learning and behaviour should be examined further.

6.5 Practical implications

The studies described in this dissertation provide practical implications for teacher practice, teacher education and continuing professionalization, and policy makers in STEM. First, some recommendations for teacher classroom practices are given.

6.5.1 Implications for teacher practice

The teachers that participated in the PLC described in chapter 4, were very positive about the learning opportunity in a group atmosphere, and the contact they had with other teachers of the subject O&O. This is congruent with literature that already indicates that teachers of integrated STEM find it important to work with colleagues and resources, and to receive support in areas outside their expertise, time to prepare, implement and evaluate projects (Eijkelhof & Krüger, 2009; Shernoff et al., 2017). Schools could therefore offer opportunities for team-teaching or project work, and promote co-operation between teachers within or between subjects (Geraedts, Boersma & Eijkelhof, 2006) or even between teachers of different local schools. Since teachers' experiences with connecting research and design are generally scarce, these co-operations should be supported by a facilitator. The teachers in chapter 4 also indicated a need for tools and materials regarding their pedagogies, for example a tool to let students choose between different research and design methods. As the studies in chapter 4 and 5 of this dissertation focused on how to facilitate the connection between research and design activities in STEM projects, some promising instructional strategies for this topic were found. Teachers developed two short instructional strategies that are described in chapter 4, the 'Flip over signs' and the game 'Explain it!'. These are good examples of strategies that can be used within STEM projects to elicit a conversation in which teachers reflect with their students on the research process, the design process, and the ways in which research and design could be related.

The studies in this dissertation also provide some suggestions for teachers considering students' ideas about research and design. Chapter 2 shows that students' general attitudes towards doing research activities were less positive than their attitudes towards doing design activities. In chapter 5, the findings suggest that students generally view doing research as a 'passive' activity that most students regard as less enjoyable than design. Teachers should therefore provide their students with numerous possibilities for doing research other than report writing or literature searches, for example experimentation, simulation, interviews or testing prototypes. This is not only important for integrated STEM education, but for regular science education as well because doing research is often required by the curriculum in single science subjects. Chapter 5 also shows that some students were less willing to include research in their design projects if their autonomy was limited by a strict design protocol. The firm image held by students and teachers of what a design process should look like, contrasts the notion that instruction should be tailored to different students' needs (Tomlinson, 2001). This could be due to students' and teachers' lack of experience with conducting or facilitating design projects, as research activities often receive more attention in science curricula than do design activities. Teachers could offer design projects in the regular science subjects as well, and be more flexible in their approach of the design cycle. Teachers should include alternative approaches to the design cycle which allow students to start from different steps in the design cycle, for example 'reverse designing', that was mentioned by one teacher in chapter 5. This was a successful strategy for some students, as it is known that they can indeed have difficulty to visualize non-existing products and make better sketches after they have modelled their artefacts first (Anning, 1997; Lemons et al., 2010). To prevent design fixation, a problematic phenomenon in design education that was

6

mentioned by teachers in chapters 4 and 5, teachers should promote a focus on iterating processes instead of a focus on product completion.

6.5.2 Implications for teacher education and continuing professionalization

Teacher professionalization in pedagogies for research, design and the connection between research and design is needed. The studies in chapters 3, 4 and 5 illustrate that STEM teachers can have varying backgrounds and beliefs. To address all the different knowledge gaps that exist due to these differing backgrounds, it is important that ample time, support and professional development courses are provided to STEM teachers (Stohlmann et al. 2012). Chapter 3 also implies a special need for professionalization of non-science teachers who are beginning to teach STEM subjects. Teacher education and professional development should not only address the *content* of STEM projects, but the *pedagogy* for facilitating research and design should be emphasized as well. In addition, teachers should practice implementing these pedagogies in their classrooms, as reflecting on these actions strengthens teachers' personal PCK (Clarke & Hollingsworth, 2002). Often, teacher professionalization courses are aimed at single STEM disciplines. Courses specifically aimed at integrated STEM could attract more STEM teachers and could enhance their willingness to attend such professional development opportunities. The results of chapter 4 are promising as they show that even in a short amount of meetings teachers can develop their knowledge on connecting research and design both individually and collectively.

It is also important that during teacher education and continuing professionalization, teachers gain some experience in conducting research and design activities themselves. The finding that teachers 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 (chapter 5), implies that teachers are only routine experts in design themselves, probably due to little experience with (teaching) the design process (Christensen et al., 2018; McLellan & Nicholl, 2011). Teachers should become familiar with multiple models for research and design processes, in order to develop more sophisticated heuristics and to get a better idea of what research and design practices entail in the professional world. This could be achieved by letting teachers gain experience in STEM industries, for example through internships at institutes or companies (Bowen, 2018). Conversely, professionals from STEM industries could also temporarily join a team of STEM teachers, to enhance knowledge exchange between schools and professional STEM practice.

6.5.3 Implications for policy makers in STEM

Research and design processes are often used and combined in STEM professional practice where students might eventually end up, such as in industrial laboratories or technical universities. Therefore, it is important that students understand the ways in

which research and design activities can be connected to each other. However, research and design activities are still often applied in separate projects in STEM education. STEM education would therefore benefit from more integration between research and design in STEM projects because this would better reflect professional practices. The findings in this dissertation show that both students and teachers are able to understand the importance of this connection, but that teachers need support and materials to develop successful pedagogies regarding the integration of research and design. Merely combining research and design within a subject (take O&O for example, which literally means 'research and design') or within a project does not automatically ensure that students apply and connect both research and design activities. The findings described in chapters 4 and 5 indicate that students and teachers have very firm images of what a design process should look like. Educational materials should therefore include multiple models for research and design to illustrate that there are many possible ways in which to conduct a research or design. In addition, such a focus requires assessment practices that enable various ways for meeting the criteria, and for this, curriculum developers should provide rubrics or tools that offer guidance without being prescriptive.

The findings in this dissertation show that a frequent implementation of authentic research and design activities can decrease anxiety and enhance students' confidence and self-efficacy. Therefore, it is important that *all* students are provided with regular experiences in conducting research and design activities in a STEM context. International and national curriculum developers could learn from subjects such as O&O and NLT, and implement similar projects in primary and secondary schools. Young children in primary school already have developed images of what science, or doing research, is (Zhai, Jocz & Tan, 2014). Therefore, it is important to start offering authentic research and design projects in a STEM context already at primary school, because by the time students enter secondary school, their images might already have solidified and are harder to change. The subject O&O provides suitable examples of projects for younger students in upper primary and lower secondary education, and projects can increase in size, complexity and STEM content knowledge over time. The subject NLT treats more in-depth STEM content knowledge, and its modules are therefore more suitable for older students who have elected science as a subject. Research and design activities such as employed in O&O and NLT should not only be available in elective subjects, but should also be employed on a frequent basis in regular science education to give students a more accurate and sophisticated image of STEM disciplines, and to prepare students for the STEM labour market.

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Appendices

Appendix 1

We used explorative principal component analyses (PCA) on both the research and design sections of the ADRADA questionnaire, that each contained 24 items that were supposed to cluster in 7 categories: Relevance, Difficulty, Enjoyment, Anxiety, Self-efficacy, Context dependency and Future. Below are the eigenvalues of the components (Table A for the research section, Table B for the design section), the correlations between the components (Table C for the research section, Table D for the design section) and the component loadings after the Varimax rotation (Table E for the research section, Table F for the design section). For tables C and D we used a Promax rotation. The pattern matrices of the Promax rotation gave the same results as the Varimax rotation, hence we chose to display the Varimax rotation in tablees E and F as it is easier to interpret. Table G represents all item numbers and their corresponding categories of the research and design components of the ADRADA questionnaire. All analyses were performed in IBM SPSS Statistics version 22.

Table A. Eigenvalues of the components in the research section of the ADRADA questionnaire.

Total Variance Explained

Component	Initial Eigenvalues		
	Total	% of Variance	Cumulative %
1	6,149	25,623	25,623
2	2,650	11,043	36,666
3	1,742	7,257	43,923
4	1,402	5,842	49,765
5	1,320	5,499	55,264
6	1,169	4,872	60,137
7	0,963	4,013	64,149
8	0,799	3,327	67,476
9	0,735	3,062	70,539
10	0,694	2,892	73,431
11	0,653	2,722	76,152
12	0,603	2,512	78,664
13	0,598	2,492	81,156
14	0,549	2,287	83,443
15	0,534	2,225	85,668
16	0,468	1,951	87,620
17	0,464	1,934	89,553
18	0,431	1,797	91,351
19	0,410	1,708	93,058
20	0,393	1,636	94,694
21	0,371	1,545	96,240
22	0,330	1,376	97,616
23	0,303	1,264	98,880
24	0,269	1,120	100,000

Extraction Method: Principal Component Analysis.

Table B. Eigenvalues of the components in the design section of the ADRADA questionnaire.

Total Variance Explained

Component	Initial Eigenvalues		
	Total	% of Variance	Cumulative %
1	7,710	32,125	32,125
2	2,743	11,428	43,554
3	1,596	6,651	50,205
4	1,321	5,506	55,711
5	1,136	4,734	60,445
6	0,908	3,784	64,230
7	0,845	3,519	67,749
8	0,757	3,155	70,904
9	0,658	2,743	73,647
10	0,628	2,618	76,265
11	0,596	2,484	78,749
12	0,575	2,396	81,144
13	0,526	2,191	83,336
14	0,495	2,061	85,397
15	0,477	1,988	87,384
16	0,447	1,862	89,247
17	0,421	1,753	91,000
18	0,392	1,633	92,633
19	0,356	1,485	94,118
20	0,348	1,452	95,569
21	0,345	1,437	97,006
22	0,276	1,150	98,156
23	0,230	0,958	99,115
24	0,212	0,885	100,000

Extraction Method: Principal Component Analysis.

Table C. Correlations between the seven components in the research section of the ADRADA questionnaire.

Component Correlation Matrix							
Component	1	2	3	4	5	6	7
1	1,000	0,506	0,402	-0,079	0,442	0,345	-0,266
2	0,506	1,000	0,371	0,040	0,319	0,156	-0,064
3	0,402	0,371	1,000	0,097	0,311	0,254	-0,124
4	-0,079	0,040	0,097	1,000	-0,128	-0,126	0,254
5	0,442	0,319	0,311	-0,128	1,000	0,382	-0,303
6	0,345	0,156	0,254	-0,126	0,382	1,000	-0,231
7	-0,266	-0,064	-0,124	0,254	-0,303	-0,231	1,000

Extraction Method: Principal Component Analysis.
Rotation Method: Promax with Kaiser Normalization.

Table D. Correlations between the seven components in the design section of the ADRADA questionnaire.

Component Correlation Matrix							
Component	1	2	3	4	5	6	7
1	1,000	0,591	0,476	-0,079	0,555	0,410	-0,383
2	0,591	1,000	0,434	0,062	0,341	0,197	-0,115
3	0,476	0,434	1,000	0,140	0,327	0,258	-0,108
4	-0,079	0,062	0,140	1,000	-0,067	-0,094	0,335
5	0,555	0,341	0,327	-0,067	1,000	0,423	-0,331
6	0,410	0,197	0,258	-0,094	0,423	1,000	-0,240
7	-0,383	-0,115	-0,108	0,335	-0,331	-0,240	1,000

Extraction Method: Principal Component Analysis.
Rotation Method: Promax with Kaiser Normalization.

Table E. Component loadings after Varimax rotation in the research section of the ADRADA questionnaire.

Rotated Component Matrix[a]							
	Component						
	1	2	3	4	5	6	7
vII_1_24	0,810						
vII_1_14	0,736	0,331					
VII_1_18a	-0,719						
vII_1_9	0,667	0,418					
VII_1_6a	-0,536						0,358
vII_1_4		0,865					
vII_1_19		0,809					
vII_1_3	0,316	0,753					
vII_1_22			0,752				
vII_1_21			0,750				
vII_1_26	0,327		0,695				
vII_1_1			0,630				
vII_1_17				0,844			
vII_1_13				0,814			
vII_1_12				0,794			
vII_1_2					0,770		
vII_1_5					0,734		
vII_1_25					0,492		
vII_1_15					0,474	0,313	
vII_1_7						0,779	
vII_1_11						0,689	
vII_1_20						0,659	
vII_1_10							0,863
vII_1_23							0,853

Extraction Method: Principal Component Analysis.
Rotation Method: Varimax with Kaiser Normalization.[a]
a. Rotation converged in 6 iterations.

Table F. Component loadings after Varimax rotation in the design section of the ADRADA questionnaire.

Rotated Component Matrix[a]							
	Component						
	1	2	3	4	5	6	7
vII_2_6	0,758	0,341					
vII_2_1	0,745						
vII_2_12	0,696	0,384					
VII_2_14a	-0,681						
VII_2_17a	-0,614						
vII_2_5	0,590				0,336		
vII_2_2	0,302	0,825					
vII_2_22		0,820					
vII_2_9	0,337	0,780					
vII_2_7			0,765				
vII_2_24			0,744				
vII_2_19			0,735				
vII_2_4	0,361		0,626				
vII_2_10				0,817			
vII_2_20				0,805			
vII_2_8				0,801			
vII_2_21					0,772		
vII_2_23					0,742		
vII_2_13	0,444				0,465		
vII_2_3						0,808	
vII_2_11						0,778	
vII_2_15					0,321	0,565	
vII_2_25							0,855
vII_2_16							0,833

Extraction Method: Principal Component Analysis.
Rotation Method: Varimax with Kaiser Normalization.[a]
a. Rotation converged in 7 iterations.

Table G. All item numbers and their corresponding categories of the research and design components of the ADRADA questionnaire. Strike-through numbers were problematic items (which lowered the Cronbach's alpha and were not further included in the following Multilevel analyses).

Main category	**Subcategory**	**Items in research component ADRADA (VII_1)**	**Items in design component ADRADA (VII_2)**
Cognition	Relevance	~~1~~, 21, 22, 26	4, 7, 19, 24
	Difficulty	12, 13, 17	8, 10, 20
Affec	Enjoyment	9, 14, ~~16a~~, 24	1, 6, 12, ~~26a~~
	Anxiety	6a, 10, 18a, 23	14a, 16, 17a, 25
Control	Self-efficacy	2, 5, 15, 25	5, 13, 21, 23
	Context	7, ~~8~~, 11, 20	3, 11, 15, ~~18~~
Behaviour	Future	3, 4, 19	2, 9, 22

Appendix 2

Example items of the research component of the ASRADA questionnaire (translated from Dutch). Items in the design components were the same, except these statements were about 'design projects' rather than 'research projects'. The complete ASRADA questionnaire was constructed in Dutch and is available upon request.

Main category	Sub category	Example item.
Cognition	Relevance	I think that students in secondary school should learn to do research projects themselves as early as possible.
	Difficulty	I think that teachers find it difficult to supervise research projects.
Affection	Enjoyment	Supervising students doing research projects makes me enthusiastic.
	Anxiety	I feel nervous when supervising students doing research projects.
Control	Self-efficacy	If students have difficulties during research projects, I think I can manage to help them in a good way.
	Context	I have sufficient time to let students do research projects in my classroom.
Behaviour	Future	I would like to do a course to learn more about the research process myself.

Appendix 3

Table A. Intended learning outcomes of the four PLC meetings, organized per domain of Magnusson et al. (1999).

M1: knowledge of goals and objectives	**Moment in PLC** *supporting literature*
There is a difference between doing research (objective, analyzing knowledge) and designing (subjective, solving a problem).	1st meeting, lecture F *Vossen et al. (2018)*
In O&O projects, research and design complement each other, and can be combined by students and teachers.	1st meeting, lecture TE
Doing research (gaining knowledge) is part of, and necessary for, designing.	1st meeting, lecture TE *Sanders and Stappers (2008)* *Frankel and Racine (2010)*
Designing without any form of research is intuitive design, and almost becomes art.	1st meeting, lecture TE *De Jong and Van der Voordt (2002)*
When designing, one can also do research by testing and experimenting.	1st meeting, lecture TE
Looking up knowledge relies on existing facts, and doing research is creating/synthesizing new knowledge yourself.	1st meeting, lecture TE
Doing research or conducting a design request different skills.	1st meeting, lecture TE
One can do research through design, when the design itself helps to provide knew knowledge.	1st meeting, lecture TE *Frankel and Racine (2010)*
Design can enhance a research project when there is a 'need to do': for example, by designing an experimental setup.	1st meeting, oral explanation F
Basic knowledge about the research and design cycle(s).	1st meeting, lecture TE
The design cycle has multiple varieties, can be conducted more than once, is not linear, and has multiple dimensions.	1st meeting, lecture TE *Van Dooren et al. (2014)*
There are multiple research approaches: describing, explanatory, comparative, evaluative and design research.	1st meeting, lecture F
Knowing how to fine-tune a research question.	1st meeting, lecture F
After doing research, one can make a recommendation for the design of an application of the results.	1st meeting, oral explanation F
Reasons why it is important students learn about the connection between research and design.	2nd meeting, collective CoRe
M2: knowledge of students	
Knowledge of students' ideas about the connection between research and design.	2nd meeting, collective CoRe
Knowledge of difficulties students may have when learning/applying the connection between research and design.	2nd meeting, collective CoRe
Ideas about when (in which grade) students are mentally capable to learn about connection between research and design.	Discussion in 1st meeting
M3: knowledge of instructional strategies	

An O&O project can be adjusted to include both research and design components.	3rd meeting
The 'need to know' and 'need to do' can be made explicit in the O&O project or by the teacher.	3rd meeting *Kolodner et al. (2003a)*
Think of plug-in activities that can help enhance the connection between research and design in the O&O lesson.	2nd meeting, collective CoRe and design of plug-ins
Teachers test and apply these plug-ins.	Between 2nd and 3rd meeting
Teachers can evaluate applied plug-ins.	3rd meeting, evaluation
Teacher know they can make explicit the connection between research and design by denominating it to their students.	Oral explanation F *Puntambekar and Hubscher (2005)*
M4: knowledge of assessment	
Teachers can think about ways to measure whether students have understood that a connection exists between research and design.	2nd meeting, collective CoRe

Appendix 4

Technical design in biomedical technology
NLT module

Index

Appendix 5

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

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 minutes)

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 minutes)

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 6

Interview protocol of the semi-structured teacher interviews.
Each interview lasted about 45-60 minutes.

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 minutes)
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 minutes)
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.

1. 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?
2. 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?

3. 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)
4. 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)
5. What difficulties did you and your students encounter during the module? (M2)
   a. What caused these difficulties? How did you react to them?
6. 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?
7. 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?
8. What instructional strategies did you use during the module? (M3)
9. 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?
10. How did you motivate students for a project in which they had to do both research and design activities? (M3)
11. 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.]?
12. Which do's and don'ts would you recommend to a colleague who was also going to teach this module?
13. 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 7

Student focus groups are indicated with a letter A-D, to indicate in which of the student groups certain codes were mentioned. Teacher scores (from the two interviews) are indicated by an X. Teacher names are abbreviated: Joanne (J), Lisa (L), Samuel (S), Mary (Ma) and Mitchell (Mi). Grey marked codes are functions of research within design based on literature (deductive), white marked codes emerged during analyses (inductive).

Code	Explanation + literature	Student groups				Teachers				
		J	L	S	M+M	J	L	S	Ma	Mi
Functions of research within design										
FUN_RforD_notspecified	"You need research to do a design". The exact function of research in design is not specified.	AC	ABC	AC	BCD	X	X	X	X	X
FUN_RforD_lookingup	Looking up information about the topics involved in the design project (Christensen et al. 2016; Wild et al. 2010).	ABC	BC	ABCD	ABCD	X	X	X	X	X
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).	C	ABC	ABCD	BC	X	X	X		X
FUN_RforD_relevance	Research to discover whether the product you (want to) make actually solves a problem.	ABC	BC	C	AD	X				
FUN_RforD_improve	Research is used to improve existing ideas (Mehalik et al. 2008)	AC	AB	ACD	B	X			X	X
FUN_RforD_users	Target group/user research (Christiaans and Dorst 1992; Crismond and Adams 2012).	ABC	AB	C	CD	X				X
- FUN_RforD_users_experience	Research on users from your own experience.		C							
- FUN_RforD_users_simulation	Research on users by simulating their situation, for example by roleplay (Crismond and Adams 2012).			A		X	X	X		X
FUN_RforD_test	When designing, one can also do research by testing and experimenting. (Crismond and Adams 2012).	C	AC	A	BC	X	X	X	X	X

- FUN_test_troubleshoot	Experiments with prototypes: 'analytic/diagnostic troubleshooting' by testing hypotheses (Crismond and Adams 2012).			C		X				
- FUN_test_users	Checking prototype with target group (Crismond and Adams, 2012).				B				X	
- FUN_test_materials	Testing whether the materials used in the prototype are adequate (Mehalik et al. 2008).					X				
FUN_RforD_clearproblem	Orientation research for problem formulation (Christensen et al. 2016; Crismond and Adams 2012).	BC	AB		ABCD	X	X		X	X
FUN_RforD_PoR	Research to compose the Program of Requirements.		C	AD	BC	X	X		X	X
FUN_RforD_materials	Research on which materials are suitable for the design (Bursic and Atman 1997; Crismond and Adams 2012).	A	C	AC		X	X	X		X
FUN_RforD_solvedesignproblems	Analysis of problems that arise during designing.	A	B	B		X				X
FUN_RforD_ collabresearchersanddesigners	Researchers can collaborate with designers to make a product.	C	AB		B			X		
FUN_RforD_ideatable	Investigating alternative options for each requirement, and systematically compare these options in a table of ideas.	B	A		A	X	X			
FUN_RforD_analysing	Critically analyzing the workings of the designed product on paper.		A							X
FUN_RforD_askexperts	Acquire information from contact with experts on the design topic.		A	C						
FUN_RforD_bestidea	Researching which idea is best.		A		B	X	X			X
FUN_RforD_costs	Analyzing the costs of (different parts of) the design (Bursic and Atman 1997; Christensen et al. 2016).	A	A			X				
FUN_RforD_howitworks	Analyzing critical questions in regard to how the design works (Crismond and Adams 2012).				CD			X		
FUN_RforD_howtomake	Research on how to manufacture the product/prototype (Crismond and Adams 2012; Kuffner and Ullman 1990).		AB					X		
FUN_RforD_location	Research on the location in which the designed product is to be used.		C	AC						
FUN_RforD_marketing	Research on which marketing strategies to use to promote the product.				D	X				
FUN_RforD_otherfields	Retrieving information from other fields related to the area in which the design problem is positioned.	C								
FUN_RforD_safety	Research on safety and legal issues (Bursic and Atman 1997; Crismond and Adams 2012).			A						

FUN_RforD_justify	Use research to justify the making of informed design decisions (Crismond and Adams 2012).					X	X	X	X	X
FUN_RforD_compare	Analyzing and systematically comparing different design ideas to one another.					X		X		
FUN_RforD_exteriordesign	Research on what the design should look like esthetically.					X				
FUN_RforD_methods	Examine which research or design methods to apply.								X	
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).		BC		C		X		X	
FUN_RaboutD	One can do research *about* design, to learn from good or failed practices (Crismond and Adams 2012; Frankel and Racine 2010).				C					
Key ideas										
KEY_iteration	Design *is* iteration (cf. Crismond and Adams 2012).	ABC	B		ACD	X	X	X		X
KEY_multiplecycle	The design cycle has multiple varieties, can be conducted more than once, is not linear, and has multiple dimensions (cf. Van Dooren et al. 2014).	A			A			X		
KEY_multipledesignspossible	There is not one single right solution for a design problem, multiple designs are possible.	B	A			X		X		
Value/relevance										
REL_improveproduct	Doing research within design is relevant because it helps students to improve existing products.	AC								
REL_dontstartoutoftheblue	Doing research within design is relevant because you cannot just start designing from nothing.		AC	B	CD	X		X		
REL_originalproduct	Doing research within design is relevant because research helps students to determine whether their product is original or innovative.		B	ABC	AB					

REL_qualityproduct	Doing research within design is relevant because it enhances the quality of the designed product/service (Crismond and Adams 2012).	C	AB	AD	B	X				X
REL_realworld	Doing research within design is relevant because it reflects real world practices (Sanders and Stappers 2008; Vossen et al. 2019).	ABC	AB	ABCD	BCD	X			X	
REL_study	Doing research within design is relevant because it will help students in their further studies (Vossen et al. 2019).		C	C			X		X	
REL_school	Doing research within design is relevant because it can help students in other school subjects or projects.								X	
REL_deeperlearning	Doing research within design is relevant because it can lead to deeper learning and mastery of theoretical concepts.						X			X
REL_stimulateinvestigativeattitude	Doing research within design is relevant because it can stimulate student to develop an investigative attitude.								X	
REL_negative	Doing research within design is perceived as irrelevant or boring by students.		B	AD	A			X		X
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.		B	ABCD	BCD			X	X	
REL_logical	Doing research within design is perceived as relevant by students, because it is logical or better to so.	BC	ABC	ABCD	ABCD	X			X	

Nederlandse samenvatting

Samenvatting

Onderzoeken en ontwerpen zijn kernactiviteiten in het internationale STEM-onderwijs (Science, Technology, Engineering and Mathematics; Engels voor wetenschap, technologie, ontwerpen en wiskunde). Onderzoeks- en ontwerpactiviteiten worden vaak gebruikt tijdens projecten in een STEM-context. Binnen deze projecten ligt de focus echter vaak op onderzoeken óf op ontwerpen, terwijl deze twee processen in de professionele STEM-praktijk vaak met elkaar verbonden zijn. Het combineren van onderzoeken met ontwerpen zorgt er bijvoorbeeld voor dat leerlingen goed verantwoorde ontwerpkeuzes kunnen maken. Er is echter nog veel onduidelijk over hoe onderzoeks- en ontwerpactiviteiten in de onderwijspraktijk met elkaar verbonden kunnen worden, omdat weinig docenten hier ervaring mee hebben.

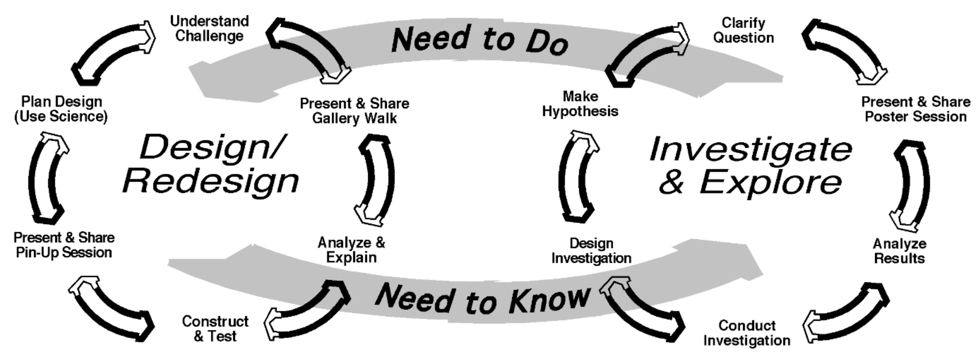
Het doel van dit proefschrift is bij te dragen aan theoretische en praktische kennis over het verbinden van onderzoeks- en ontwerpactiviteiten in het voortgezet onderwijs. Daarom is er gekeken naar hoe de onderwijspraktijk door leerlingen en docenten wordt ervaren. De hoofdvraag van dit onderzoek is: Wat denken docenten en leerlingen in STEM-onderwijs over onderzoeken, ontwerpen en de verbinding daartussen? Deze vraag is onderverdeeld in vier deelvragen die in de hoofdstukken van dit proefschrift behandeld worden aan de hand van studies die gericht zijn op twee schoolvakken in het voortgezet onderwijs met een nadruk op STEM:

1) Wat zijn de attitudes van leerlingen ten aanzien van het doen van onderzoeks- en ontwerpopdrachten? (hoofdstuk 2)
2) Wat zijn de attitudes van docenten van een STEM-vak ten aanzien van het begeleiden van onderzoeks- en ontwerpopdrachten? (hoofdstuk 3)
3) Hoe ontwikkelen de kennis en overtuigingen van docenten van een STEM-vak zich voor en na het deelnemen aan een professionele leergemeenschap (PLG) gericht op de verbinding tussen onderzoeken en ontwerpen? (hoofdstuk 4)
4) Wat zijn de percepties van leerlingen en docenten van een STEM-vak met betrekking tot de functies van onderzoek binnen een ontwerpmodule? (hoofdstuk 5)

Theoretisch kader van dit proefschrift

In dit proefschrift staan de activiteiten onderzoeken en ontwerpen, en de verbinding hiertussen, centraal. Onderzoeken is een activiteit met het doel bepaalde fenomenen te beschrijven, te verklaren of te vergelijken door gegevens te verzamelen en deze te analyseren. Het onderzoeksproces bestaat over het algemeen uit de volgende fasen: oriëntatie op onderzoeksvraag; hypothesen genereren; het onderzoek plannen; data verzamelen; gegevens organiseren en analyseren; conclusies trekken en deze bespreken; communiceren en presenteren van de bevindingen. Gegevens kunnen worden verzameld uit experimenten: kwantitatieve of kwalitatieve metingen die leerlingen zelf uitvoeren of door informatie te verzamelen: door boeken te lezen, op internet te zoeken of experts te interviewen. Het doel van ontwerpen is om producten of diensten te ontwikkelen of te verbeteren. Het ontwerpproces bestaat over het algemeen uit de volgende fasen: het ontwerpprobleem verduidelijken en verkennen; een programma van eisen samenstellen; het ontwerp plannen; het bouwen van een prototype; het prototype testen en optimaliseren; het product analyseren; het product presenteren aan de klant of doelgroep. Het onderzoeks- en ontwerpproces worden beide beschouwd als iteratief, systematisch, doelgericht en hebben de mogelijkheid om elkaar te informeren.

Onderzoeksactiviteiten worden door veel wetenschappers erkend als een noodzakelijk onderdeel van het ontwerpproces. Onderzoeksactiviteiten zijn belangrijk omdat ze ontwerpbeslissingen kunnen rechtvaardigen, bijvoorbeeld door materialenonderzoek, doelgroeponderzoek, literatuuronderzoek over het domein waarvoor het ontwerp wordt gemaakt, veiligheidsonderzoek, testen van het prototype of productanalyse. Al deze onderzoeksactiviteiten informeren het ontwerpproces. Het belang van het verbinden van onderzoeken en ontwerpen in een educatieve context wordt al erkend door andere onderwijswetenschappers. Kolodner en collega's (2003a) beschrijven bijvoorbeeld de verbinding tussen onderzoeken en ontwerpen met de termen 'need to know' en 'need to do' (figuur 6.1). De 'need to know' verwijst naar de noodzaak om tijdens een ontwerpproject kennis te vergaren over de theoretische achtergrond van het ontwerpprobleem, of over de doelgroep. De 'need to do' verwijst naar het toepassen van deze kennis in het ontwerpproces. In dit proefschrift wordt deze 'need to do' nog verder uitgebreid, namelijk als een vraag die zich ook kan voordoen in een onderzoeksproject zoals de noodzaak om een meetinstrument te ontwerpen, of de noodzaak om praktische aanbevelingen te doen die het ontwerp van een product of dienst informeren.



Figuur 6.1 De verbinding tussen de onderzoeks- en ontwerpcyclus (Kolodner et al., 2003a)

Er is nog niet veel onderzoek beschikbaar over hoe docenten de verbinding tussen onderzoeken en ontwerpen in STEM-onderwijs kunnen faciliteren. Veel docenten die een STEM-vak geven, hebben een achtergrond in een van de bètavakken, maar niet in het combineren van vakgebieden en bijbehorende processen. Ook hebben veel docenten geen ervaring met ontwerpen, of met ontwerpen in combinatie met onderzoeken. Omdat docenten de belangrijkste factor zijn in het laten slagen van onderwijsvernieuwingen en omdat ze grote invloed hebben op de attitude- en kennisontwikkeling van leerlingen is het belangrijk om te weten wat de kennis, overtuigingen en percepties zijn van docenten over onderzoeken en ontwerpen. Ook is het belangrijk om te weten hoe leerlingen denken over de verbinding tussen onderzoeken en ontwerpen, want studies wijzen uit dat dit vaak niet goed gaat. Het is belangrijk om te weten of dit ligt aan een gebrek aan kennis, een negatieve attitude, of andere opvattingen.

Context: de vakken O&O en NLT

De context van de studies in dit proefschrift wordt gevormd door de Nederlandse vakken O&O (onderzoeken en ontwerpen) en NLT (natuur, leven en technologie). Dit zijn twee vakken die gebruik maken van contextgericht onderwijs gerelateerd aan vakgebieden in STEM. O&O bestaat in Nederland sinds 2004, en wordt op dit moment op bijna honderd gecertificeerde, zogenoemde Technasiumscholen gegeven. De belangrijkste doelen van O&O zijn om (1) leerlingen voor te bereiden op opleidingen en beroepen in de bèta-technische sector; en (2) leerlingen stimuleren om zich te ontwikkelen tot competente ontwerper of onderzoeker. Het is de bedoeling dat leerlingen deze doelen bereiken door kennis toe te passen in het kader van actuele en authentieke vraagstukken van bedrijven en instellingen uit de bèta-technische sector. O&O is een keuzevak dat 4-6 uur per week wordt gegeven van de eerste tot de zesde klas op middelbare scholen met het Technasiumpredicaat. Leerlingen voeren onderzoeks- of ontwerpprojecten uit in groepjes, waarbij ze bijvoorbeeld een onderzoeksrapport opstellen met advies over het optimaliseren van een algenreactor, of een app ontwikkelen voor een lokale kinderboerderij. Docenten van alle schoolvakken mogen O&O geven als ze een aantal cursussen van de stichting Technasium hebben gevolgd. Op de technische universiteiten kunnen studenten met een ontwerpachtergrond een eerstegraads lesbevoegdheid voor O&O behalen.

Het schoolvak NLT werd in 2007 in Nederland geïntroduceerd als een overheidsinitiatief. Op dit moment zijn er rond de 220 scholen die NLT aanbieden. De hoofddoelen van NLT zijn (1) het vergroten van de aantrekkelijkheid van STEM opleidingen; en (2) de samenhang tussen de afzonderlijke bètavakken vergroten. NLT wordt alleen in de bovenbouw van het voortgezet onderwijs gegeven, soms verplicht, maar vaak als keuzevak voor ongeveer 3-4 uur per week. Het vak NLT is volledig gebaseerd op interdisciplinaire modules. Leerlingen ontwerpen bijvoorbeeld tools om problemen in de biomedische wetenschap op te lossen of doen onderzoek naar de technische aspecten van waterzuivering. Alleen docenten die gekwalificeerd zijn in een van de bètavakken (natuurkunde, wiskunde, scheikunde, biologie en aardrijkskunde) mogen NLT geven. Hoewel er geen aparte lerarenopleiding is voor NLT, kunnen lerarenopleidingen korte cursussen aanbieden, en kunnen NLT-docenten de jaarlijkse NLT-conferentie bijwonen.

Bevindingen per hoofdstuk

Voor de studie in ***hoofdstuk 2*** is een vragenlijst ontwikkeld om de attitudes van leerlingen in het voortgezet onderwijs te beschrijven ten aanzien van *het doen van* onderzoeks- en ontwerpopdrachten. Het theoretisch kader voor attitude van dat hiervoor werd gebruikt[1], bevat de componenten cognitie (relevantie, moeilijkheid), affect (plezier, stress), controle (zelfeffectiviteit, context), en intentie tot gedrag. De onderzoeksvragen waren: (1) Wat zijn de attitudes van leerlingen in het voortgezet onderwijs ten aanzien van het doen van onderzoeks- en ontwerpopdrachten in het algemeen? (2) Zijn er verschillen in attitude tussen het doen van onderzoekopdrachten en het doen van ontwerpopdrachten? (3) Zijn er verschillen in attitudes tussen leerlingen die het vak O&O volgen en leerlingen die dit vak niet volgen? (4) Zijn er verschillen in attitude tussen de 2^e^ en de 5^e^ klas? en (5) Zijn er verschillen in attitude tussen jongens en meisjes? De resultaten van 1625 geretourneerde vragenlijsten toonden aan dat leerlingen over het algemeen een neutrale tot licht positieve houding hadden ten aanzien van het doen van onderzoeksopdrachten en iets positievere attitudes ten aanzien van het doen van ontwerpopdrachten. De attitudes ten aanzien van het doen van ontwerpopdrachten waren vooral positief bij leerlingen die het vak O&O volgden en dus al enige ervaring hadden met ontwerpen. Leerlingen vonden onderzoeksopdrachten over het algemeen relevanter dan ontwerpopdrachten, maar ook moeilijker. Leerlingen die het vak O&O volgden, hadden significant positievere attitudes ten aanzien van het doen van ontwerpactiviteiten dan niet-O&O-leerlingen. Ook rapporteerden ze minder stress voor onderzoeksopdrachten te ervaren en scoorden ze significant hoger op zelfeffectiviteit voor het doen van onderzoek. Vijfdeklassers die het vak O&O volgden, scoorden hoger op zelfeffectiviteit dan O&O-leerlingen in de 2^e^ klas, wat er op duidt dat het vertrouwen in hun eigen kunnen toeneemt gedurende hun schooltijd. Daarentegen scoorden niet-O&O-leerlingen in de 5^e^ klas hoger op het stresscomponent voor zowel onderzoeks- als

[1] Van Aalderen-Smeets, S. I., Walma van der Molen, J. H., & Asma, L. J. (2012). Primary teachers' attitudes toward science: A new theoretical framework. *Science Education, 96*(1), 158-182.

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ontwerpopdrachten dan leerlingen in de 2e klas, wat erop duidt dat ze gedurende hun schooltijd nerveuzer worden voor onderzoeks- of ontwerpopdrachten. Uit de gegevens bleek dat meisjes over het algemeen een lagere zelfeffectiviteit hadden dan jongens voor het doen van onderzoeks- en ontwerpopdrachten. Meisjes uit de niet-O&O-groep scoorden significant hoger dan jongens op moeilijkheid van en stress bij onderzoeksopdrachten, terwijl er op deze componenten geen verschillen waren tussen jongens en meisjes uit de O&O-groep. Dit zou erop kunnen duiden dat het volgen van een vak als O&O een positieve invloed heeft op de attitude van meisjes ten aanzien van het doen van onderzoeksopdrachten. De gevonden verschillen tussen de O&O leerlingen en niet-O&O-leerlingen suggereren dat een vak als O&O de attitudes van leerlingen ten aanzien van onderzoeks- en ontwerpopdrachten kan verbeteren.

In ***hoofdstuk 3*** werd de vragenlijst voor leerlingattitudes uit hoofdstuk 2 aangepast om de attitudes van docenten te beschrijven ten aanzien van *het begeleiden van* onderzoeks- en ontwerpopdrachten. 78 O&O-docenten en 52 NLT-docenten namen deel aan het onderzoek waarvan de gegevens werden geanalyseerd met multilevel analyses. Het doel van deze studie was om (1) de attitudes van STEM-docenten te beschrijven ten aanzien van het begeleiden van onderzoeksopdrachten en ontwerpopdrachten; (2) verschillen in attitude tussen O&O- en NLT-docenten te meten; en (3) verschillen in attitude tussen O&O-docenten met verschillende achtergronden (een bèta- versus een niet-bèta-achtergrond) te meten. Net als de studie in hoofdstuk 2 was de vragenlijst voor docentattitudes gebaseerd op een kader voor attitude met de componenten cognitie (relevantie, moeilijkheid), affect (plezier, stress), controle (zelfeffectiviteit, context) en intentie tot gedrag[2]. De resultaten laten zien dat de docenten over het algemeen een positieve houding hadden ten aanzien van het begeleiden van onderzoeksopdrachten en ontwerpopdrachten. O&O-docenten hadden over het algemeen een positievere attitude ten aanzien van het begeleiden van ontwerpopdrachten in vergelijking met het begeleiden van onderzoeksopdrachten, voor NLT-docenten gold juist het tegenovergestelde. NLT-docenten scoorden hoger op de component moeilijkheid bij het begeleiden van ontwerpopdrachten dan O&O-docenten. Opmerkelijk was dat alle docenten, zelfs de O&O-docenten met een niet-bèta-achtergrond, vrij hoog scoorden op zelfeffectiviteit met betrekking tot het begeleiden van onderzoeks- en ontwerpopdrachten. Het is mogelijk dat de hoge zelfeffectiviteit van de docenten gebaseerd is op een sterk enthousiasme voor het lesgeven in de vakken O&O of NLT, in plaats van op feitelijke competenties. Een resultaat vergelijkbaar met dat van de leerlingen was dat docenten het begeleiden van onderzoeksopdrachten als relevanter beschouwden dan het begeleiden van ontwerpopdrachten. Omdat ontwerpen op dit moment steeds meer aandacht

[2] Van Aalderen-Smeets, S. I., Walma van der Molen, J. H., & Asma, L. J. (2012). Primary teachers' attitudes toward science: A new theoretical framework. *Science Education, 96*(1), 158-182.

krijgt in het internationale STEM-onderwijs, is het belangrijk dat docentprofessionalisering zich niet alleen richt op het leren begeleiden van onderzoek, maar ook op de didactiek van het begeleiden van ontwerpopdrachten.

Een manier van docentprofessionalisering is deelname aan een professionele leergemeenschap (PLG). In ***hoofdstuk 4*** wordt de kennisontwikkeling van zes O&O-docenten beschreven die deelnamen aan een PLG gericht op het verbinden van onderzoeks- en ontwerpactiviteiten. Interviews voor en na de PLG met individuele docenten hadden tot doel de ontwikkeling van hun 'pedagogical content knowledge' (PCK) te bestuderen. PCK wordt in de literatuur beschreven als een speciale combinatie van kennis over inhoud en didactiek die eigen is aan de professionele kennis van docenten[3]. Deze studie was gericht op (1) het karakteriseren van de ontwikkeling van de persoonlijke PCK en overtuigingen van docenten over het verbinden van onderzoeken en ontwerpen; en (2) bestuderen hoe docenten gezamenlijk betekenis gaven aan de verbinding tussen onderzoeken en ontwerpen tijdens de PLG. Tijdens de PLG kregen docenten informatie over onderzoeken en ontwerpen, voerden ze discussies over de verbinding tussen deze twee activiteiten, en ontwikkelden ze zelf instructiestrategieën gericht op het verbinden van onderzoeken en ontwerpen in de klas. De interviews werden geanalyseerd volgens de vijf componenten van het PCK-model van Magnusson en collega's (1999)[4]: overtuigingen; kennis over leerdoelen; kennis over leerlingen; kennis over instructiestrategieën; en kennis over toetsing. Uit de resultaten van de interviews bleek dat de persoonlijke PCK per docent verschilde en zich ook per docent verschillend ontwikkelde. Sommige docenten verbreedden hun kennis over leerdoelen met betrekking tot het verbinden van onderzoeks- en ontwerpactiviteiten, terwijl andere docenten hun bestaande kennis en overtuigingen verder verdiepten. De docenten hadden verschillende overtuigingen over het faciliteren van de verbinding tussen onderzoeks- en ontwerpactiviteiten, die hun PCK-ontwikkeling en soms ook de collectieve ideeën over verbinding in de PLG beïnvloedden. Zo hadden de docenten allen de overtuiging dat het belangrijk is dat leerlingen eerst vooronderzoek doen voordat ze beginnen met een ontwerp, dat het belangrijk is om onderzoeks- en ontwerpkeuzes te verantwoorden, en dat het belangrijk is om geschikte onderzoeks- en ontwerpmethoden te kiezen. Deze studie toont aan dat een PLG waarin docenten met verschillende achtergronden samen kennis en instructiestrategieën ontwikkelen, een goede methode is om de persoonlijke en gezamenlijke kennis van docenten te verbeteren.

[3] Shulman, L. (1987). Knowledge and teaching: Foundations of the new reform. *Harvard educational review, 57*(1), 1-23.

[4] Magnusson, S., Krajcik, J., & Borko, H. (1999). Nature, sources, and development of pedagogical content knowledge for science teaching. In J. Gess-Newsome & N. G. Lederman (Eds.), *Examining pedagogical content knowledge* (pp. 95–132). Dordrecht: Kluwer.

Na het onderzoeken van de kennis en overtuigingen van O&O docenten, was het ook interessant om de percepties van NLT-docenten en hun leerlingen over de verbinding tussen onderzoeken en ontwerpen te bestuderen. ***Hoofdstuk 5*** richt zich op (1) welke functies van onderzoek doen binnen een ontwerpproces door leerlingen van het vak NLT herkend worden en welke waarde ze hieraan toekennen; en (2) welke functies van onderzoek doen binnen een ontwerpproces NLT-docenten herkennen en hoe ze die in de klas faciliteren. Alle docenten en hun leerlingen in deze studie werkten op dat moment aan de NLT-module 'Technisch ontwerpen in de biomedische technologie', een module waarbij leerlingen kennismaken met de ontwerpcyclus in de context van vraagstukken uit de biomedische technologie. In deze verkennende casestudie werden vijf NLT-docenten en hun vier klassen geïnterviewd. De docenten werden voor en na de module geïnterviewd, en de leerlingen namen deel aan focusgroepen van 3-4 leerlingen per keer vlak voor het eind van de module. Deze interviewdata werd geanalyseerd met behulp van een lijst van verschillende functies van onderzoek binnen een ontwerpproces, opgesteld op basis van wetenschappelijke literatuur. De interviews waarin docenten rapporteerden over de manier waarop ze de functies van onderzoeken binnen ontwerpen faciliteerden voor hun leerlingen, werden geanalyseerd met behulp van de verschillende domeinen van 'pedagogical content knowledge' (PCK), zoals ook gedaan is in hoofdstuk 4. Uit deze studie bleek dat de docenten en leerlingen veel verschillende functies van onderzoek binnen het ontwerpproces konden herkennen en benoemen. Dit impliceert dat het gebruik van een NLT-module gericht op ontwerpen een goed startpunt is om functies van onderzoek binnen een ontwerpproces herkenbaar te maken voor leerlingen. Hoewel leerlingen wel de waarde inzagen van onderzoek doen binnen een ontwerpproces, meldden zowel de docenten als de leerlingen dat sommige leerlingen geen onderzoeksactiviteiten uitvoerden, en in plaats daarvan liever direct begonnen met het maken van hun ontwerp. De docenten benadrukten het belang van onderzoek doen door mondelinge uitleg te geven, beoordelingscriteria op te stellen of door instructiestrategieën te gebruiken die het belang van onderzoek duidelijk moesten maken. Een voorbeeld hiervan is de 'omgekeerde ontwerpstrategie' die werd toegepast door een van de NLT-docenten, waarbij zijn leerlingen de ontwerpcyclus in de omgekeerde volgorde volgden en zodoende begonnen met het maken van het ontwerp en eindigden met het doen van (voor)onderzoek. Zowel docenten als leerlingen hadden het beeld dat ontwerpen altijd moet worden voorafgegaan door onderzoeksstappen. Deze overtuiging kan ervoor zorgen dat de ontwerpcyclus wordt gezien als een stappenplan dat alle leerlingen in dezelfde volgorde moeten doorlopen. Dit komt niet overeen met het idee dat de leerstof gedifferentieerd zou moeten zijn voor leerlingen met verschillende leervoorkeuren. Daarom is vervolgonderzoek nodig naar de manier waarop docenten kunnen differentiëren voor de verschillende leervoorkeuren van leerlingen tijdens onderzoeks- en ontwerpopdrachten.

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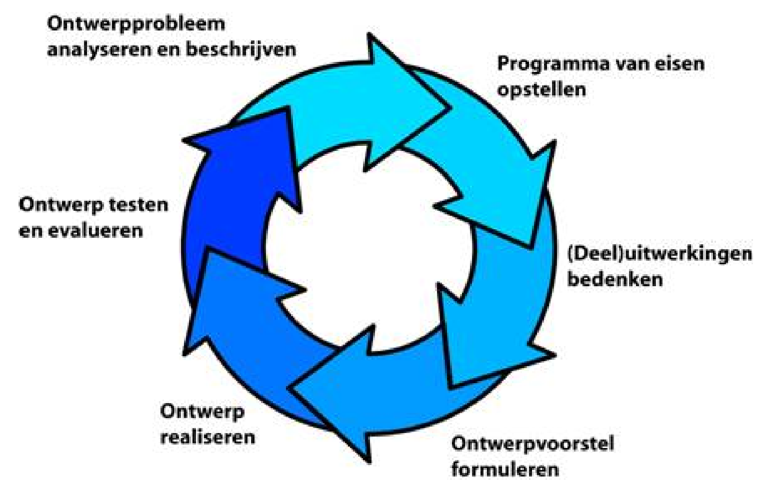
Interpretatie van de bevindingen

De deelstudies uit dit proefschrift laten zien dat het verbinden van onderzoeks- en ontwerpactiviteiten relevant wordt gevonden door docenten en leerlingen, maar dat de implementatie van deze verbinding in STEM-vakken niet automatisch gaat. Uit hoofdstuk 5 blijkt bijvoorbeeld dat enige kennis over de functies van onderzoek doen binnen ontwerpen er niet automatisch toe leidt dat leerlingen deze kennis ook toepassen in hun projecten. Beeldvorming zou wel eens een rol kunnen spelen bij de motivatie van leerlingen om wel of geen onderzoek toe te passen binnen hun ontwerpproject. In hoofdstuk 5 bespraken leerlingen inderdaad dat ze onderzoeksstappen liever oversloegen, en in hoofdstuk 2 is te zien dat als leerlingen eenmaal kennis hebben gemaakt met ontwerpopdrachten, ze deze veel leuker vinden dan onderzoeksopdrachten. Het is aannemelijk dat het beeld dat leerlingen hebben van het onderzoeks- of ontwerpproces, van invloed is op hun overtuigingen over hoe je een onderzoek of ontwerp idealiter zou moeten aanpakken. Om complexe onderzoeks- en ontwerpprocessen begrijpelijk te maken, worden deze vaak weergegeven in modellen zoals de onderzoekscyclus of de ontwerpcyclus (figuur 6.2). Een mogelijk probleem met deze modellen is dat ze vaak een bepaalde volgorde suggereren die je idealiter zou moeten doorlopen voor een goed onderzoek of ontwerp. Afbeeldingen van deze modellen kunnen van invloed zijn op de beeldvorming van leerlingen en docenten over hoe een onderzoeks- of ontwerpproces zou moeten verlopen, en dit kan ertoe leiden dat leerlingen en docenten denken dat er maar één 'juiste' manier is om een onderzoek of ontwerp uit te voeren. Terwijl verschillende leerlingen verschillende leervoorkeuren hebben, ook bij onderzoeks- en ontwerpactiviteiten.



Figuur 6.2 Een voorbeeld van de ontwerpcyclus uit de NLT module 'Technisch ontwerpen in de biomedische technologie'.

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Eerder onderzoek heeft aangetoond dat docenten de belangrijkste factor zijn bij het succesvol implementeren van vernieuwend STEM-onderwijs. STEM-docenten staan echter voor veel uitdagingen. Zo hebben ze bijvoorbeeld kennislacunes doordat ze niet expliciet zijn opgeleid om in alle aspecten van STEM les te geven, kunnen ze meer stress ervaren en een negatievere houding hebben ten opzichte van de onderwijsvernieuwingen. De studies in hoofdstuk 3, 4 en 5 van dit proefschrift laten echter zien dat O&O- en NLT-docenten juist positieve attitudes hebben en hun kennis over de verbinding tussen onderzoeken en ontwerpen snel kunnen ontwikkelen. De belangrijkste uitdaging voor docenten is misschien niet zozeer de ontwikkeling van hun attitude of kennis (hoewel deze zeker niet onbelangrijk zijn), maar de toepassing van een succesvolle didactiek voor onderzoeks- en ontwerpopdrachten.

Beperkingen en aanbevelingen voor vervolgonderzoek

Een sterk punt van de studies in deze dissertatie is dat zowel kwantitatieve als kwalitatieve onderzoeksmethoden gebruikt worden. De context van twee Nederlandse STEM-vakken kan beperkt lijken, maar biedt in feite twee excellente voorbeelden van STEM-vakken die zijn geïntegreerd in het reguliere curriculum. Het feit dat O&O en NLT beide gebruik maken van een opeenvolging van projecten of modules, maken de resultaten van dit onderzoek ook geschikt om kortlopende STEM-projecten te informeren. Doordat leerlingen en docenten van O&O en NLT kunnen kiezen of ze deze vakken willen volgen of geven, ontstaat er misschien al een positieve attitude ten aanzien van onderzoeken en ontwerpen. Hiervoor kon met de beschikbare data helaas niet worden gecontroleerd. Eerdere studies hebben wel aangetoond dat, ondanks het tonen van interesse voor een bepaalde cursus, leerlingen die de cursus ook daadwerkelijk volgden positievere attitudes hadden dan leerlingen met alleen de intentie om de cursus te volgen. Samen met de resultaten uit hoofdstuk 2 wijst dit erop dat het waarschijnlijk is dat het vak O&O een positieve invloed heeft op de attitudes van leerlingen. De studies in dit proefschrift zijn vooral gebaseerd op hoe leerlingen en docenten hun eigen attitudes, kennis, overtuigingen en percepties beschrijven. Dit biedt rijke inzichten in de ideeën van leerlingen en docenten over onderzoeken en ontwerpen, conform het hoofddoel van het onderzoek. Het zou voor vervolgonderzoek interessant zijn om te bestuderen of deze ideeën van leerlingen en docenten overeen komen met hun feitelijke gedrag, bijvoorbeeld door naast interviews ook observatie-instrumenten te gebruiken. Het zou ook interessant zijn om de invloed van de achtergrond van STEM-docenten op hun onderwijs te onderzoeken, omdat veel STEM-docenten geschoold zijn in verschillende vakgebieden en verschillende ervaringen hebben met onderzoek doen of ontwerpen. Daarnaast zou vervolgonderzoek de beelden van leerlingen en docenten in kaart moeten brengen, om zo meer te weten te komen over de redenen waarom beide groepen denken dat de ontwerpcyclus altijd in een bepaalde volgorde moet worden doorlopen, of de redenen waarom beide groepen onderzoek doen relevanter vinden dan ontwerpen. Als laatste zou toekomstig onderzoek zich moeten richten op de vraag hoe gedifferentieerde instructie voor onderzoeks- ontwerpprojecten eruit zou moeten zien, zodat leerlingen met verschillende leervoorkeuren van passende leervormen voorzien kunnen worden. Vervolgstudies zouden daarom het gebruik van nieuwe heuristieken, of vuistregels, voor onderzoeken en ontwerpen kunnen bestuderen, en hun effecten op het leren en de opvattingen van leerlingen.

Implicaties voor de praktijk

De studies in dit proefschrift bieden praktische implicaties voor docenten, lerarenopleidingen en professionaliseringsactiviteiten, en beleidsmakers in STEM-onderwijs. Primair is het van belang dat docenten van STEM-vakken als O&O en NLT de gelegenheid krijgen om samen met collega's van binnen of buiten de school hun kennis te ontwikkelen, en dat ze voldoende tijd en materialen tot hun beschikking hebben om projecten voor te bereiden, te implementeren en te evalueren. In hoofdstuk 4 van dit proefschrift zijn verschillende instructiestrategieën ontwikkeld door docenten die verder zouden kunnen worden uitgewerkt en toegepast tijdens onderzoeks- en ontwerpprojecten. In hoofdstuk 5 werd de 'omgekeerde ontwerpcyclus' als alternatieve methode beschreven door een van de docenten: dit zou een startpunt kunnen zijn voor meer differentiatie van de ontwerpcyclus in de klas. Verder blijkt uit het onderzoek dat het belangrijk is dat docenten weten wat de ideeën zijn die leerlingen hebben over onderzoeken en ontwerpen, zoals het idee van sommige leerlingen dat onderzoek een saaie activiteit is waaraan ze niet veel plezier beleven. Docenten zouden leerlingen daarom verschillende mogelijkheden moeten bieden om onderzoek te doen, zoals experimenten, simulaties, interviews of het testen van prototypen.

Lerarenopleidingen en ontwikkelaars van docentprofessionalisering zouden zich niet alleen moeten richten op het ontwikkelen van didactische kennis over concepten, maar ook op didactische kennis over het begeleiden van onderzoeks- en ontwerpprocessen. Voor sommige STEM-vakken, zoals O&O, hoeven docenten geen bèta-achtergrond te hebben. Vooral voor deze docenten is het belangrijk dat ze genoeg ondersteuning en nascholing aangeboden krijgen. Vaak zijn nascholing en cursussen gericht op docenten van een enkel bètavak, en niet op docenten van interdisciplinaire vakken. Er zou ook professionalisering speciaal voor STEM-docenten beschikbaar moeten zijn, zeker omdat de studie in hoofdstuk 4 aantoont dat STEM-docenten al in relatief korte tijd veel met en van elkaar kunnen leren. Het is ook belangrijk dat docenten tijdens de lerarenopleiding en nascholing zelf enige ervaring opdoen met het uitvoeren van onderzoeks- en ontwerpopdrachten. Dit zou bijvoorbeeld bereikt kunnen worden door docenten stages te laten lopen bij instellingen en bedrijven in verschillende STEM-disciplines. Docenten moeten vertrouwd raken met meerdere modellen voor onderzoeks- en ontwerpprocessen, om zo genuanceerdere heuristieken te ontwikkelen om te voorkomen dat zijzelf en hun leerlingen teveel vasthouden aan één 'ideaal' model.

Onderzoeks- en ontwerpactiviteiten worden nog te vaak gescheiden behandeld in STEM-curricula. STEM-onderwijs zou daarom baat hebben bij meer integratie tussen onderzoeks- en ontwerpactiviteiten, omdat dit de professionele praktijk van STEM-disciplines beter weerspiegelt. Om deze nieuwe vaardigheden zoals het combineren van onderzoeks- en ontwerpactiviteiten te beoordelen, zouden curriculumontwikkelaars beoordelingsinstrumenten moeten ontwikkelen. Tevens zouden educatieve materialen meerdere modellen van de onderzoeks- en ontwerpcyclus moeten bevatten om te illustreren dat er verschillende manieren zijn om een onderzoek of ontwerp uit te voeren. Het is belangrijk dat niet alleen leerlingen die een STEM-vak kiezen ervaring opdoen met authentieke onderzoeks- en ontwerpopdrachten, maar ook leerlingen die deze vakken niet volgen of aangeboden krijgen. Ook op de basisschool en binnen de reguliere vakken van het voortgezet onderwijs moet er aandacht besteed worden aan onderzoeks- en ontwerpopdrachten in STEM, zodat leerlingen een beter beeld krijgen van wat onderzoeken en ontwerpen is, en een beter beeld krijgen van de arbeidsmarkt in STEM-disciplines.

Curriculum Vitae

Tessa Vossen was born on 08 May 1991, in Haarlem. After graduating from secondary education at the Ichthus Lyceum in Driehuis in 2009, she completed her Bachelor Biology at Leiden University in 2012. She obtained her Master of Science in Biology and Science Communication in 2014 at Leiden University. During her master, Tessa did a research internship at Naturalis Biodiversity Center including ethnobotanical fieldwork in Suriname, studying local plant use for cultural-bound children's ailments. Furthermore, she studied the readability of patient informed consent forms for children at the department of Science Communication. After graduating from Leiden University, Tessa worked for De Praktijk, an office developing science education materials. In November 2014 she started her PhD research at Leiden University and TU Delft. This research project focused on how students and teachers in a secondary STEM (Science, Technology, Engineering and Mathematics) education context think about research, design and the connection between research and design. Tessa is currently employed as a project scientist at the department of Astronomy and Science Communication at Leiden University, where she develops and studies inclusive STEM education materials with a focus on girls and children from a minority background in primary school.

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