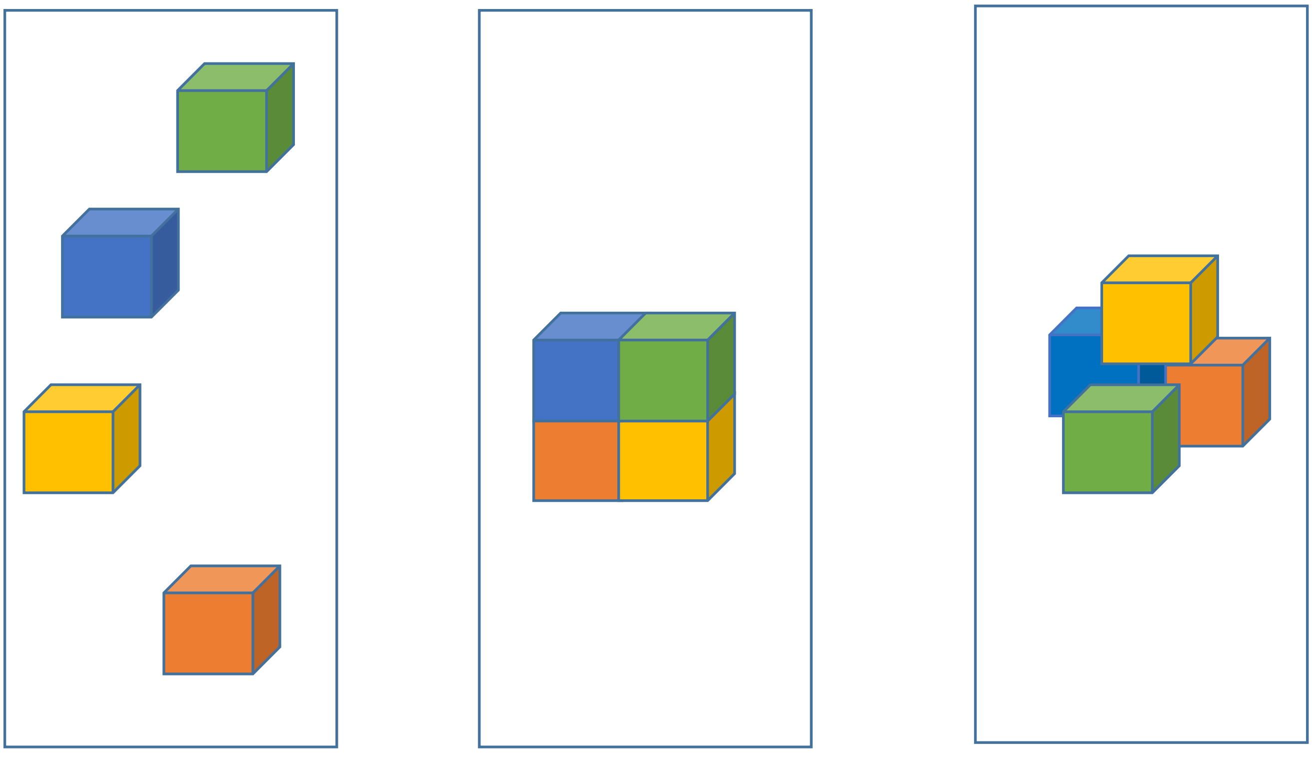
Teaching and learning of interdisciplinary thinking in higher education in engineering



Elsbeth Spelt

Teaching and learning of interdisciplinary thinking in higher education in engineering

Elisabeth Jacoba Hendrika Spelt

Thesis committee

Promotors

Prof. Dr M. Mulder

Professor of Education and Competence Studies

Wageningen University

Prof. Dr M.A.J.S. van Boekel

Professor of Product Design and Quality Management

Wageningen University

Co-promotor

Dr P.A. Luning

Associate professor, Food Quality and Design Group

Wageningen University

Other members

Prof. Dr J.W.F. van Tartwijk, Utrecht University

Prof. Dr C.A.M. van Boxtel, University of Amsterdam

Prof. Dr A. Pilot, Utrecht University

Prof. Dr H.B.J. Leemans, Wageningen University

This research was conducted under the auspices of the Graduate School WASS (Wageningen School of Social Sciences) and the Graduate School ICO (Interuniversity Center for Educational Sciences).

Teaching and learning of interdisciplinary thinking in higher education in engineering

Elisabeth Jacoba Hendrika Spelt

Thesis

submitted in fulfilment of the requirements for the degree of doctor
at Wageningen University
by the authority of the Rector Magnificus
Prof. Dr A.P.J. Mol
in the presence by the Academic Board
to be defended in public
on Monday 26 October 2015
at 11 a.m. in the Aula.

Elisabeth Jacoba Hendrika Spelt

Teaching and learning of interdisciplinary thinking in higher education in engineering

200 pages.

PhD thesis, Wageningen University, Wageningen, NL (2015)

With references, with summary in English

ISBN: 978 – 94 – 6257 – 477 – 9

CONTENTS

Chapter 1

General introduction

1.1 Importance of teaching and learning of interdisciplinary thinking

Teaching and learning of interdisciplinary thinking (IDT) is important for higher education (Newell, 2010b; Repko, Szostak, & Philips Buchberger, 2014) and, in particular, for higher education in engineering (HEE), because engineers need to be able to integrate knowledge of different disciplines (Redish & Smith, 2008; Schaefer, Panchal, Thames, Haroon, & Mistree, 2012; Vale et al., 2012). In their jobs, engineers have to work in various interdisciplinary teams and therefore, it is a necessity for them to be able to understand disciplinary knowledge and to be able to integrate disciplinary knowledge in collaboration with other engineers (Adams, 2007; Schmidt et al., 2012). The ultimate goal of IDT is disciplinary knowledge integration, but other cognitive activities with respect to disciplinary boundary-crossing, such as critically appraising the disciplinary knowledge and switching between disciplinary perspectives, are also important (Nikitina, 2005). Similar to disciplinary thinking, the teaching of IDT should start as early as possible in curricula, so that students get used to thinking outside the disciplines (MacKinnon, Hine, & Barnard, 2013; Tong, 2010). By early introducing, HEE is preparing engineering students to be able to work on complex societal problems, like water supply (Chanan, Vigneswaran, & Kandasamy, 2012), sustainability (O'Byrne, Dripps, & Nicholas, 2015), and conservation of marine resources (Fortuin, Van Koppen, & Leemans, 2011). These complex problems necessitate the use of an interdisciplinary approach to achieve a comprehensive understanding of these problems, eventually, leading to the inventory of causes and solutions (Klein, 1996; Newell, 2010a; Wolman, 1977). Viewing a complex problem or phenomena from an interdisciplinary viewpoint, thereby connecting different disciplines to achieve an enriched understanding of the problems or phenomena, is the rationale of IDT.

1.2 Defining interdisciplinary thinking

IDT as intended learning outcome in higher education is investigated to a limited extent. IDT or interdisciplinary understanding is defined in literature as:

> *"The capacity to integrate knowledge and modes of thinking in two or more disciplines or established areas of expertise to produce a cognitive advancement – such as explaining a phenomenon, solving a problem, or creating a product – in ways that would have been impossible or unlikely through single disciplinary means" (Boix Mansilla, Miller, & Gardner, 2000, p. 17)*

Two types of IDT exist; one type is narrow IDT referring to the integration of disciplinary knowledge within a single science. The other type is broad IDT referring to the integration of disciplinary knowledge across sciences (Newell, 2007).

The concept of IDT can be found in literature by various synonyms, the commonly used one is 'integration of disciplinary knowledge' (e.g., Fortuin, Van Koppen, & Kroeze, 2013) or 'synthesis' (e.g., Defila & DiGiulio, 2015) which is the integration of knowledge to bring about an advance in understanding. Other synonyms are 'the integrated approach' or 'the integrative approach' (e.g., Linnemann, Schroën, & Van Boekel, 2011). These two terms refer to the approach of taking multiple disciplines in which individuals integrate the disciplinary knowledge in a meaningful way. The distinction between multidisciplinary thinking and IDT is the integration of disciplinary knowledge. With multidisciplinary thinking, the disciplinary knowledge is summarized without any attempt to integrate the knowledge (Klein, 2005). In literature and in practice, the terms 'multidisciplinarity' and 'interdisciplinarity' are not so strictly used as in this thesis research. Similarly, the terms 'knowledge integration', 'integrated curricula', and 'course integration' also have various meanings in literature depending on the disciplinary origin of the particular study reported.

In the education literature, the term ‘knowledge integration’ refers to the integration of new knowledge to existing knowledge structures in the minds of individuals. This integration does not necessarily refer to the integration of disciplinary knowledge (e.g., Linn, Lee, Tinker, Husic, & Chiu, 2006). Additionally, in the education literature the terms ‘integrated curricula’ and ‘course integration’ (e.g., Van Boxtel, 2009) refer to the coherence of courses in a curriculum design or to the coherence between courses. Confusingly, this coherence is also called ‘interdisciplinary’ or ‘alignment’ in education. In literature as well as in practice, it is always a matter of clarifying what is meant with the term ‘integration’, whether it refers to the integration of knowledge, the integration of disciplinary knowledge, the alignment of disciplinary courses, and the application of multiple disciplines.

The present thesis research demarcated the terms ‘interdisciplinary’ and ‘integrated/integrative approach’ to individuals being capable of integrating the disciplinary knowledge. The terms ‘interdisciplinary thinking’, ‘disciplinary knowledge integration’, and ‘integration of disciplinary knowledge’ used in the report of this research referred to this demarcation. Accordingly, this research is based upon scientific publications with a focus on the teaching and learning of the disciplinary knowledge integration, regardless whether or not the term IDT is explicitly mentioned in these publications. The aforementioned definition of IDT was taken as the intended learning outcome of interdisciplinary higher education. Furthermore, the thesis research demarcated the terms ‘constructive alignment’ or ‘alignment’ to the alignment of education that aims to achieving the intended learning outcome of IDT.

1.3 Research on teaching and learning of interdisciplinary thinking

Research on teaching and learning of IDT in higher education is proliferating, because of the increased awareness that students need to be taught in this complex cognitive skill. The previous research shows a relatively broad range of publications on newly designed education on IDT (e.g., Bajada & Trayler, 2013; Hooker, Deutschman, & Avery, 2014; McFadden, Chen, Munroe, Naftzger, & Selinger, 2011), a range of publications on the teaching and the evaluation of the newly designed education on IDT (e.g., Lyall & Meagher, 2012; Mobley, Lee, Morse, Allen, & Murphy, 2014; Wagner, Murphy, Holderegger, & Waits, 2012) and, to a smaller extent, publications on researching student learning of IDT (e.g., Boix Mansilla, 2010; Haynes & Brown Leonard, 2010; Holley, 2013). Specifically for HEE, a relatively large number of publications can be found reflecting the *teaching-focus* on education, i.e., the evaluative investigation on developed instructional designs, whereas publications reflecting the *learning-focus* on education i.e., the examination of student learning processes, have not been found yet.

The previous research on *teaching* IDT in higher education shows consensus on the need for pedagogical support of learning IDT (Augsburg et al., 2013; Nardone & Lee, 2011). A potential pedagogical tool for the required pedagogical support is the constructive alignment theory of Biggs (Stefani, 2009; Yang, 2009). This theory, firstly published in 1999 (Biggs, 1999a, 1999b), was continuously developed resulting in new editions in 2003 (Biggs, 2003), in 2007 (Biggs & Tang, 2007), and in 2011 (Biggs & Tang, 2011). The two main design principles of this theory are: (a) outcome-based, and (b) constructively aligned (see chapter 1.4 for more explanation on these principles). It is therefore that this theory is also being named in literature as outcome-based and constructive alignment theory. Although this theory has been multiply recommended as having the potential to help students in achieving the learning outcomes on IDT, scientific research on the implementation of this theory has not been done yet (Borrego & Newswander, 2010; Gharaibeh et al., 2013), nor on the design criteria to enhance the learning of IDT (Lattuca, Voigt, & Fath, 2004). The implementation should help teachers to develop pedagogical content knowledge for teaching and learning IDT (MacPhail, Tannehill, & GocKarp, 2013).

Pedagogical content knowledge as described by Shulman (1987, p. 8) involves *"the blending of content and pedagogy into an understanding of how particular topics, problems, or issues are organized, represented, and adapted to the diverse interests and abilities of learners, and presented for instruction"*. In 2012, the publication of Biggs of 1999 was published again in the scientific journal of 'Higher education research and development' to, probably, accelerate this movement towards developing pedagogical content knowledge via the use of the constructive alignment theory of Biggs and Tang. The argument for using this theory to develop pedagogical content knowledge is the prescribed way of designing education, thereby prescribing teachers coming from different disciplines to formulate the learning outcomes beyond the disciplines and thereby connecting the disciplinary subjects (Brand & Triplett, 2012). Another argument is the resulting consistency of interdisciplinary learning environments via the constructive alignment, which may lead to the enhancement of student deep approaches to learning (Ten Dam, Van Hout, Terlouw, & Willems, 2004; Wang, Su, Cheung, Wong, & Kwong, 2013).

The few available scientific publications (e.g., Holley, 2013) on the *learning* of IDT in higher education focus more on the long-term (curriculum-related) rather than on the short-term (course-related) learning processes. In addition, the few publications show an explorative approach to investigate student learning, thereby taking a, predominantly, cognitive theoretical perspective. Systematic research on short-term student learning processes in HEE thereby taking, for instance, an integrated viewpoint to learning has not been conducted yet. Additionally, the suggested analytical characterization of these learning processes (Haynes & Brown Leonard, 2010) has also not been conducted yet. A comprehensive understanding of the learning processes would contribute to the development of the pedagogical content knowledge for IDT in HEE.

1.4 Present thesis research

The present thesis research aim is to gain insight in the pedagogical content knowledge for IDT as suggested by Boix Mansilla (2010), in order to develop a conceptual framework representing the teaching and learning aspects of IDT that need to be taken into account. To achieve this aim, the understanding of design criteria of IDT learning environments (*teaching*-focus) and the understanding of IDT learning process characteristics (*learning*-focus) are considered as necessary. The gain in understanding of the design criteria starts, in the present research, via the use of the constructive alignment theory of Biggs and Tang. In particular, the general 3P model of teaching and learning was used as starting point to review the literature (see chapter 2). Figure 1.1 presents the 3P model of teaching and learning for higher education (Biggs, 1999a, 2003).

The 3P model describes the three points in time at which learning-related factors are placed: (a) presage, before learning takes place, (b) process, during learning, and (c) product, the outcome of learning. In addition, the 3P model represents the elements of an education practice, which can be a curriculum, course, or classroom setting, that influence the learning outcomes of students. In particular, the arrows of the 3P model show the mutual interdependencies between these elements. The major flow of influence (see bold arrows in Figure 1.1) is the joint influence of the student factors and teaching context that lead to particular learning-focused activities, and that in turn lead to particular learning outcomes.

The premise of this theory is: "*good teaching is getting most students to use the level of cognitive processes needed to achieve the intended learning outcomes that the more academic* *students use spontaneously"* (Biggs & Tang, 2011, p. 7). The theory features a student-centred approach to teaching and learning to achieve good teaching and comprises three levels: 1) what the student is (i.e., recognizing differences between students in learning), 2) what the teacher does (i.e., knowing when and how deployment of teaching have the desired effect on student learning, and 3) what the student does (i.e., teaching is to support the learning of students). This student-centred approach to teaching and learning in higher education differs from a content-centred approach to teaching and learning in which the content of the particular subject(s) is centralized. The constructivism basis of this theory matches well with the rationale of IDT (see chapter 1.1) with respect to the conduct of knowledge construction by individuals.

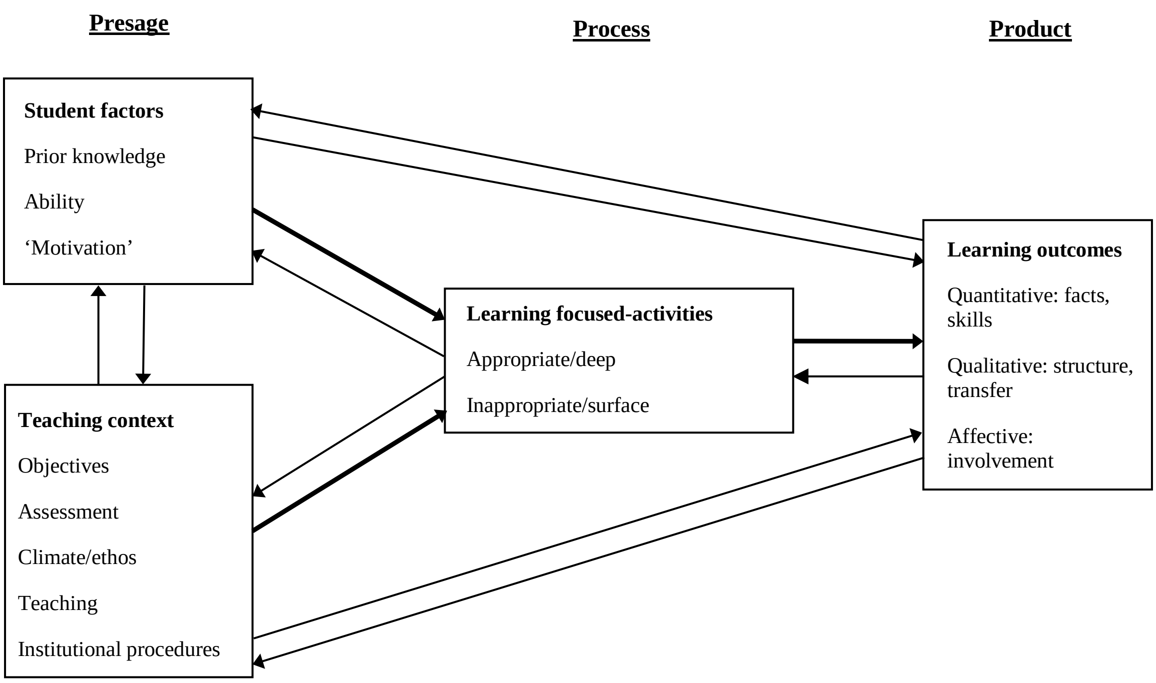


Figure 1.1 3P model of teaching and learning (Biggs, 1999a, p. 18; 2003, p. 19)

Figure 1.2 presents the outcome-based design model for higher education that was used as starting point in chapter 3 of this thesis to advance the scientific insights on design criteria.

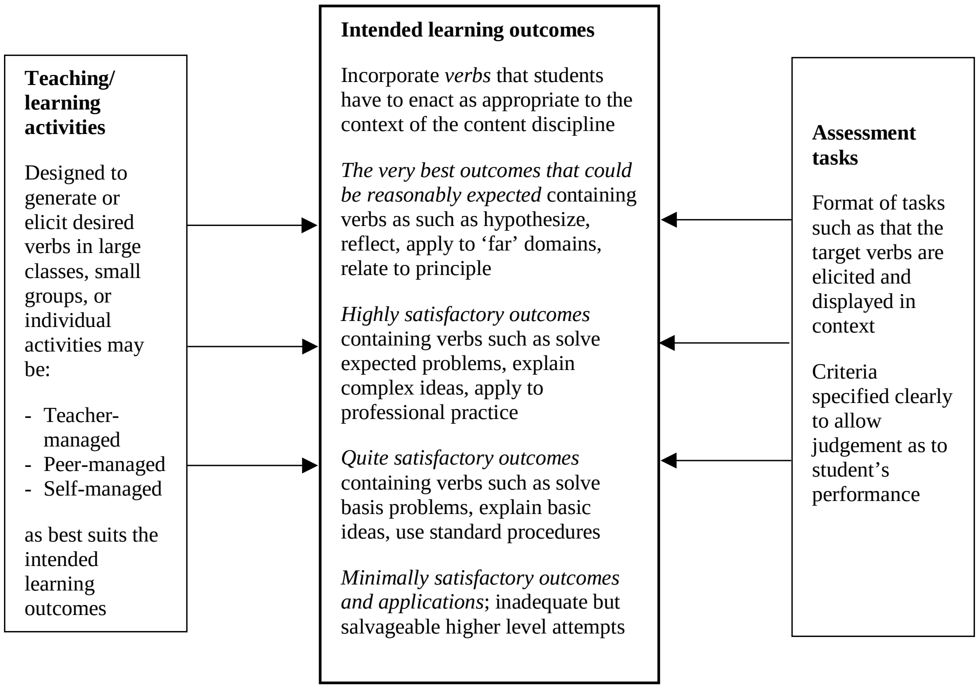


Figure 1.2 Outcome-based design model (Biggs & Tang, 2007, p. 59; 2011, p. 105)

The outcome-based design model comprises three parts (Biggs & Tang, 2007, 2011): (a) the intended learning outcomes, (b) teaching and learning activities, and (c) the assessment tasks. The outcome-based design model prescribes the formulation of intended learning outcomes followed by the formulation of teaching and learning activities, and assessment tasks. The formulation of teaching and learning activities, and assessment tasks should be aligned with the formulated intended learning outcomes, as schematically represented by the arrows in Figure 1.2. Starting the design of education with defining the intended learning outcomes is known as the outcome-based design principle and the alignment of the teaching, learning, and assessment with the intended learning outcomes is known as the constructive alignment design principle (Biggs, 2012; Biggs & Tang, 2011). As depicted in Figure 1.2 the intended learning outcomes vary from *minimally satisfactory outcomes and applications* to *the very best outcomes* demanding for cognitive activities such as reflecting, applying, relating, and integration. The intended learning outcome of IDT studied in this research was considered as one of the category ‘very best outcomes’.

The gain in understanding of learning processes characteristics starts, in the present research, via the use of the general learning theory of Illeris. In particular, the learning triangle, representing the interrelated tensions between the three dimensions of learning, was used in chapters 4 and 5 (Illeris, 2002, 2007) as a basis. Figure 1.3 shows the learning triangle with these three dimensions of learning: content, incentive, and interaction.

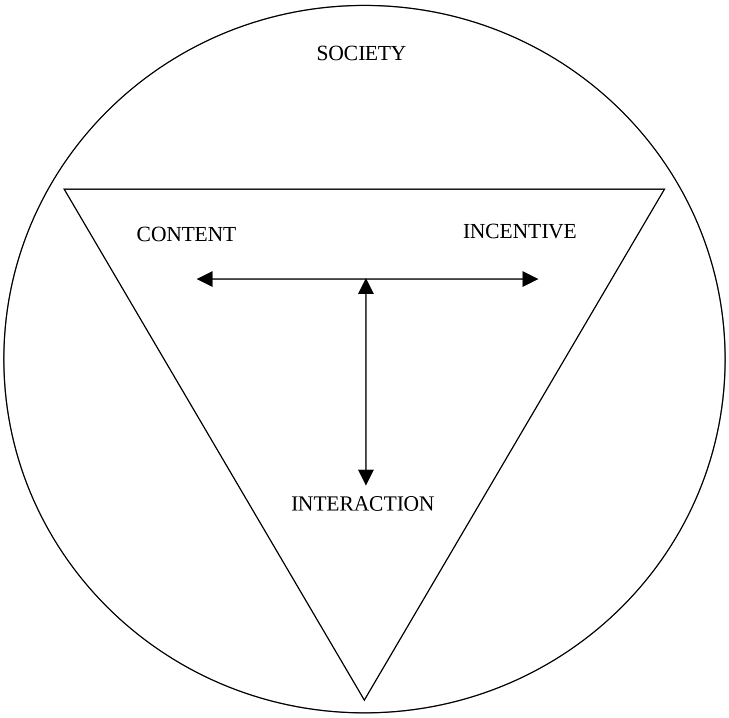


Figure 1.3 The three dimensions of learning (Illeris, 2007, p. 26)

The learning dimensions *content* and *incentive* refer to the individual learner’s acquisition process, represented by the horizontal arrow in Figure 1.3, and the learning dimension *interaction* refers to the acquisition process of the learner and its environment, represented by the vertical arrow in Figure 1.3. The basic conception of learning of this theory is reflected in the multiple tensions between cognition (content dimension), emotions and psychodynamics (incentive), and social and societal aspects (interaction dimension) during the learning processes (Illeris, 2002). The concept of learning is defined as '*any process that in living organisms leads to permanent capacity change and which is not solely due to biological maturation or ageing*' (Illeris, 2007, p. 3). This means that in case of learning, the permanent capacity change can be content-related, incentive-related, or interaction-related, or an integrated content-incentive-interaction change. This theory, similar to the constructive alignment theory of Biggs and Tang, also features the constructivism basis; the concept of learning is considered as the construct of knowledge of individual learners by adapting their mental structures, schemes, and patterns (Illeris, 2003).

Both theories, the theory of Biggs and Tang, and the learning theory of Illeris, were used to advance the understanding on teaching and learning of IDT in HEE in order to answer the main research question:

"Which teaching and learning aspects need to be taken into account in order to teach engineering students IDT with respect to complex problem solving?"

Four studies were conducted to investigate the teaching and learning aspects. The first two studies mainly focused on the *teaching* aspects, using the constructive alignment theory of Biggs and Tang. Additionally, the other two studies mainly focused on the *learning* aspects, using the learning theory of Illeris. Each study addressed one sub research question in order to answer the main research question:

a. What are the main subskills of IDT and the main enabling conditions to teach IDT in interdisciplinary higher education? (***study I***)
b. What are the key design criteria that need to be taken into account to teach engineering students IDT in HEE? (***study II***)
c. What are the key learning experiences that need to be taken into account to teach engineering students IDT in HEE? (***study III***)

d. What are the typical learning challenges that need to be taken into account to teach engineering students IDT in HEE? (***study IV***)

The first study reviewed the literature on teaching and learning of IDT in higher education in general and not specific for HEE. The other three studies were conducted in HEE, in particular, in the interdisciplinary field of food quality management (FQM). The sub research questions feature an 'open formulation' due to the phase of the research field which is, yet, attempting to deepen the understanding of the teaching and learning of IDT in higher education. The two hypotheses, which were tested in the present thesis research, are:

1. The constructive alignment theory of Biggs and Tang is suitable to identify design criteria for interdisciplinary learning environments (*teaching*-focus)
2. The learning theory of Illeris is suitable to characterize the learning of IDT in HEE (*learning*-focus)

1.5 Research approach

The research approach features an interdisciplinary and transdisciplinary approach. The interdisciplinary research approach includes the integration of the teaching and learning. This approach towards teaching and learning is adopted to achieve the present thesis research aim of developing pedagogical content knowledge. The transdisciplinary research approach includes the integration of theory and practice via concurrent consultation of the scientific literature and education practice. This approach is adopted to improve education practice by disseminating research insights to practice, to conduct research that is relevant to education practice, and to increase the external validity of present research, as being identified by Anderman (2011) as challenges for educational psychology research. Figure 1.4 presents the four steps of the thesis research.

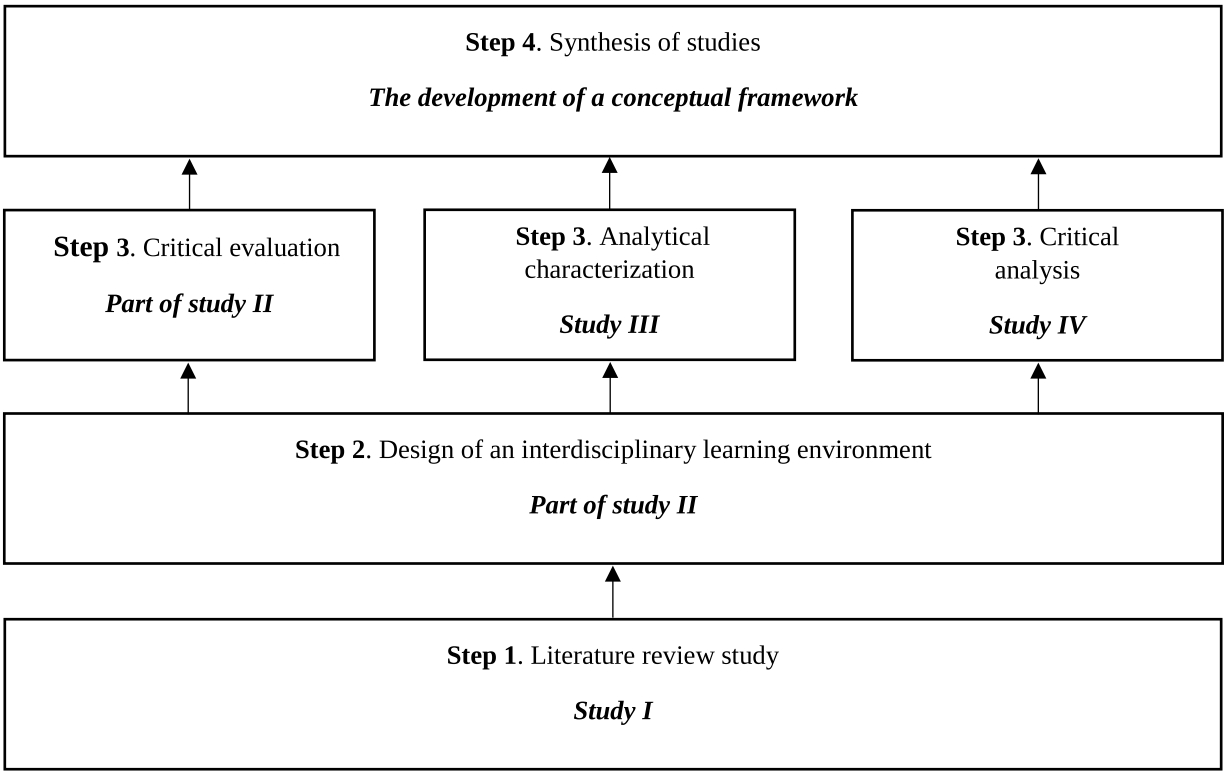


Figure 1.4 Overview of the four research steps

The **first step** is the conduct of a systematic literature review with respect to the teaching and learning of IDT (*study I*). This review provides the theoretical basis for the second step considering the development and implementation of an instructional design for an interdisciplinary learning environment (*part of study II*). The **second step** provides the empirical basis for analysing a self-designed interdisciplinary teaching and learning practice. The **third step** includes the analysis of this practice from three different angles: in order (a) to critically evaluate the instructional design of the learning environment via student evaluations (*part of study II*), (b) to analytically characterize student learning processes with respect to learning experiences (*study III*), and (c) to critically analyse the learning challenges, student strategies, and outcomes of education (*study IV*). The **fourth step** includes the synthesis of the conducted studies in order to develop a conceptual framework on the teaching and learning aspects of IDT and to answer the main research question.

The research context of steps 2 and 3 was the interdisciplinary field of FQM, which involves the knowledge integration between technology-related and management-related disciplines (see chapters 3, 4, and 5 for more information about FQM). The research context of the master curriculum on FQM was chosen for a couple of reasons varying from theoretical to practical: (a) the master curriculum is based upon theoretical concepts with respect to IDT (Luning & Marcelis, 2006) and interdisciplinary research (Luning & Marcelis, 2007, 2009b), (b) this curriculum aimed at the development of broad IDT which is necessary for HEE (e.g., Schaefer et al., 2012), (c) this curriculum features problem-centred teaching, which is one of the identified commonly used pedagogical strategies in interdisciplinary education (Nikitina, 2006), and (d) this curriculum has several interdisciplinary courses which are provided by teachers who have experience in interdisciplinary higher education for a number of years. It was expected that the field of FQM is representative to explore the teaching and learning of IDT of engineering students with respect to complex problem solving.

1.6 Thesis outline

Chapter 2 reports on the literature review on teaching and learning of IDT in higher education. **Chapter 3** reports on the critical evaluation of the implementation of the instructional design on IDT in HEE. **Chapter 4** reports on the analytical characterization of student learning processes on IDT in HEE. **Chapter 5** reports on the critical analysis of learning challenges, student strategies, and outcomes of education in IDT. **Chapter 6** synthesizes and reflects upon the research described in this thesis and presents the developed conceptual framework on teaching and learning of IDT.

Chapter 2

Teaching and learning in interdisciplinary higher education: A systematic review

Abstract

Interdisciplinary higher education aims to develop boundary-crossing skills, such as interdisciplinary thinking (IDT). In the present review study, IDT was defined as the capacity to integrate knowledge of two or more disciplines to produce a cognitive advancement in ways that would have been impossible or unlikely through single disciplinary means. It was considered as a complex cognitive skill that constituted of a number of subskills. The review was accomplished by means of a systematic search within four scientific literature databases followed by a critical analysis. The review showed that, to date, scientific research into teaching and learning in interdisciplinary higher education has remained limited and explorative. The research advanced the understanding of the necessary subskills of IDT and typical conditions for enabling the development of IDT. This understanding provides a platform from which the theory and practice of interdisciplinary higher education can move forward.

This chapter has been published as:

Spelt, E. J. H., Biemans, H. J. A., Tobi, H., Luning, P. A., & Mulder, M. (2009). Teaching and learning in interdisciplinary higher education: A systematic review. *Educational Psychology Review*, *21*(4), 365-378.

2.1 Introduction

Various groups of professionals are increasingly confronted with complex issues like food quality (Luning & Marcelis, 2006) or biodiversity conservation (Warren, 2006). In order to deal with these issues, professionals need to be able to critically analyse, conceptualize, and synthesize knowledge and to reach conclusions on the basis of ambiguous information (Tynjälä, Slotte, Nieminen, Lonka, & Olkinuora, 2006). In response, higher education is increasingly called on to train students to become capable of dealing with such complex issues in both scientific and professional environments (Jacobson & Wilensky, 2006; Roehler, Fear, & Herrmann, 1998).

Interdisciplinarity can help to address today's complex issues since it is believed that a cross-disciplinary approach facilitates a comprehensive understanding (Newell, 2007). This belief has led to an increased interest in interdisciplinary higher education over the years (Newell, 2010b). In comparison with traditional higher education, which focuses on domain-specific knowledge and general skills development, this kind of higher education also aims to develop boundary-crossing skills. Boundary-crossing skills are, for instance, the ability to change perspectives, to synthesize knowledge of different disciplines, and to cope with complexity.

Unlike multidisciplinarity, which is additive, interdisciplinarity is integrative: Knowledge of different disciplines is contrasted and changed by integration (Klein, 1990). This integration or synthesis of knowledge is seen as the defining characteristic of interdisciplinarity. As a consequence, the ability to synthesize or integrate is considered as a beneficial learning outcome of interdisciplinary higher education. In that case, the learning outcome is called interdisciplinary understanding or interdisciplinary thinking (IDT). Boix Mansilla, Miller, and Gardner (2000) formulated a definition of interdisciplinary understanding or IDT (see chapter 1.2). According to this definition, IDT can be considered as a complex cognitive skill that consists of a number of subskills (Van Merriënboer, 1997), such as the ability to change disciplinary perspectives and create meaningful connections across disciplines. IDT does not occur spontaneously, it can take a considerable amount of time for students to achieve an adequate level of expertise in its practice. In addition, students need help in order to be able to synthesize two or more disciplines. All too often a curriculum is called *interdisciplinary* when it is actually *multidisciplinary*: multiple perspectives are presented, without any support for the integration of disciplinary knowledge throughout the curriculum. As a consequence, in curricula on food studies, for instance, students lack the ability to integrate the required disciplinary knowledge of food processing and food microbiology to keep bacterial growth within food safety criteria. Specific support and learning tasks intended to develop IDT appear to be important.

Students have problems of working across disciplines, working in different disciplines, and synthesizing different disciplines. This poses difficulties for the development of IDT in interdisciplinary higher education. These student problems may be caused by disciplinary differences in epistemologies, discourses, and ways of teaching (Bradbeer, 1999). In addition, curricula that aim to develop IDT on a broad scale are likely to experience more difficulties than curricula that aim to develop IDT on a narrow scale. This is by virtue of the fact that, in contrast to narrow IDT, broad IDT requires the integration of disciplines across sciences (Newell, 2007). To illustrate, the aforementioned example of integration in food safety concerns IDT on a narrow scale. In the case of broad IDT, students are taught to integrate knowledge of sciences like food processing and microbiology as well as social sciences, such as management and psychology, to realize safe food production without contamination by employees (Luning & Marcelis, 2009b). This means that students also need to overcome differences between sciences. Explicit attention to these disciplinary and scientific differences appears to be a typical condition for enabling the development of IDT.

Considering the complexity of teaching and learning IDT, interdisciplinary higher education faces challenges in accomplishing both broad and narrow IDT among its students. Realizing desired learning outcomes demands consistent and well-designed learning environments within a coherent and learner-centred curriculum (Ten Dam et al., 2004). For this reason, curriculum and course developers need a comprehensive understanding of the typical conditions that underpin the development of IDT (Stefani, 2009). This necessitates, for example, gaining insight into the extent to which students need to be equipped with knowledge of different disciplines as well as didactic ways of enabling integration (Chen, Hsu, & Wu, 2009). However, in view of the lack of an applicable teaching and learning model, it is necessary to examine the literature to seek a basis for this kind of higher education. This line of reasoning motivated the present review of the scientific research on teaching and learning IDT in interdisciplinary higher education.

2.2 Review framework

The objectives of the review were to systematically identify, critically analyse, and discuss scientific research on teaching and learning IDT in interdisciplinary higher education. For this purpose, the theory of Biggs (2003) was used as a frame of reference; it provided an organized way of reviewing the literature that corresponded well with our line of reasoning. This theory describes a comprehensive model for teaching and learning in higher education. In particular, teaching and learning are conceived as an interacting system of four components: *student*, *learning environment*, *learning process*, and *learning outcomes* (Biggs, 1993). Such a model might enable curriculum and course developers in interdisciplinary higher education to gain a comprehensive understanding of teaching and learning IDT. In addition, the model follows the alignment principle, which means that teaching and learning activities are aligned with desired learning outcomes. This principle leads to an outcome-based approach to teaching and learning that facilitates coherent and pedagogically underpinned curriculum design.

According to Biggs (2003), the components student, learning environment, and learning process represent several characteristics influencing the learning outcomes (see chapter 1.4). In the present study, the student and learning environment components were similar to Biggs (2003). Student characteristics are brought into the learning environment by the student, for instance prior knowledge and skills. In addition, learning environment addressed situational characteristics like teaching and assessment methods, which are decided by the institution, curriculum, and course developers. The component learning process in this study addressed learning process characteristics and learning activities, such as the sequencing of specific learning activities. The component learning outcomes of Biggs' theory (2003) was defined as IDT and represented subskills that constitute the complex cognitive skill IDT (Van Merriënboer, 1997).

Figure 2.1 shows the four components used in this review study in accordance with the general teaching and learning model of Biggs (2003). As shown by the Conceptual Review Framework (see Figure 2.1), the learning outcome IDT is determined by the other components student, learning environment, and learning process interacting with each other. The general direction of interaction, represented by the bold arrows, follows that of Biggs (2003): the components student and learning environment (presage level) are precursors to the learning process, and jointly produce the activities students undertake for a given learning task (learning process level), and the learning process in turn produces the learning outcome IDT (product level). All components are connected by light arrows (see Figure 2.1) in order to demonstrate the conceptualization of teaching and learning as an interactive system (Biggs, 1993).

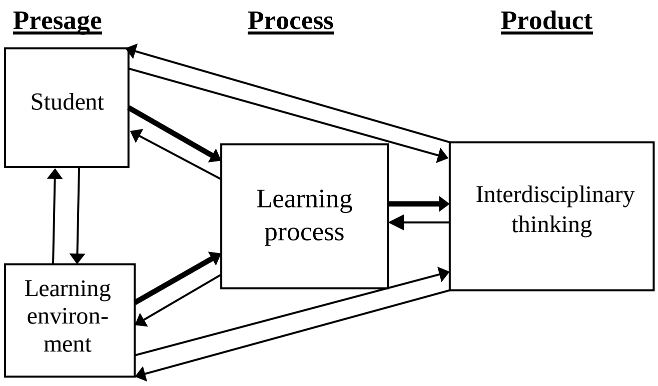


Figure 2.1 Conceptual Review Framework, adapted from Biggs (2003)

The main purpose of this review was to identify the subskills constituting the component IDT and typical conditions for developing IDT as present within the components student, learning environment, and learning process. Using the outcome-based perspective of Biggs' theory (2003), five research questions were formulated:

1. Which subskills that constitute IDT within the context of interdisciplinary higher education are mentioned?
2. Which student conditions that influence IDT within the context of interdisciplinary higher education are mentioned?
3. Which learning environment conditions that influence IDT within the context of interdisciplinary higher education are mentioned?
4. Which learning process conditions that influence IDT within the context of interdisciplinary higher education are mentioned?

5. Which relationships between student, learning environment, and learning process conditions and IDT within the context of interdisciplinary higher education are mentioned?

The present review study explored these research questions by (a) describing, and (b) evaluating scientific research into teaching and learning in interdisciplinary higher education.

2.3 Method

The review process consisted of the four stages described below.

2.3.1 Formulation of inclusion and exclusion criteria

Before searching the literature, the following inclusion criteria were formulated. First, each publication should be relevant, meaning that the publication should examine teaching and learning in interdisciplinary higher education within the scope of the Conceptual Review Framework (see Figure 2.1). Second, each publication should be peer reviewed. Third, publications written in English, German, and Dutch were included, as the authors could read and understand these languages. Finally, the time span of the literature search was limited to 1992-2009 to provide an overview of the most recent research in this field. Publications reporting on individual faculty experiences, courses, curricula, or projects without any scientific examination of teaching and learning were excluded. Publications on institutional or organizational topics such as the implementation of interdisciplinary higher education fell outside the scope of this review.

2.3.2 Development of a search strategy

In order to develop a search strategy appropriate to the main purpose of this review, various search terms were listed, such as *multidisciplinary learning* and *integrated approach*. After careful consideration of the consequences of removing potential search terms, the following search terms were identified as being the most informative: *interdisciplinary thinking*, *interdisciplinary understanding*, *interdisciplinary teaching*, *interdisciplinary course*, *interdisciplinary courses*, *interdisciplinary curriculum*, *interdisciplinary curriculums*, *interdisciplinary curricula*, *interdisciplinary program*, *interdisciplinary programs*, *interdisciplinary programmes*, *interdisciplinary education*, and *interdisciplinary learning*, each in combination with *undergraduate*, *graduate*, *higher education*, and *university*. Quotation marks were used to search for phrases. The chosen search strategy focused on title, abstract, and keywords in order to obtain publications with a clear focus on teaching and learning within the context of interdisciplinary higher education. The chosen search terms followed the four components of the Conceptual Review Framework (see Figure 2.1). For the component student, no search terms were identified since the term *interdisciplinary student* was not used and *student* only resulted in too many irrelevant publications. In view of this, it was hoped that the search terms identified for the components IDT, learning environment, and learning process would reveal publications concerning the component student.

2.3.3 Identification of relevant publications

Four databases were searched: the Educational Resources Information Centre (ERIC) catalogue, the Science Citation Index Expanded (SCI-EXPANDED), the Social Sciences Citation Index (SSCI), and the Arts & Humanities Citation Index (A&HCI); the latter three provided by the Web of Science®. The abstracts of the publications resulting from the aforementioned search strategy were screened for relevancy. If the abstract did not provide sufficient information, then the full text was scanned to determine whether or not the publication met the inclusion criteria. The identification process was carried out twice by the first author for two reasons: (a) to be sure that all relevant publications were included, and (b) to categorize the non-relevant publications. Where the identified relevant publications reported on the results of the same study, the publication with the most extensive coverage of the reported study was included in the analysis.

2.3.4 Critical analysis and exploration

Following careful reading, the critical analysis was carried out using a self-devised literature review form based on the review framework adopted in this study. This provided the scope for the description and evaluation of the found publications. The literature review form also served to standardize the critical analysis. The form consisted of two parts: (a) questions intended to afford insight into the research design characteristics of the publications, thereby enabling the description of scientific research into teaching and learning in interdisciplinary higher education, and (b) questions formulated to embody the principles of Biggs' theory, thereby enabling the evaluation of the scientific research into teaching and learning in interdisciplinary higher education. The formulated questions were applicable to the analysis of theoretical publications as well as empirical research. The form contained descriptive questions with, in most cases, a short-answer possibility. A detailed answer should always be provided to clarify the given short answers. In order to explore our research questions, only typical conditions for enabling the development of IDT were included. Conversely, general conditions such as student motivation or congruence between learning goals and assessment were not included. Once all the publications had been reviewed and the review forms had been completed, the identified research design characteristics and the identified presence of Biggs' principles were examined. In addition, a content analysis of the extracted subskills and conditions was conducted. This analysis included two steps: (a) all extracted subskills and conditions were categorized according to the four components of the Conceptual Review Framework (see Figure 2.1), and (b) similar subskills or conditions were grouped and labeled.

2.4 Results and discussion

2.4.1 Description of scientific research into teaching and learning in interdisciplinary higher education

The search resulted in 309 unique publications. Of these, 14 publications met the aforementioned criteria for inclusion. While two relevant publications reported on the same empirical study results, only the publication with the most extensive coverage was included. Of those 13 relevant publications, ten were empirical and three were theoretical studies. The publications that were removed included 172 describing individual faculty experiences, courses, curricula, or projects and 73 publications that fell outside the scope of this review. Also excluded were 50 publications on a different topic.

The majority of the reviewed publications (11 out of 13) were published in the twenty-first century and in the domain of education (nine out of 13). All relevant publications were written in English. Three publications – Boix Mansilla and Duraising (2007) and Nikitina (2005, 2006) – concerned one particular research project on interdisciplinarity at Harvard University.

A broad range of topics on teaching and learning was researched. This resulted in: potential frameworks (seven out of 13), best practices (four out of 13), and essential conditions (two out of 13). To start with the proposed frameworks, these publications considered the following teaching and learning topics: an adaptation of Biggs and Collis' Structure of Observed Learning Outcome (SOLO) taxonomy to illustrate interdisciplinary learning (Ivanitskaya, Clark, Montgomery, & Primeau, 2002), a proposed research agenda based on teaching and learning theories to encourage research in the field of interdisciplinary higher education (Lattuca et al., 2004), a framework illustrating three major cognitive movements in interdisciplinary thought (Nikitina, 2005), three strategies for interdisciplinary teaching (Nikitina, 2006), four dimensions of a potential interdisciplinary pedagogy (Manathunga, Lant, & Mellick, 2006), an empirically grounded framework for assessing students' interdisciplinary work (Boix Mansilla & Duraising, 2007), and a framework for conceptualizing interdisciplinary classroom communication (Woods, 2007). Second, best practices dealt with the relationship between disciplinary background and interdisciplinary education (Newell, 1992), with the lack of adequate and appropriate methods for assessing interdisciplinary higher education programs (Field & Lee, 1992), with the experiences of graduate students who pursued interdisciplinary studies (Graybill et al., 2006), and a successful course approach (Eisen, Hall, Soon Lee, & Zupko, 2009). Third, the following essential conditions were identified through the evaluation of two interdisciplinary training programs: participation, training in group skills, information sharing, networking, critical reflection (Gilkey & Earp, 2006), participation in a collaborative interdisciplinary team project, and faculty mentors (Misra et al., 2009).

As a rule, the empirical studies (ten out of 13) used surveys, interviews, observations, product appraisal, and reflection on experiences as their research methods. The theoretical studies (three out 13) put forward several theories such as Perry and Vygotsky (e.g., Lattuca et al., 2004) to describe the phenomenon under examination, but lacked empirical evidence. The educational context of the reported studies varied: undergraduate and graduate curricula in sciences, social sciences, and humanities and the studies were mainly conducted in the United States (12 out of 13).

2.4.2 Evaluation of scientific research into teaching and learning in interdisciplinary higher education

The evaluation based on the principles of Biggs' theory (2003) showed that all publications reviewed were explorative. The research field is still in the phase of attempting to deepen the understanding of the nature of interdisciplinary higher education. This formative stage of development can be attributed to the perceived lack of specific educational models and empirical research in this field (e.g., Woods, 2007). Accordingly, strong empirical studies addressing the research questions of this review study were lacking.

The evaluation also revealed the absence of a comprehensive view of teaching and learning; the reviewed publications adopted a narrower focus. Using the Conceptual Review Framework (see Figure 2.1) to categorize the aforementioned researched teaching and learning topics resulted in nine publications that addressed mainly learning environment, two publications that addressed mainly IDT, two publications that addressed mainly learning process, and zero publications that addressed mainly student. In addition, there was slight evidence of the outcome-based approach as adopted in this review study. Three of the reviewed publications (Boix Mansilla & Duraising, 2007; Nikitina, 2005; Woods, 2007) tend towards the outcome-based approach. Concerning the conceptualization of IDT, Boix Mansilla and Duraising defined IDT in a manner similar to that used in this review study. The other publications referred to the synthesis or integration characteristic of interdisciplinarity.

The content analysis resulted in an understanding of potential subskills that constitute IDT and potential conditions for enabling the development of IDT (see Table 2.1).

Table 2.1 Overview of potential subskills and conditions; potential subskills and conditions for interdisciplinary higher education

Interdis-ciplinary thinking	**Having knowledge**		**Having skills**	
	knowledge of disciplines		higher-order cognitive skills	
	knowledge of disciplinary paradigms		communication skills	
	knowledge of interdisciplinarity			
Student	**Personal characteristics**		**Prior experiences**	
	curiosity	patience	social	
	respect	diligence	educational	
	openness	self-regulation		
Learning environment	**Curriculum**	**Teacher**	**Pedagogy**	**Assessment**
	balance between disciplinarity and interdisciplinarity	intellectual community focused on interdisciplinarity	aimed at achieving interdisciplinarity	of students' intellectual maturation
	disciplinary knowledge inside or outside courses on interdisciplinarity	expertise of teachers on interdisciplinarity	aimed at achieving active learning	of interdisciplinarity
		consensus on interdisciplinarity	aimed at achieving collaboration	
		team development		
		team teaching		
Learning process	**Pattern**		**Learning activities**	
	phased with gradual advancement		aimed at achieving interdisciplinarity	
	linear		aimed at achieving reflection	
	iterative			
	milestones with encountering questions			

Despite the differing focus of the reviewed publications, similarities in subskills and conditions were noticed. To illustrate, *phased with gradual advancement* (see Table 2.1) was suggested by three publications (Ivanitskaya et al., 2002; Manathunga et al., 2006; Woods, 2007). Similar subskills and conditions were subsequently grouped and labeled. While conditions and subskills were mentioned in several of the reviewed publications within the context of a narrower focus as referred to above, it was necessary to synthesize the insights found to construct a full picture of teaching and learning in interdisciplinary higher education according to Biggs' theory. In view of the nature of the present research, the need for empirical evidence is recognized.

Table 2.1 shows that in becoming capable of IDT, the reviewed publications suggested the importance of two categories *having knowledge* as well as *having skills*. Each category consists of a number of subskills such as knowledge of disciplinary paradigms and communication skills. In addition, in enabling IDT the publications suggested the importance of eight categories (see Table 2.1): *personal characteristics*, *prior experiences* (student component), *curriculum*, *teacher*, *pedagogy*, *assessment* (learning environment component), *pattern*, and *learning activities* (learning process component). Each category consists of a number of typical conditions, ranging from two to six, such as openness, intellectual community focused on interdisciplinarity, pedagogy aimed at achieving collaboration, and learning activities aimed at achieving reflection.

2.5 Exploration of research questions

2.5.1 Which subskills that constitute interdisciplinary thinking within the context of interdisciplinary higher education are mentioned?

Five subskills, divided into two categories, seemed to be important to become capable of IDT (see Table 2.1). The first category, having knowledge, consists of three subskills: *knowledge of disciplines*, *knowledge of disciplinary paradigms*, and *knowledge of interdisciplinarity*. These subskills suggest the importance of disciplinary declarative, procedural, and paradigm knowledge, such as the characteristics of natural and social scientific theories as, for instance, classified by Szostak (2003), supplemented with knowledge of interdisciplinarity, such as knowing the differences between disciplinarity, multidisciplinarity, and interdisciplinarity. Acquisition of these types of knowledge appears to be required for enabling students to step beyond the disciplinary theories and methods in order to make connections between disciplines, to identify disciplinary contradictions, and to consider opportunities for integration at a meta-level (Boix Mansilla & Duraising, 2007). In particular, explicit attention to the students' exposure to disciplines and meta-coordination seems to be important to avoid their feeling overwhelmed and losing the curricular thread (Eisen et al., 2009; Manathunga et al., 2006).

The other category, having skills, consists of *higher-order skills* and *communication skills*. Higher-order skills indicate the necessary ability to search, identify, understand, critically appraise, connect, and integrate theories and methods of different disciplines and to apply the resulting cognitive advancement together with continuous evaluation (Boix Mansilla & Duraising, 2007; Ivanitskaya et al., 2002; Woods, 2007). Inherently, this also requires the ability to change disciplinary perspectives, to switch between depth and breadth, and to transfer new knowledge structures to other appropriate contexts. Communication skills indicate the necessity of learning the language of discourse of different disciplines in order to be able to negotiate meaning, resolve epistemological differences, develop shared understanding, and to communicate cognitive advancements to a broad audience (Manathunga et al., 2006; Woods, 2007).

2.5.2 Which student conditions that influence interdisciplinary thinking within the context of interdisciplinary higher education are mentioned?

Eight student conditions, divided into two categories, seemed to be important to enabling IDT (see Table 2.1).The first category, personal characteristics, includes six conditions. The three conditions *curiosity*, *respect*, and *openness* point at the necessary appreciative attitude towards other disciplines (Bruce, Lyall, Tait, & Williams, 2004). Importantly, students appeared to have a wide variation in attitude towards other disciplines (Woods, 2007). The other three conditions *patience, diligence,* and *self-regulation* likely refer to characteristics essential to enabling the production of a cognitive advancement. The second category, prior experiences, includes the two conditions *social experiences* and *educational experiences*. These conditions point at, for instance, students' experienced way(s) of thinking, styles of teaching, and beliefs about the nature of knowledge and learning (Lattuca et al., 2004).

2.5.3 Which learning environment conditions that influence interdisciplinary thinking within the context of interdisciplinary higher education are mentioned?

Twelve learning environment conditions, divided into four categories, seemed to be important to enabling IDT (see Table 2.1). The first category, curriculum, consists of two conditions: *balance between disciplinarity and interdisciplinarity* and *disciplinary knowledge inside or outside courses on interdisciplinarity*. In particular, an overarching framework that links and sequences curricular content seems to be essential to provide both context and a roadmap for learning (Newell, 1992). The second category, teacher, contains five conditions: *intellectual community focused on interdisciplinarity*, *expertise of teachers on interdisciplinarity, consensus on interdisciplinarity, team development*, and *team teaching*. These conditions refer to the importance of teacher teams and their professional development in interdisciplinarity as a means of facilitating the necessary understanding and integration of each other's' disciplines and of realizing a safe environment in which to mentor students on their journey towards interdisciplinarity (Gilkey & Earp, 2006; Graybill et al., 2006; Newell, 1992). The third category, pedagogy, includes three conditions: *pedagogy aimed at achieving interdisciplinarity*, *pedagogy aimed at achieving active learning*, and *pedagogy aimed at achieving collaboration*. These conditions seem to point to the necessity of learning tasks that actively engage students in applying knowledge rather than memorizing facts, in collaboration with peers in other disciplines to encourage an appreciation of ambiguity (Manathunga et al., 2006). In addition, such learning tasks need to provide students with the opportunity to gain experience of inquiry activities typical of interdisciplinarity, for instance, the negotiation of common ground (Woods, 2007). The fourth category, assessment, includes the condition *assessment of students' intellectual maturation*, which seems to point to the importance of a formative assessment of IDT subskills. This category also includes the condition *assessment of interdisciplinarity* that suggests a summative assessment of the learning outcome IDT. Both conditions suggest assessment instruments that include a combined development and performance perspective to help teachers as well as students to analyse the progression of IDT (Field & Lee, 1992; Ivanitskaya et al., 2002; Woods, 2007).

2.5.4 Which learning process conditions that influence interdisciplinary thinking within the context of interdisciplinary higher education are mentioned?

Six learning process conditions, divided into two categories, seemed to be important to enabling IDT (see Table 2.1). The first category, pattern, contains four conditions: *phased with gradual advancement*, *linear*, *iterative*, and *milestones with encountering questions*. These four conditions seem to point to the need for a gradual, linear, phased pattern combined with predetermined learning outcomes that serve as milestones for each phase in which students are repeatedly exposed to IDT (Graybill et al., 2006; Ivanitskaya et al., 2002; Manathunga et al., 2006; Woods, 2007). It has been suggested that this development process may follow that of Biggs' SOLO taxonomy (Ivanitskaya et al., 2002) or intellectual maturation theories such as that of Perry (Field & Lee, 1992). The second category, learning activities, includes the conditions *learning activities aimed at achieving interdisciplinarity* and *learning activities aimed at achieving reflection*. Both conditions likely refer to the need for learning activities aiming at the acquisition of subskills of IDT. In particular, provoking students in contrasting and conflicting disciplinary perspectives combined with developing a critical stance seems to be essential to stimulate students to depart from their notion of absolute knowledge (Ivanitskaya et al., 2002; Lattuca et al., 2004).

2.5.5 Which relationships between student, learning environment, and learning process conditions and interdisciplinary thinking within the context of interdisciplinary higher education are mentioned?

No empirical evidence was provided by the publications reviewed regarding the relationships between student, learning environment, and learning process conditions and IDT. However the review results, as presented in Table 2.1, do provide the basis for several hypothetical relationships between the identified conditions and the learning outcome IDT. It can be hypothesized, for instance, that the student condition curiosity and the learning environment condition team teaching have a positive relationship with the development of IDT. In addition, phased with gradual advancement appears to be a desirable condition of the learning process that is positively related with the learning outcome IDT and so on. Importantly, a proper balance between knowledge and skills development, repeated exposure, and scaffolding appears to be required to enable IDT (Ivanitskaya et al., 2002; Manathunga et al., 2006; Woods, 2007).

2.6 Conclusions and considerations

This literature review set out to disclose the subskills that constitute IDT and to unravel the typical student, learning environment, and learning process conditions that enable IDT development in interdisciplinary higher education. The first finding is that despite repeated acknowledgement of the lack of scientific research in the field of teaching and learning in interdisciplinary higher education (e.g., Lattuca et al., 2004), to date, such research has been limited and explorative. Second, the present review should be regarded as one of the first scientific studies to offer a clear and comprehensive view of the teaching and learning IDT in interdisciplinary higher education. Third, the adopted outcome-based approach, consistent with the theory of Biggs (2003), also appears to be innovative in interdisciplinary higher education presumably because interdisciplinary higher education is still being defined not in terms of what students gain in ability but in terms of its own pedagogical characteristics. It is desirable that the proposed performance view of interdisciplinary higher education be adopted since: (a) recent research (Misra et al., 2009) has exemplified the difficulty in realizing the beneficial synthesis or integration outcome, and (b) it will promote the unification of terminology as exemplified in the present review study, the need for which has been identified (e.g., Manathunga et al., 2006). Fourth, the research designs in the reviewed publications inevitably differed in quality. In this review study, the methodological quality of the research designs were not taken into account as such. However, generally speaking, it is clear from the review results that in order to move scientific research in this field a step forward, strong empirical studies are needed.

The present systematic review study has advanced the understanding of the potential subskills and conditions (see Table 2.1) that can serve as the basis for strong empirical studies. The subskills of IDT that were obtained are: knowledge of disciplines, knowledge of disciplinary paradigms, knowledge of interdisciplinarity, higher-order cognitive skills, and communication skills. The student conditions that were obtained are: curiosity, respect, openness, patience, diligence, self-regulation, social experiences, and educational experiences. The learning environment conditions that were obtained are: balance between disciplinarity and interdisciplinarity, disciplinary knowledge inside or outside courses on interdisciplinarity, intellectual community focused on interdisciplinarity, expertise of teachers on interdisciplinarity, consensus on interdisciplinarity, team development, team teaching, pedagogy aimed at achieving interdisciplinarity, pedagogy aimed at achieving active learning, pedagogy aimed at achieving collaboration, assessment of students' intellectual maturation, and assessment of interdisciplinarity. The learning process conditions that were obtained are: phased with gradual advancement, linear, iterative, milestones with encountering questions, learning activities aimed at achieving interdisciplinarity, and learning activities aimed at achieving reflection.

Despite the modest number of relevant publications found, this review should be considered as a suitable preparatory study, encouraging others to explore the field of teaching and learning IDT in more depth. The number of publications was found to be sufficient to explore our research questions. The theory of Biggs (2003) has been helpful in: (a) recognizing similarities in subskills and conditions between the reported studies despite their differing focus, and (b) providing an organized way of identifying and categorizing these subskills and conditions. In retrospect, the selected time span of the literature search, languages, scientific literature databases as well as the search strategy used were adequate for the purposes of this review. Although no specific search terms concerning the component student were included, eight possible conditions could be extracted (see Table 2.1).

2.7 Suggestions for further research

Further research should examine whether empirical evidence can be found for the subskills and conditions obtained in the present study (see Table 2.1). Strong empirical research is required to test hypothetical relationships between student, learning environment, and learning process conditions and IDT within the context of interdisciplinary higher education. Such testing would open the way for research into the exact nature of these relationships; for example, the extent of the influence of one factor on another, the stability of such influence and its mutation over time. Additionally, empirical research should focus on identifying the optimum combination of conditions to enable IDT. In particular, research into the extent and sequence of knowledge and skills development and the balance between knowledge and skills development is recommended (Ivanitskaya et al., 2002; Manathunga et al., 2006; Woods, 2007).

Investigation whether the proposed performance view of curriculum design in interdisciplinary higher education does indeed facilitate the achievement of the learning outcome IDT is recommended. It would be interesting to investigate if and how the operationalization of the learning outcome IDT differs along interdisciplinary higher education curricula lines, between curricula with a focus on narrow and broad IDT and between educational contexts (Boix Mansilla & Duraising, 2007; Nikitina, 2005, 2006).

To summarize, while interdisciplinary higher education is commonly practiced nowadays, a surprisingly small body of theory has accumulated. The present systematic review has analysed some of that theory in order to establish a platform from which the theory of interdisciplinary higher education can be moved forward. It is hoped that this will encourage further empirical research that will lead in time to a framework for interdisciplinary higher education design and will deepen understanding of the nature of teaching and learning IDT.

Chapter 3

Constructively aligned teaching and learning in higher education in engineering: What do students perceive as contributing to the learning of interdisciplinary thinking?

Abstract

Increased attention to the need for constructively aligned teaching and learning in interdisciplinary higher education in engineering (HEE) is observed. By contrast, little research has been conducted on the implementation of the outcome-based pedagogical approach to interdisciplinary HEE. Therefore, the present design-based research was undertaken to develop, implement and evaluate a constructively aligned learning environment in the interdisciplinary field of food quality management. The practical aims were to reduce the perception held by the students of choppiness and to prevent them floundering in the disciplines; the theoretical aim was to accumulate theory on learning environment aspects that would help students to learn interdisciplinary thinking (IDT). The design-focused evaluation among 26 students showed that the practical aims were met and concerning the theoretical aim, eight learning environment aspects were identified such as learning within an interdisciplinary framework. Further research should validate these aspects to continue with tackling teacher challenges on teaching IDT.

This chapter has been published as:

Spelt, E. J. H., Luning, P. A., Van Boekel, M. A. J. S., & Mulder, M. (2015). Constructively aligned teaching and learning in higher education in engineering: What do students perceive as contributing to the learning of interdisciplinary thinking? *European Journal of Engineering Education*, *40*(5), 459-475.

3.1 Introduction

Various pedagogical approaches to interdisciplinary higher education have been implemented worldwide (Franks et al., 2007; Froyd & Ohland, 2005; He, Chen, & Wu, 2011; Ivanitskaya et al., 2002; Johannes & Kasteren, 1996; Liebert, 2013; Lok, 2008; Ollis, 2004; Pharo, Davison, McGregor, Warr, & Brown, 2014; Tong, 2010; Vale et al., 2012; Van Zonneveld, 1996). These approaches differ from one another with respect to their intended learning outcomes and their designs. Among the various intended learning outcomes employed by these approaches are the following: the ability to work in multidisciplinary teams (Boni, Weingart, & Evenson, 2009; Chanan et al., 2012; Hersam, Luna, & Light, 2004); the ability to integrate disciplinary knowledge (Fortuin et al., 2013; Guo & Liu, 2011); and the ability to solve complex problems (Mascarelli, 2013; Mobley et al., 2014; Ng, Yap, & Hoh, 2011). The various designs used in interdisciplinary higher education are, by way of example, short-term training sessions (Hackett & Rhoten, 2009; Schmidt et al., 2012), mid-term courses (Nardone & Lee, 2011; Rhee, Cordero, & Quill, 2010; Wagner et al., 2012) and long-term curricula (Gero, 2013; Knight, Lattuca, Kimball, & Reason, 2013; McFadden et al., 2011). Other aspects of the designs that differ from approach to approach are, for instance, the instructional strategies used by teachers and the roles of the disciplines (Augsburg et al., 2013; Davies, Devlin, & Tight, 2010; Klein, 2005; Newell, 1992).

The defining characteristic of interdisciplinary or interdisciplinarity is the ability to integrate disciplinary knowledge (Klein, 1990). When this complex cognitive skill is not taught, it is likely that the teaching and learning will remain multidisciplinary, which is an additive process and does not involve the integration of disciplinary knowledge. The skill of disciplinary knowledge integration can be performed by individuals (Augsburg, 2006; Nikitina, 2005) or by interdisciplinary collaborations (O'Rourke, Crowley, Eigenbrode, &

Wulfhorst, 2013; Thompson, 2009). In interdisciplinary higher education, the name given to the ability to integrate or synthesize knowledge of disciplines is 'interdisciplinary thinking' (IDT), or 'interdisciplinary understanding' (Eisen et al., 2009; Spelt, Biemans, Tobi, Luning, & Mulder, 2009). In IDT, the blending of knowledge enables the integration of the disciplinary knowledge and allows an advance in understanding (Klein, 2010). This integration ability is an important intellectual cognitive activity of our minds that need to be taught as intended learning outcome across interdisciplinary higher education (Eckstein, 1976; Gardner, 2008; Harrison, Macpherson, & Williams, 2007; Newell, 2010a). IDT was defined in literature (Boix Mansilla & Duraising, 2007; Boix Mansilla et al., 2000) as the ability to integrate disciplinary knowledge to achieve a cognitive advancement that would have been impossible by the use of one single discipline (see chapter 1.2). In interdisciplinary classrooms, the intended learning outcome on IDT can be, for instance, a conceptual model that demonstrates the application of factors derived from different disciplines (Boix Mansilla & Duraising, 2007; Repko, 2012). The definition of IDT provides scope for various specific intended learning outcomes on IDT. For each of these specific learning outcomes of IDT, the disciplinary perspectives are blended by students to bring about an advance in understanding.

While the need for empirical research into the successfulness of pedagogical approaches to teaching and learning IDT in higher education is recognized (Gouvea, Sawtelle, Geller, & Turpen, 2013; Lattuca et al., 2004; Nikitina, 2006; Woods, 2007) such empirical research with regard to engineering students is still limited. Previous empirical research for engineering students indicated that the lack of coherence between course elements (Eisen et al., 2009) and the lack of clarity as to the learning outcomes (Borrego & Cutler, 2010) may result in perceptions by students that the course is 'choppy', that is, just bits and pieces, and that they themselves are floundering in the disciplines. Eisen et al. (2009, p. 103) reported that the most common complaint about the designed interdisciplinary courses was still their tendency towards choppiness and lack of clear connection or organization, despite their efforts. A pedagogical approach that has been identified as having the potential to prevent these perceptions is the outcome-based pedagogical approach (Gharaibeh et al., 2013; Lattuca, Knight, & Bergom, 2013). It is argued that the constructive alignment principle of the outcome-based pedagogical approach may help teachers in designing consistent interdisciplinary learning environments and may help students in understanding what is expected from them in those learning environments (Borrego & Cutler, 2010; Yang, 2009). The implementation of the constructive alignment principle likely leads to the required supportive environments to achieve the interdisciplinary learning outcomes (J. A. Smith & Carey, 2007; Stefani, 2009).

It is the interplay between the concepts outcome-based education, constructive alignment and interdisciplinarity that likely amplify the fostering aid of interdisciplinary learning environments in supporting students to achieve the intended learning outcome on IDT. The concept of outcome-based education considers a precise clarification of intended learning outcomes; these outcomes represent the desired students' performances on particular abilities or competencies (Spady, 1994). The emphasis on students' performances led to a student-centred way of teaching. Additionally, the concept constructive alignment considers a precise formulation of teaching, learning and assessment that perfectly matches with the intended outcomes (Harden, Crosby, & Davis, 1999). The focus on a perfect match leads to the design of consistent learning environments. The concept interdisciplinarity considers a precise explanation of connections between relevant disciplinary insights (Newell, 2007). The scrutiny of those connections results in a comprehensive understanding which is required for IDT. The joint use of outcome-based education, constructive alignment, and interdisciplinarity by designers of interdisciplinary higher education would contribute to the design of consistent and supportive learning environments with clear connections between the disciplinary course elements, aiming at the intended learning outcomes of students demonstrating the connections of relevant disciplinary insights and their gained comprehensive understandings.

The present research implemented the outcome-based pedagogical approach to interdisciplinary higher education within the context of a food quality management (FQM) course. This course on FQM encountered problems with perceived choppiness and poor alignment. The practical aims of the implementations were to reduce the perception held by the students of choppiness and to prevent them floundering in the disciplines; the theoretical aim was to accumulate theory on key learning environment aspects that would help students to learn IDT. These research aims were formulated in agreement with the methodology of design-based research in education that features the simultaneous pursuit of theory building and practical improvement by analysis of students' reasoning and of the learning environment (Cobb, Confrey, diSessa, Lehrer, & Schauble, 2003; Plomp & Nieveen, 2013).

The present research focus was on theory building in the field of key aspects of interdisciplinary learning environments (Gilkey & Earp, 2006; Misra et al., 2009), instead of theory building in the field of interdisciplinary collaborations among faculties in higher education (Kockelmans, 1979; Pharo et al., 2012; Wolman, 1977), or theory building on designing interdisciplinary curricula in higher education (Chandramohan & Fallows, 2009; Chen et al., 2009; Haynes, 2002; Holley, 2009). The conviction that student inquiry can help in assessing the quality of the designed prototypes (Aziz, Yusof, & Yatim, 2012; Biggs & Tang, 2011; Fernandez et al., 2012; Graybill et al., 2006; Sandoval & Bell, 2004) has led to several investigations in interdisciplinary HEE using student inquiry (Ng et al., 2011; Rhee et al., 2010; Wagner et al., 2012). The needed advance in scientific understanding into key design aspects for interdisciplinary HEE (Hmelo-Silver & Azevedo, 2006; Richter & Paretti, 2009; Rives-East & Lima, 2013; Vedeld & Krogh, 2005) via design-based research and student inquiry motivated the present research.

3.2 Roots of the actual design of the interdisciplinary learning environment

The actual design of the constructively aligned interdisciplinary learning environment (see chapter 3.3) was based chiefly on outcome-based education theory (chapter 3.2.1), a literature review of the teaching and learning of IDT (chapters 3.2.2 and 3.2.3), and the course content for FQM (chapter 3.2.4).

3.2.1 Outcome-based pedagogical approach

The pivotal characteristic of the outcome-based pedagogical approach is the emphasis placed on the learning outcomes that are intended to be achieved in the learning environment. Therefore, the outcome-based pedagogical approach requires the precise clarification of what students need to enact (Biggs, 1999b, 2012). This requirement stems from the conviction that student achievement is enhanced when the learning outcomes are clarified by teachers and designers. The intended learning outcomes need to be clarified into terms of verbs that suggest abilities such as memorize, classify, analyse, and build. The outcome-based pedagogical approach of Biggs and Tang (2007) also features the constructive alignment principle, which prescribes the alignment of the individual instructional elements with the intended learning outcomes. The outcome-based design model for higher education of Biggs and Tang (2011, p. 105) comprises three parts: the intended learning outcomes, the teaching and learning activities, and the assessment tasks (see chapter 1.4). These parts need to be constructively aligned in designing education. The outcome-based pedagogical approach can be used in either aligning curricula, aligning courses, or aligning the actual teaching in classrooms.

3.2.2 Subskills of interdisciplinary thinking

The mastery of five subskills likely leads to the achievement of the intended learning outcomes of IDT (Spelt et al., 2009). These five subskills are: (a) having knowledge of disciplines, (b) having knowledge of disciplinary paradigms, (c) having knowledge of interdisciplinarity, (d) higher-order cognitive skills, and (e) communication skills. The subskills (d) and (e) concern the mastery of functioning knowledge which is explained as knowing how to apply knowledge. For example, knowing how to communicate the cognitive advancements, subskill (e), resulting from blending the knowledge of the disciplinary perspectives is a necessary ability of being an interdisciplinarian (Woods, 2007). The five subskills of IDT can be considered as intermediate learning outcomes helping teachers and designers in identifying essential teaching, learning, and assessing activities to achieve the intended learning outcomes of IDT.

3.2.3 Enabling conditions to develop interdisciplinary thinking

Particular enabling conditions embedded in the learning environment likely foster the development of IDT (Spelt et al., 2009). The categories of enabling conditions are: (a) personal characteristics, (b) prior experiences, (c) teacher, (d) pedagogy, (e) learning process pattern, (f) learning activities, and (g) assessment. These categories are grounded in the concepts of outcome-based education and constructive alignment (Spelt et al., 2009). More specifically, each category provides enabling conditions that are aligned with student achievements in learning outcomes of IDT. The enabling conditions in categories (a) and (b) are student attributes, whereas those in categories (c)–(g) are attributes of the learning environment itself. This distinction has consequences for the manner in which these conditions can be embedded in the learning environment. For example, embedding of enabling conditions of categories (c)–(g) is expressed as follows: the greater the presence of the enabling conditions of categories (c)–(g) in the learning environment, the more that will facilitate student achievement of the intended learning outcomes on IDT. These enabling conditions can be considered as design propositions necessary to be embedded in the actual design of an interdisciplinary learning environment.

3.2.4 Interdisciplinary and problem-based learning in food quality management

The interdisciplinary course on FQM teaches the 'Techno-Managerial' (T-M) approach which involves the integration of disciplinary knowledge from the technological disciplines and the managerial disciplines (Luning & Marcelis, 2006). The T-M approach is to deal with the complexity involved in managing the quality of food products. The complexity lies in the fact that the causes of food quality problems may lie within one or more disciplines. The course teaches students complex problem-solving which involves four sequential phases of an interdisciplinary research process (Luning & Marcelis, 2009b). In each of these phases, students are required to apply the T-M approach. The first research phase considers the appreciation of the complex FQM problem followed by an in depth analysis of the problem in the second research phase. The third research phase deals with diagnosing the actual problem situation to bring about the best solution in the fourth research phase (Luning & Marcelis, 2009b). The new learning environment included these four phases with the aim of achieving in each phase the intended learning outcome of IDT. This problem-based learning as a teaching strategy is one of the three commonly used pedagogical strategies for interdisciplinary teaching (Nikitina, 2006).

3.3 Actual design of the constructively aligned interdisciplinary learning environment

Table 3.1 shows the actual design of the learning environment in a format analogous to that of the outcome-based design model of Biggs and Tang (2011).

Table 3.1 The actual design of the constructively aligned interdisciplinary learning environment

Teaching and learning elements	Specific intended learning outcomes	Assessment elements
1. Lecture Content, skills, and methodology lectures with the aim of teaching the subskills of IDT	*I. Apply* Disciplinary knowledge integration which is achieved by applying the T-M approach to the complex problem	*5. Plenary* Feedback by teachers with the aim of assessing the intended learning outcomes of IDT
2. Individual task Interdisciplinary problem-solving task with the aim of learning the five subskills of IDT	*II. Construct* Disciplinary knowledge integration which is achieved by constructing the T-M research instrument	*6. Peer* Feedback by students with the aim of assessing the intended learning outcomes of IDT
3. Individual presentation Progress and final presentations by students with the aim of learning from each other's individual outcomes concerning IDT	*III. Identify* Disciplinary knowledge integration which is achieved by identifying the technological and managerial causes for the complex problem	*7. Individual* Feedback by teachers with the aim of assessing the five subskills and the intended learning outcomes of IDT
4. Group task Group interdisciplinary problem-solving with the aim of collaboratively learning the five subskills of IDT	*IV. Create* Disciplinary knowledge integration which is achieved by creating the interdisciplinary argument in support of the best solution for the complex problem	*8. Self* Reflection by students with the aim of assessing the five subskills and the intended learning outcomes of IDT

The four specific intended learning outcomes are a sequential line of outcomes (outcomes I-IV) in agreement with the four phases of the interdisciplinary research process taught in this course. The learning periods of these four learning outcomes were of similar duration, thereby providing the students with repeated opportunities to learn IDT. The teaching and learning, and the assessment elements (elements 1-8) were constructively aligned with each of the four intended learning outcomes. The teaching element (1) lecture was to teach the five subskills of IDT (Table 3.1) whereas the learning elements of the (2) individual task, (3) individual presentation, and (4) group task were to engage the students in the learning activities concerning the five subskills of IDT. The assessment elements of the (5) plenary feedback, (6) peer feedback, (7) individual feedback, and (8) self-reflection were to formatively assess student performances. The present research investigated the following research question: *What do students perceive in the learning environment as contributing to the achievement of the intended learning outcomes of IDT?* The answer to this question would lead to refinement of the actual design which can, in turn, be the input for new iterative cycles of design and implementation to proceed with theory building and improving educational practices (Barab & Squire, 2004; Edelson, 2002).

3.4 Method

3.4.1 Present design-based research

The present design-based research provided insights from three different angles: (a) the adequacy of the implementation of the pedagogical approach of Biggs and Tang to the teaching and learning of IDT, (b) the usefulness of the constructed actual design for teaching and learning of IDT in the field of FQM, and (c) the particular aspects of the learning environment that enable engineering students in learning IDT. The present research dealt with the developmental stage of 'what is happening in the interdisciplinary learning environment' prior to the developmental stage of 'is there a systematic effect between the instructional design and the learning outcomes' (Collins, Joseph, & Bielaczyc, 2004; Shavelson, Philips, Towne, & Feuer, 2003). The developmental stage of what is happening requires formative evaluations of gathering information on the actual practicality and actual effectiveness, instead of summative evaluations proving the systematic effectiveness of newly created designs (Nieveen, 2007). Following the generic model for conducting design-based research in education (McKenney & Reeves, 2012, p. 77), an interdisciplinary team of teachers and researchers co-created the interdisciplinary learning environment in a systematic manner. The formative evaluation was conducted by asking the students whether they considered that the new learning environment had contributed to their achievement of the intended learning outcomes.

3.4.2 Course context

The context of the redesigned course was a European university dealing with the delivery of education in the domain of healthy food and living environment. This domain is rarely related to a single discipline; often there are multiple disciplines involved. Therefore, the connections between disciplinary knowledge of the natural sciences and social sciences, in both education and research, are fostered. At this university the philosophy of outcome-based education has been implemented and continuous improvement takes place. The redesigned course is part of an interdisciplinary graduate program FQM consisting of three interrelated interdisciplinary courses and different clusters of disciplinary courses. The redesigned course is the second course in the row of these interdisciplinary courses.

3.4.3 Course redesign

The steps of the course redesign included alpha trials in academic year 2009–2010 and beta-testing in academic year 2010–2011 (McKenney & Reeves, 2012). Each of these steps was followed by an in-depth reflection phase including comparisons with other interdisciplinary courses; the purpose of which was to enable a comprehensive understanding (Postholm & Moen, 2011). A team of four researchers conducted the course redesign, its implementation and evaluation. The role of the first two authors was to take care of the development, implementation, and evaluation of the course redesign. This was done in close collaboration with the second two authors, other researchers, and teachers in the departments of food sciences and educational sciences who all reflected upon the research and design activities. The redesigned course took 12 weeks, in which the students were required to participate every weekday (full-time) during the first four weeks and to spend a minimum of 20 hours of the study week (part-time) during the remaining eight weeks (in total 12 European credits). At the start of the course, students received instruction about the student-driven pedagogy in this course and their accompanying responsibilities of the learning processes.

3.4.4 Course evaluation

The course evaluation included 20 statements and questions intended to ascertain the perceived contribution of the total learning environment and its individual elements (see Table 3.1) to the achievement of the intended learning outcomes. This design-focused approach to evaluation questions the link between the educational design and the outcomes (C. Smith, 2008). From Table 3.1, four statements were derived from the specific intended learning outcomes (middle column), 12 questions were derived from the individual teaching and learning elements (left column), and four questions were derived from the individual assessment elements (right column). Responses to the four items covering the perceived contribution of the total learning environment ranged on a scale from one (1 = *strongly disagree*) to five (5 = *fully agree*). Responses to the 16 items covering the perceived contribution of the individual teaching, learning, and assessing elements ranged from one (1 = *very low extent*) to five (5 = *very high extent*). The evaluation form also included an open question by means of which the student was invited to elaborate on the given response. At the end of the course, the 30 students received an email asking them to complete the evaluation form and 26 students completed this form. The 26 students ranged in age from 23 to 41-years-old; the majority of them (20 out of 26) had a background in food sciences. The group comprised 18 women and eight men, and 12 nationalities.

3.4.5 Data analysis

A mixed methods data analysis (Johnson & Onwuegbuzie, 2004) determined the perceived contribution of the actual design (Table 3.1) to the achievement of the learning outcomes of IDT. The quantitative part of the mixed methods data analysis included the construct of frequency distributions of the answers given to the 20 items. Having an ordinal measurement level of items, the *mode* (most frequently given answer) is the adequate descriptive statistic to show the central tendencies in the perceived contributions (Reid, 2014). The qualitative part of the mixed methods analysis included comparing and contrasting of the answers given (Boeije, 2010) to the open questions using MAXQDA 10. The comparing and contrasting showed that similar responses were made by students on particular aspects of the learning environment. A label to these particular aspects of the learning environment was given, following the method of pattern coding (Saldaña, 2009). The grouping of the similar responses was labelled when at least five students addressed that particular aspect in their response.

3.5 Results and discussion

The quantitative results, presented in Tables 3.2 to 3.5, showed the contribution of the constructively aligned learning environment to the achievement of the intended learning outcomes as perceived by the students.

In Table 3.2, for all inquiry items, with respect to the total learning environment, the most common categories (*mode*) are categories 4 and 5.

Table 3.2 The perceived degrees of contribution of the total learning environment to the achievement of the intended learning outcomes measured per specific intended learning outcome (*N* = 26 students)

Total learning environment	The perceived degrees of contribution				
Specific intended learning outcomes:	1.Strongly disagree	2.Partly disagree	3.Neutral	4.Partly agree	5.Fully agree
Apply: The learning environment enhanced my ability to <apply> the T-M approach in situations involving a FQM problem.	0	1	1	8	**16**
Construct: The learning environment enhanced my ability to <construct> a T-M research instrument for use in situations involving a FQM problem.	0	0	0	**13**	**13**
Identify: The learning environment enhanced my ability to <identify> technological and managerial causes of situations involving a FQM problem.	0	0	1	**13**	12
Create: The learning environment enhanced my ability to <create> an interdisciplinary argument for the best solution in a situation involving a FQM problem.	0	0	3	**13**	10

Note: The *modes* (most frequently given answer) are printed in bold.

In Table 3.3, for all inquiry items with respect to the teaching element, the most common categories (*mode*) are categories 3 and 4. The perceived contribution was not consistent for the three lecture types; the lecture type of skills lectures earned a lower rating. Accordingly, a refinement to the actual design (see Table 3.1) is the better alignment of the skills lectures to the achievement of the learning outcomes of IDT.

In Table 3.4, for all inquiry items with respect to the learning elements, the most common category (*mode*) is category 4, with the exception of one instructional part of the individual task which relates to the food problem description. The relatively lower score for this instructional part tallied with our expectations. Since the individual task was an ill-defined problem task, the food problem description did not include all the necessary information. This was deliberate because the lack of information is consistent with the daily practice of complex problem solving that students will encounter in their future careers.

Table 3.3 The perceived degrees of contribution of the teaching element to the achievement of the intended learning outcomes measured per type of lecture (*N* = 26 students)

	The perceived degrees of contribution				
Teaching element:	1.Very low extent	2. Rather low extent	3. Neutral	4. Rather high extent	5. Very high extent
Lecture: To what extent did the <content> lectures facilitate you in achieving the intended learning outcomes?	0	1	7	**11**	7
Lecture: To what extent did the <skills> lectures facilitate you in achieving the intended learning outcomes?	1	0	**11**	8	6
Lecture: To what extent did the <methodology> lectures facilitate you in achieving the intended learning outcomes?	1	0	6	**12**	7

Note: The *modes* (most frequently given answer) are printed in bold.

The data presented in Table 3.4 on the student perception on the contribution was, however, broad relative to Tables 3.2 and 3.3. This broad range in perceptions may be attributable to several factors: the range of student prior social and educational experiences, the range of student preferences for a particular type of pedagogical approach, the delivery of the course by the teaching staff, or the extent of alignment between the intended learning outcomes and those elements involved, or a combination of factors. Extension of the design-focused evaluation with semi-structured questions related to these factors is recommended.

Table 3.4 The perceived degrees of contribution of the learning elements to achievement of the intended learning outcomes measured per part of the learning elements (*N* = 26 students)

	The perceived degrees of contribution				
Learning elements:	1.Very low extent	2. Rather low extent	3. Neutral	4. Rather high extent	5. Very high extent
Individual task: To what extent did the <assignment introductions> facilitate you in achieving the intended learning outcomes?	0	3	5	**14**	4
Individual task: To what extent did the <assignment descriptions> facilitate you in achieving the intended learning outcomes?	0	1	3	**17**	5
Individual task: To what extent did the <food problem description> facilitate you in achieving the intended learning outcomes?	1	6	**8**	**8**	3
Individual task: To what extent did the <assignments report writing> facilitate you in achieving the intended learning outcomes? *	0	0	1	**14**	10
Individual presentation: To what extent did the <students' presentations> facilitate you in achieving the intended learning outcomes?	0	4	5	**10**	7
Individual presentation: To what extent did the <your own student presentation> facilitate you in achieving the intended learning outcomes?	1	0	4	**14**	7
Group task: To what extent did the <food problem group assignment> facilitate you in achieving the intended learning outcomes?	1	4	4	**13**	4
Group task: To what extent did the <FQM topic group> facilitate you in achieving the intended learning outcomes?	2	3	5	**11**	5
Group task: To what extent did the <interdisciplinary research learning community> facilitate you in achieving the intended learning outcomes?	2	4	6	**11**	3

*one response is missing
Note: The *modes* (most frequently given answer) are printed in bold.

In Table 3.5, for all inquiry items, with respect to the assessment elements the most common categories (*mode*) are categories 3 and 5. Table 3.5 indicates that students perceived plenary and individual feedback as being more valuable than peer feedback and self-reflection. This discrepancy in attributed value seems to be due to the fact that these engineering students were more familiar with plenary and individual feedback than with peer feedback and self-reflection. It might even be the case that these engineering students were engaging in peer feedback and self-reflection for the first time. Extra time was spent on introducing peer feedback and self-reflection to the students and should be continued.

Table 3.5 The perceived degrees of contribution of the assessment elements to the achievement of the intended learning outcomes measured per assessment element (*N* = 26 students)

	The perceived degrees of contribution				
Assessment elements:	1.Very low extent	2. Rather low extent	3. Neutral	4. Rather high extent	5. Very high extent
Plenary: To what extent did the <plenary feedback> facilitate you in achieving the intended learning outcomes?	1	2	7	7	**9**
Peer: To what extent did the <peer feedback> facilitate you in achieving the intended learning outcomes?	1	3	**13**	9	0
Individual: To what extent did the <individual feedback> facilitate you in achieving the intended learning outcomes?	0	0	3	6	**17**
Self: To what extent did the <self-reflection> facilitate you in achieving the intended learning outcomes?	3	5	**11**	5	2

Note: The *modes* (most frequently given answer) are printed in bold.

With respect to the qualitative results, 25 of the 26 students perceived the new learning environment as constructively contributing to the achievement of the intended learning outcomes; one student perceived the new learning environment as still not being interdisciplinary and argued what disciplinary knowledge integration actually is. Table 3.6 shows the identified key aspects of the learning environment to the achievement of the intended learning outcomes of IDT.

Table 3.6 The perceived contribution of key aspects of the total learning environment and its individual elements, which was expressed by *n* students (*N* = 26 students)

Part of the learning environment:	The perceived contribution of key aspects	*n*
Total learning environment	Learning within an interdisciplinary framework	12
	Learning via a step-by-step roadmap	8
Teaching element	Receiving cognitive guidance	8
	Receiving examples to familiarize oneself	5
Learning elements	Engaging in a range of disciplinary perspectives	10
	Conducting disciplinary knowledge integration a number of times	12
Assessment elements	Determining concrete improvements	9
	Tackling difficult issues during learning activities	8

The perceived contribution of the key aspect ‘learning within an interdisciplinary framework’ (Table 3.6) reflects the interdisciplinary levels model of Gouvea et al. (2013) which shows an interdisciplinary framework between the disciplines physics and biology comparable to the interdisciplinary framework in this research between the technological and managerial disciplines. Additionally, the perceived contribution of key aspects related to the learning and the assessment instructional elements (Table 3.6) mirrors the active learner-centred model of Nardone and Lee (2011) that included particular learning activities for interdisciplinary courses such as reflecting. The successfulness of reflecting in interdisciplinary learning has also been addressed by Gilkey et al. (2006), Boix Mansilla and Duraising (2007), Woods (2007), and Lyall and Meagher (2012). The successfulness of each of these key aspects needs further investigation.

In retrospect, the development of the new learning environment facilitated in this particular context a common understanding of how to teach IDT and how to critically evaluate new interdisciplinary learning environments. From the development viewpoint, a major limitation was the considerable investment in time that was required to enable the team members to adopt the interdisciplinary mode of thinking, coming as they did from various disciplines. In contrast, from the research viewpoint, the major limitation was the lack of empirical research into the contribution of constructively aligned course designs to the learning of IDT, which forced us to adopt a fully structured approach in the innovation process (Van Boekel, 2009) and the decision to strictly follow the principles of scientific research in education (Shavelson et al., 2003).

Additionally, the design-focused evaluation proposed by Smith (2008), being used as a formative evaluation in the educational design process, matched well with the research aims. However, the need for elaboration with semi-structured questions and the validation of this kind of evaluation is recognized, to allow investigations of a large number of educational innovations and to validate the design-based research methodology (Joseph, 2004). Therefore, an appropriate balance needs to be found between the internal validity of the evaluation, that is, the 'truth' of the findings by means of methodological alignment between theory, educational innovation, data gathering and interpretation (Hoadley, 2004) and the external validity, that is, the 'generalizability' of the findings (Kelly, 2004). At this point, it is also worth noting that the open manner of inquiry remains necessary in order to take account of the confirmation bias inevitable in design-based research (Kelly, 2004; Stam, 2011).

The major recommendation for further research is the repetition of the outcome-based pedagogical approach to other fields than FQM in order to ascertain whether it has indeed potential in fostering the learning of IDT. The repetition is also recommended to determine whether the Hawthorne effect, which is the effect of enhanced attention of the interdisciplinary team received by the students, occurred (Brown, 1992). Additionally, the repetition is recommended to validate the identified key aspects of the learning environment which may lead to design frameworks (Edelson, 2002; Kelly, 2004) or design principles

(Mulder & Kintu, 2013). Figure 3.1 presents the initial design framework on teaching and learning IDT in HEE, based upon present empirical research. It is also recommended to take the lessons of Goodman and Huckfeldt (2013) into account in extending empirical research with larger groups of students in interdisciplinary HEE.

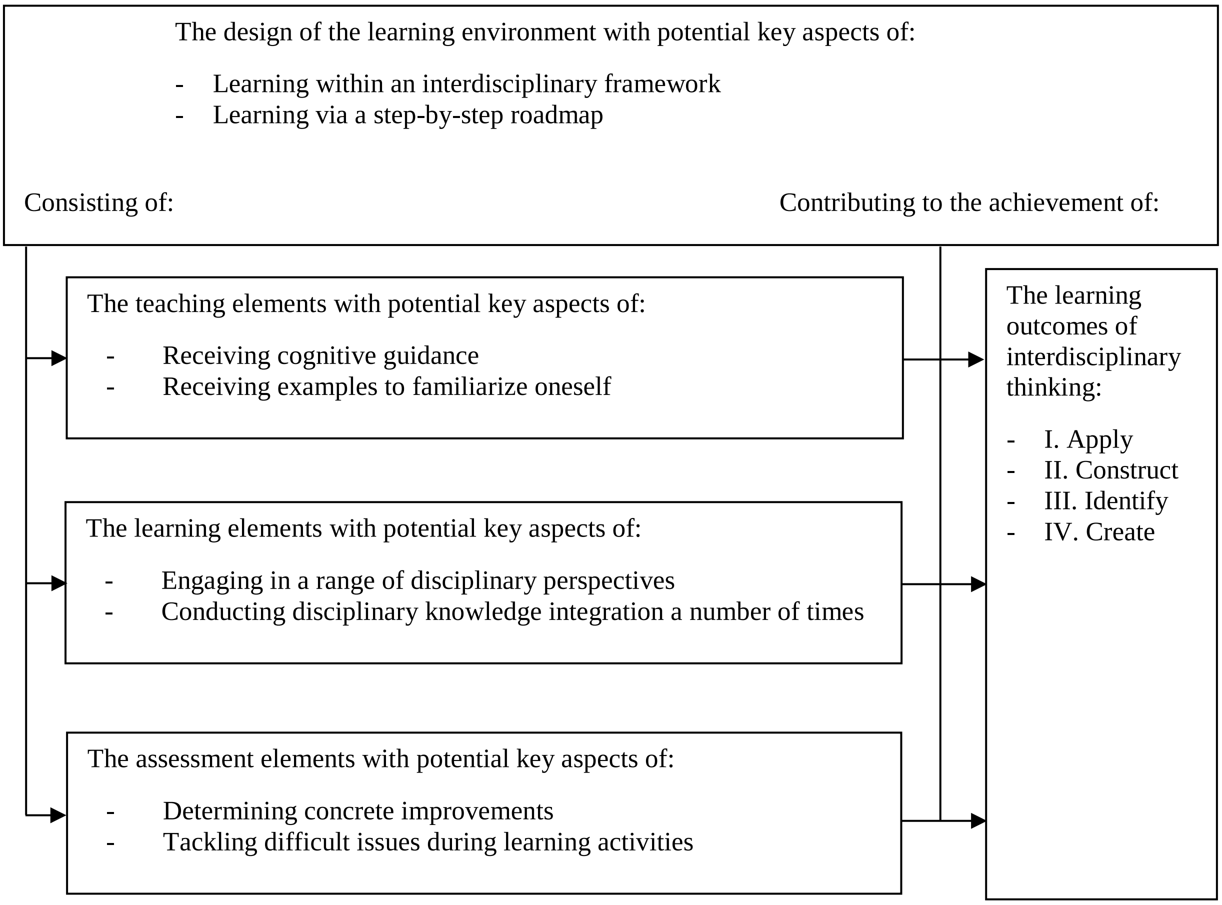


Figure 3.1 The initial design framework with hypothesized relationships between potential key aspects of the learning environment, of the individual elements of the learning environment and the learning outcomes, based on Briggs (2007)

In conclusion, the implementation of the pedagogical approach of Biggs and Tang seems to be adequate for the redesigned course to enhance the teaching and learning for IDT in the field of FQM (Tables 3.2 – 3.5). The adequacy lies, in our opinion, in the student-centred approach to teaching and learning that likely leads to autonomous students. In turn, these relatively more autonomous students are likely better equipped in reaching the necessary adequacy in the disciplines themselves, in adequately synthesizing the disciplinary knowledge, and then in revising the obtained disciplinary knowledge integration (Boix Mansilla & Duraising, 2007; Nikitina, 2005; Repko, 2012). This better equipment is important because each engineering student in interdisciplinary higher education develops unique scholarly identities and areas of expertise (Graybill et al., 2006) which is required for working in industry (Martin, Maytham, Case, & Fraser, 2005) and in research (Lach, 2014). The identified refinements of the actual design (Table 3.1) are, for instance, better alignment of the skills lectures (Table 3.3) and continuation of the in-depth instruction on peer and self-assessment (Table 3.5). The particular eight aspects of the new learning environment (Table 3.6) that would help engineering students in learning IDT need further validation in future research as schematically represented in Figure 3.1. In sum, the teacher challenge of implementing the outcome-based pedagogical approach to the FQM course seemed to be tackled via this educational innovation. However, new challenges to optimize this innovation simultaneously emerged.

Chapter 4

Characterization of short-term learning processes on interdisciplinary thinking in higher education in engineering

Abstract

The importance of preparing engineering students to work in interdisciplinary teams necessitates research into the teaching and learning of interdisciplinary thinking (IDT) in higher education in engineering (HEE). To our knowledge, the characterization of short-term IDT learning processes in HEE is lacking in current research. However, investigating student learning processes affords scientific insight into students' experience of their IDT learning. Therefore, the present research characterized the short-term learning processes of engineering students engaged in an interdisciplinary course on food quality management (FQM) using the learning theory of Illeris. The results showed that the learning processes for the FQM course in question can be divided into the content (194 out of 615 experiences), incentive (214 out of 615 experiences), and interaction (207 out of 615 experiences) dimensions. The results also showed 24 key learning experiences featuring the IDT learning processes. Replication studies to validate the results of present exploration are recommended.

This chapter has been submitted for publication as:

Spelt, E. J. H., Luning, P. A., Van Boekel, M. A. J. S., & Mulder, M. (under review for publication). Characterization of short-term learning processes on interdisciplinary thinking in higher education in engineering

4.1 Introduction

The importance of preparing engineering students to work in interdisciplinary teams is often emphasized (e.g., Adams, 2007; Haase, Chen, Sheppard, Kolmos, & Mejlgaard, 2013; Mascarelli, 2013; Vale et al., 2012). Engineering students will work during their careers in interdisciplinary teams on complex problems like sustainability and food safety. In such teams, engineering students need to be able to integrate knowledge of different disciplines (Bruce et al., 2004; Lattuca et al., 2013; Redish & Smith, 2008; Schaefer et al., 2012). This disciplinary knowledge integration is necessary to advance understanding when analyzing and solving complex problems (Newell, 2010a; Van Mil, Foegeding, Windhab, Perrot, & Van der Linden, 2014). Disciplinary knowledge integration occurs in interdisciplinary teams through the sharing of disciplinary knowledge and disciplinary skills. It is likely that disciplinary knowledge integration in interdisciplinary teams increases when each engineer has prior experience of working in such teams (Lyall & Meagher, 2012; Thompson, 2009). This is because working across disciplines requires appreciation of different disciplinary viewpoints and methods on the part of these engineers (e.g., Klein, 2008; O'Rourke et al., 2013). Experience of working in interdisciplinary teams should therefore start as early as possible in higher education in engineering (HEE), in order that disciplinary knowledge integration may be fostered (e.g., Lattuca et al., 2013; Tong, 2010).

Disciplinary knowledge integration is the defining characteristic of interdisciplinarity (Klein, 1990). As in multidisciplinarity, in interdisciplinarity the relevant knowledge elements of each discipline are summarized. However, interdisciplinarity includes the extra step of integrating the identified disciplinary knowledge elements to bring about an advance in understanding. This is called interdisciplinary thinking (IDT) (Boix Mansilla & Duraising, 2007; Eisen et al., 2009). The ease with which disciplinary knowledge integration occurs depends on the conceptual distance between the disciplines. Likewise, the integration of knowledge across sciences requires more cognitive strategies compared to the integration of knowledge within a single science (Mingers & Brocklesby, 1997). Disciplinary knowledge integration between natural sciences and social sciences is essential for engineering students engaged in analysing and solving complex problems in socio-technical systems (e.g., Lund, Coleman, Gunnarsson, Calvert Appleby, & Karkinen, 2006; Luning & Marcelis, 2006; Lyall & Meagher, 2012). The learning of this so-called 'broad IDT' (Newell, 2007) in HEE requires teaching strategies that foster these broad IDT learning processes (Spelt, Biemans, Luning, Tobi, & Mulder, 2010). In particular, teaching strategies such as helping engineering students to move beyond their disciplinary comfort zones and to tackle disciplinary conflicts, such as conflicting use of concepts between disciplines (Repko, 2012), are required.

A range of publications on the teaching and learning of IDT exists in scientific literature (e.g., Boni et al., 2009; Chanan et al., 2012; Gouvea et al., 2013; Hooker et al., 2014). These publications focus either on organizational matters between faculties (e.g., Franks et al., 2007; Liebert, 2013; Lok, 2008), or teachers' experience of instructional designs (e.g., Goodman & Huckfeldt, 2013; Linn et al., 2006; Pharo et al., 2012; Rhee et al., 2010), or students' perceptions of interdisciplinary learning environments (e.g., Fortuin et al., 2013; Gero, 2013; Mobley et al., 2014; Ng et al., 2011). However, fewer publications focus on IDT learning processes (Boix Mansilla, 2010; Graybill et al., 2006; Haynes & Brown Leonard, 2010; Holley, 2013; Ivanitskaya et al., 2002). Investigating these student learning processes affords scientific insight into students' experience of their IDT learning. In turn, this insight enables greater alignment between teaching and learning of IDT in HEE.

Existing publications on IDT learning processes (Boix Mansilla, 2010; Graybill et al., 2006; Haynes & Brown Leonard, 2010; Holley, 2013; Ivanitskaya et al., 2002; Lattuca et al., 2004) recognize the challenges faced by students in acquiring the interdisciplinary research principles and in growing intellectually during IDT learning processes. This previous research mainly investigated long-term learning processes (e.g., Ivanitskaya et al., 2002) such as curricula, with a duration of at least one year, and to a lesser extent short-term learning processes (Lattuca et al., 2004) such as courses, with a duration of at least one month. In view of the few available research on short-term learning processes (Morrison, 2015), the learning of students in interdisciplinary courses in HEE such as environmental sciences education (Fortuin et al., 2013) is not yet well understood. However, it is known from teaching practice that students, engaged in those courses, experience these short-term interdisciplinary learning processes as valuable though hard (Eisen et al., 2009; Richter & Paretti, 2009; Spelt, Luning, Van Boekel, & Mulder, 2015). A characterization of these short-term learning processes by analysing the experience of students would provide scientific understanding on key experiences from students' point of view. In turn, the gain in scientific understanding on these key experiences enables teachers of these interdisciplinary courses to tailor their teaching. Furthermore, once these short-term learning processes can be measured via a standardized method, effect studies between, for instance student characteristics and IDT learning can be investigated (Spelt et al., 2009). Therefore, the present research aim was to analytically characterize short-term learning processes to better understand student IDT learning. In order to find out which theory would be suitable for such an analytical characterization that is conducted for the first time (Haynes & Brown Leonard, 2010), the previous research on IDT learning processes was used as starting point.

4.2 State of the art on learning processes and outcomes in interdisciplinary thinking

This chapter describes the scientific understanding on IDT learning outcomes as found in literature (chapter 4.2.1), the publications found on long-term learning processes (chapter 4.2.2), and the publications found on short-term learning processes (chapter 4.2.3).

4.2.1 Learning outcomes in interdisciplinary thinking: A complex cognitive skill

Previous research conceptualized IDT learning outcomes as the demonstration of a complex cognitive skill (Van Merriënboer, 1997) that constitutes of five subskills (Spelt et al., 2009). These five subskills are: (1) having knowledge of disciplines, (2) having knowledge of disciplinary paradigms, (3) having knowledge of interdisciplinarity, (4) higher-order cognitive skills such as integrating the disciplinary knowledge, and (5) communication skills. The first three subskills relate to the acquisition of particular knowledge and the fourth and fifth subskills relate to the acquisition of particular skills. Hence, the complex cognitive skill of IDT includes the combination of particular knowledge and skills that students have to enact to demonstrate IDT. For instance, students capable of IDT demonstrate, on the one hand, disciplinary knowledge of relevant disciplines and, on the other hand, skills to integrate disciplinary knowledge in a meaningful way. En route to becoming an interdisciplinary thinker, the relationships of the acquisition between the five subskills and IDT learning outcomes are still unknown.

4.2.2 Long-term (curriculum-related) learning processes on interdisciplinary thinking

Previous research on characterizing IDT learning processes focussed mainly on long-term (curriculum-related) learning processes (Boix Mansilla, 2010; Graybill et al., 2006; Haynes & Brown Leonard, 2010; Holley, 2013; Ivanitskaya et al., 2002). These characterizations feature different theoretical frameworks and research approaches. In particular, Ivanitskaya and colleagues (2002) conceptualized stages of interdisciplinary learning based upon the Structure of the Observed Learning Outcome (SOLO) taxonomy of Biggs & Collis (1982). Additionally, Graybill and colleagues (2006) identified three stages of intellectual growth in their graduate curricula based upon their own graduate experiences. Haynes and Brown Leonard (2010) categorized student experiences using a cognitive-constructive developmental lens, whereas Boix Mansilla (2010) proposed empirical investigation using a pragmatic constructionist lens. Recently, Holley (2013) analysed doctoral student learning experiences using the lenses of doctoral student socialisation and identity development. The aforementioned research does not include the learning of IDT learning outcomes nor the recommended constructively aligned instructional designs (e.g., Lattuca et al., 2013; Stefani, 2009). The influences of constructively aligned instructional designs on IDT learning processes are therefore still unknown.

4.2.3 Short-term (course-related) learning processes on interdisciplinary thinking

Previous research on short-term (course-related) IDT learning processes showed that short-term interdisciplinary learning processes are likely to have various kinds of learning outcomes (Lattuca et al., 2004). The initial exploration of Lattuca et al. (2004) did not specifically address the learning processes of IDT learning outcomes as described in chapter 4.2.1 and did not address the student's point of view. The experiences of students engaged in short-term learning processes of IDT are therefore still unknown.

4.3 Theoretical framework of present research

Since previous research on IDT learning processes did not suggest any theory suitable for the present analytical characterization, the full range of literature in educational sciences was explored. As a result of this exploration, the learning theory of Illeris (2002, 2007) was chosen to be the theoretical framework of the present research for its integrative viewpoint to learning. This is because working in interdisciplinary teams mirrors the three interrelated learning dimensions of this theory. More specifically, working in interdisciplinary teams requires disciplinary knowledge acquisition (content dimension), the exchange of emotions (incentive dimension), and the exchange of experience of moving across disciplines (interaction dimension). The nature of interdisciplinary vocational practice, such as complex problem solving in interdisciplinary teams, requires engineers to develop themselves in these three dimensions.

The learning theory of Illeris (2002, 2007) conceptualizes learning as three interrelated dimensions: content, incentive, and interaction. The *content* dimension refers to the content to be learnt; it involves the cognitive part of the learning process of acquiring disciplinary knowledge. The *incentive* dimension refers to the mobilization of energy; it involves the emotional part of the learning process of motivating oneself to acquire knowledge across disciplines. The dimension of *interaction* refers to the interactions with the environment; it involves the social part of the learning process of acquiring knowledge about interdisciplinarity in collaboration with peers. In contrast to the theories of Piaget, Vygotsky, and Dewey, which considers the cognitive, emotional, and social processes separately, the learning theory of Illeris takes an integrated view of learning.

The integrated view inherent in Illeris's learning theory (2002, 2007) can likely be used to characterize short-term IDT learning processes in HEE, because IDT learning requires cognitive strategies (content dimension), emotional appraisals (incentive dimension), and social interactions (interaction dimension). It might be that particular interplays between the content, incentive, and interaction dimensions influence the IDT learning processes of students. Once these interplays are understood, teachers can adjust their strategies, thereby enhancing IDT learning in HEE. To our knowledge, the scientific literature does not, as yet, provide any empirical evidence of the characterization of short-term IDT learning processes in HEE using the theory of Illeris. Therefore, the following research questions were investigated:

1. To what extent can short-term IDT learning processes in HEE be characterized in terms of the content, incentive, and interaction dimensions?
2. Which key learning experiences feature IDT learning by students in HEE?

These questions were explored for learning processes with respect to the interdisciplinary field of food quality management (FQM).

4.4 Method

4.4.1 Research context: The course characteristics

The FQM course requires students to apply the ‘Techno-Managerial approach’ (T-M approach) (Luning & Marcelis, 2009a). The T-M approach integrates disciplinary knowledge from technological disciplines such as food microbiology and management disciplines such as psychology (Luning & Marcelis, 2006, 2009b), and is a particular type of broad IDT in which knowledge from disciplines in natural sciences and social sciences is integrated. The intended learning outcome on IDT was: ‘At the end of this FQM course, the student will be able to apply IDT to FQM problems by using the T-M approach in the four phases of the interdisciplinary research methodology’. The four phases are (Luning & Marcelis, 2009b): (1) the appreciation phase, in which the complex problem is appreciated from an interdisciplinary techno-managerial perspective, (2) the analysis phase to analyse the problem situation in more depth using the chosen techno-managerial disciplines, (3) the assessment phase to assess the problem situation in order to identify potential causes of the complex problem, and (4) the evaluation phase to evaluate the solutions determined. The course task considered an ill-defined FQM problem in a simulated food company and the students were instructed to solve this problem via the conduct of these four phases. The problem-centring way of teaching was identified by Nikitina (2006) as one of the pedagogies for interdisciplinary learning. The course task was an individual student task to make sure that each student was engaged in the disciplinary knowledge integration. However, students also worked in groups, which were called 'learning communities', to share their experience on interdisciplinary research and to provide feedback on each other's research work. Two teachers, one teacher (second author) of the natural sciences, and one teacher of the social sciences (not in author team) provided pedagogical support to the students on the conduct of the problem-solving task and the achievement of the interdisciplinary learning goals.

Prior to the present research of characterizing the learning processes, the course was redesigned using the constructive alignment theory of Biggs and Tang (2007, 2011) and heeding multiple recommendations (e.g., Borrego & Cutler, 2010; Gharaibeh et al., 2013). This redesign was expected to be beneficial to the present research; it enables a characterization of learning processes in a systematically designed and consistent learning environment. In addition, the learning environment was student-driven and aiming to help students in achieving the IDT learning outcomes. For example, the self-assessment was designed to let students reflect themselves on their IDT learning in the context of their future profession as food quality managers. The pedagogical support by the teachers specific fostering the IDT learning was providing examples of possible disciplinary knowledge connections, explaining the interdisciplinary research principles, and giving feedback on student decisions and actions. The interdisciplinary course on FQM is provided at a European university of Life Sciences. The FQM course is part of an interdisciplinary master's curriculum on FQM which is also provided by this university.

4.4.2 Data collection

The data collection of learning experiences took place via reflective learning journals. The reflective journals were used to gain insights into student learning processes and were simultaneously used as a supportive tool to encourage students to adopt a critical attitude (e.g., Brookfield, 1995; Langer, 2002; Nardone & Lee, 2011; Woods, 2007). This encouragement is necessary to awaken student awareness of the particular relevancy of disciplinary knowledge in interdisciplinary research (Boix Mansilla & Duraising, 2007; Repko, 2012). Students were engaged in writing these reflective journals via their individual problem-solving task. This problem-solving task included eight assignments and five of these eight assignments asked for a separate reflection activity on the achievement of the IDT learning outcomes.

Students were two times plenary instructed on the writing of these learning journals. They received instruction on the journaling activity itself and on its purpose to enhance interdisciplinary learning. The report of the journal was pre-structured into the report of two positive and two negative experiences. The two positive and two negative experiences were recorded in the journals in order to ensure that the analytical characterization would be based on a full range of experiences, regardless of the value students assigned to their experience. It was expected that a set of positive and negative experiences would increase the validity of the analytical characterization. Students were free to choose themselves on which learning experience they that would like to report on and to assign it as either positive or negative. The data were digitally collected five times among 30 students; in total 615 experiences were collected and each reported learning experience counted for one unit of analysis. The course took twelve weeks and the data collection was spread almost equally over these weeks. The population of 30 students ranged in age from 23 to 41-years-old, where 22 students were women and eight were men, and 13 nationalities were represented. All 615 experiences collected were processed anonymously.

4.4.3 Data analysis

Two types of data analysis were performed: protocol coding and pattern coding. The protocol coding involved categorizing the data using pre-determined codes (Miles, Huberman, & Saldaña, 2013). The first author coded all 615 experiences by using the learning dimensions as a code. In particular, the code *content* referred to cognitive issues such as ‘I learnt to integrate the different disciplinary knowledge’. The code *incentive* referred to emotional issues such as ‘it was so difficult to integrate the different disciplinary knowledge’. Additionally, the code *interaction* referred to interaction issues such as ‘the feedback from my peer students improved the disciplinary knowledge connections made’. The protocol coding was done on each occasion of data collection ($t_1 – t_5$) using the qualitative data analysis software program MAXQDA 11 and resulted in frequency distributions (Reid, 2014).

The protocol coding was carried out twice to validate the coding procedure. The percentage of agreement was 87% for t_1, 85% for t_2, 89% for t_3, 88% for t_4, and 82% for t_5. A rule of thumb is that the percentage of agreement should be between 85 and 90% depending on the size and range of the coding scheme and the items to be coded (Miles et al., 2013). The learning experiences that were coded differently were read again to reach agreement on the best fit between learning experience and code. This re-reading resulted in 16 changes to the content code, 31 changes to the incentive code, and 15 changes in the interaction code.

The second part of the data analysis involved pattern coding to identify patterns across the reported experience. Pattern coding is a second-cycle coding method in which meaningful blocks of data are clustered together into a smaller number of themes (Saldaña, 2009). The data on learning dimensions for each data collection occasion were clustered into data sub-sets on major themes. The identified themes were labelled, at a higher level of aggregation, namely as key experiences of IDT learning. Only those experiences that reflected a pattern were clustered and labeled.

4.5 Results and discussion

This chapter describes the first impression on the collected data of experiences during IDT learning in chapter 4.5.1. In chapters 4.5.2 and 4.5.3, the results on the analytical characterization for research question 1 and, respectively, research question 2 are described.

4.5.1 First impressions

The reading of learning journals revealed variation in how a single experience was valued by students. The following example shows how two students valued the same learning experience of ‘the identification of consequences for potential solutions to the FQM problem’. The report designated as positive by the student was: *“After some initial doubts, I was finally able to justify my strategy taking into account the managerial consequences of my strategy and the technological consequences of my managerial considerations. I could also find some more considerations that came up while regarding [with respect to] the strategy as a whole* *and not only with [for] the separate sub-solutions, so I consider that I had covered all the possible implications"*. The report designated as negative by the student was: *"Finding technological consequences for [of] managerial solutions and vice versa was a challenge. For example, finding the technological consequences for [of] putting in place [a] training system based on [...] best practices"*. A possible explanation of this difference in value accorded to the same kind of learning experience might be that the second student perceived the experience of integrating disciplines as frustrating rather than recognizing it as the hard and fruitful work inherent in interdisciplinarity. According to Rives-East and Lima (2013), this value difference can also happen in interdisciplinary learning situations in which students start by negatively valuing learning situations as a result of their resistance and fear to learn new habits instead of positively valuing learning situations as a result of their efforts to step outside their disciplinary comfort zones. The effort made to step outside the disciplinary comfort zone consists of recognizing connections between disciplines and confronting complex problems that have 'no right answer'. These efforts require a relatively high tolerance of ambiguity by engineering students as compared to learning situations in which students can 'stay' in their disciplines.

The learning journals also showed that students reported on activities that are necessary to achieve the IDT intended learning outcomes in FQM. For example, one student reported: *"I still have difficulties in noticing whether the factors are managerial or technological ones. In my view, these two areas are often blurred, and the distinction are [is] unclear to me because they influence each other"*. This learning experience illustrates student's attempt to identify mutual dependencies of technological and managerial factors. In addition, one student reported: *"The research concerning the [food] quality behaviour where I have [to] figure out the importance of people [behaviour] have [has] an influence on the quality of the end product. More precisely, I have been fascinated by the different background people have (for* *instance, culture, attitude, motivation, and expectancy) and how they represent a dynamic factor to [be] take[n] into account besides the food dynamic [behaviour]"*. This learning experience illustrates the student's awareness of the influence of human characteristics (managerial perspective) in addition to food characteristics (technological perspective) on the final quality of food products. Both report examples show students engaged in IDT learning. Similar to the findings of Haynes and Brown Leonard (2010), and Wright (2005), changes in how students formulated their experiences indicated that they were changing their thinking during the IDT learning processes. In this respect, the observed change in thinking evolved from technology-oriented to include managerial-oriented, and vice versa. Moreover, it evolved from a disciplinary perspective to multidisciplinary perspectives and, eventually, to realizing how to integrate knowledge of technological and managerial disciplines.

The learning journals also showed that students reported on the four phases of the interdisciplinary research process in FQM (see chapter 4.4.1). In the first FQM phase, students appreciated the opportunity to apply knowledge of previous disciplinary courses to a real-world situation and to start searching for disciplinary knowledge within the technological and managerial disciplines in order to demarcate the FQM problem. Students also attempted in the first FQM phase to clarify what was actually expected and they realized that their peers were facing similar struggles in conducting interdisciplinary research. In the second and third FQM phases, students expressed the challenges they faced in connecting the technological and managerial factors into a conceptual model representing the FQM problem. They also expressed their relief at their advance in understanding of the impact of decision-making in the previous research steps on the next steps. In the fourth FQM phase, students emphasized their advancement in understanding of how to conduct interdisciplinary research and figure out the best solution to the FQM problem in a systematic way.

4.5.2 Analytical characterization (*research question 1*)

The analytical characterization of the short-term IDT learning processes indicated the interplay of content, incentive, and interaction dimensions. For instance, students reported on their differing levels of prior knowledge of technological and managerial disciplines (content) and on their frustrations at the disciplinary differences they encountered in how to identify factors influencing the complex problem under study (incentive), which prompted numerous discussions with peers and teachers to find ways to connect these disciplines (interaction). Table 4.1 provides illustrations of reported experiences per code. The first illustration for the content code shows a gain in understanding, while the second illustration for the incentive code shows drivers for motivation, and the third illustration for the interaction code shows the social interaction between teacher and student.

Table 4.1 Illustrations of reported learning experience per code

Code	Illustrations of reported learning experience
Content	"By searching for models, describing the essence and usefulness, I gained a deeper understanding of the linkage of T[echnological and M[anagerial] factors in models, they are not independent"
Incentive	"In these two first assignments knowledge from the past and experiences I had, emerged to the surface. The fact that you deal with a possible real problem in a company intrigues me and motivates [me] to deepen my knowledge in scientific areas that I wasn't familiar with"
Interaction	"Trying to overcome the language barrier that has become very evident between me and my teacher during teacher feedback session"

The protocol coding of the 615 experiences resulted in 194 experiences being coded as content, 214 experiences being coded as incentive, and 207 experiences being coded as interaction. The content, incentive, and interaction dimensions were equally addressed by the students during their learning processes, considering an analysis error rate of about 20% (see chapter 4.4.3). Figure 4.1 presents the frequency distribution of reported experiences by students per code and per occasion of data collection. Considering an analysis error rate of about 20%, there are no obvious differences in the variations between the reported experiences per learning dimension over time.

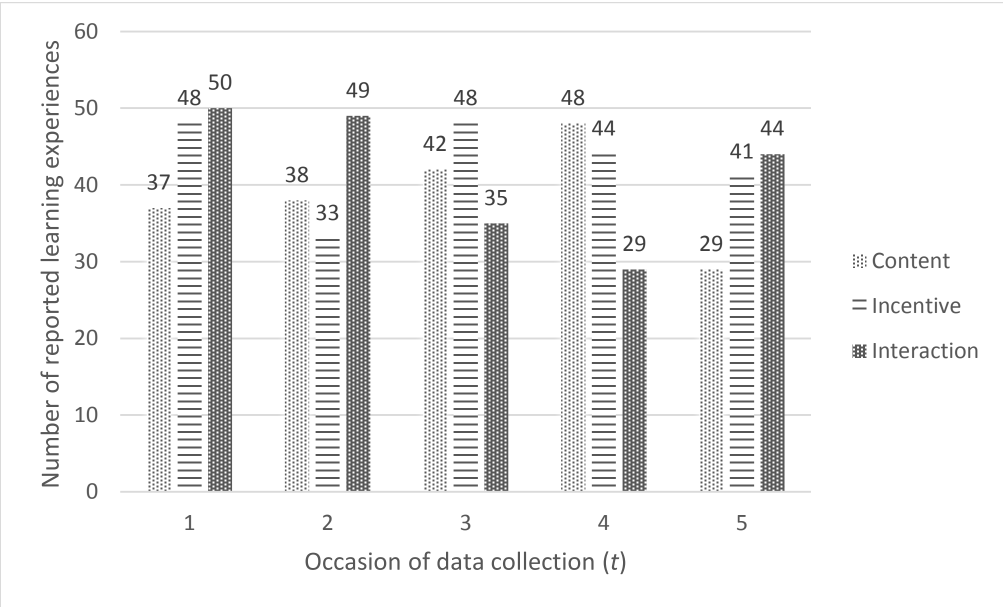


Figure 4.1 The frequency distribution of student report per code (content, incentive, and interaction) and occasion of data collection ($t_1 - t_5$)

Table 4.2 presents the number of experiences for each code over time categorized as positive and negative experiences. Remarkably, the results showed that relatively more positive experiences were coded to the content dimension (159 of 194) than to the incentive dimension (71 of 214) and to the interaction dimension (78 of 207). Apparently, students appreciated the cognitive part more than the emotional and social parts of the learning processes. A possible explanation for this might be the emotion transition observed by D' Mello and Graesser

(2012) that confusion in learning can be transformed either into engagements/flows or into frustrations leading to boredom. In IDT learning, the necessary disciplinary boundary-crossing often gives rise to confusion. Since disciplines have different jargon, methods, epistemological viewpoints and so forth, students get often confused once they start crossing disciplinary boundaries and start asking themselves ‘what is a discipline?’, ‘what is seeking the truth in science?’, and ‘how do I perceive the disciplinary differences?’ As Perry jr. (1999) described in general and as Lattuca et al. (2004) described for interdisciplinary higher education, these kinds of questions are evidence that students are growing intellectually, from the phase ‘dualism’ (i.e., students are able to make distinctions in ‘right’ or ‘wrong’), via the phase ‘relativism’ (i.e., students are able to judge multiple perspectives) to the phase ‘commitment’ (i.e., students are able to commit to personal perspectives).

Table 4.2 Number of learning experiences per code, value, and occasion of data collection ($t_1 - t_5$)

		Occasion of data collection					
Code	Value	t_1	t_2	t_3	t_4	t_5	Total
Content	Positive	32	34	36	36	21	159
	Negative	5	4	6	12	8	35
Incentive	Positive	15	11	12	13	20	71
	Negative	33	22	36	31	21	143
Interaction	Positive	20	15	15	11	17	78
	Negative	30	34	20	18	27	129

However, this confusion is apparently perceived by students as negative and may lead to frustrations and finally to boredom. In contrast to this, from the teacher’s point of view, confusion can be seen as valuable to student intellectual growth, especially when it develops into higher interdisciplinary engagements and ongoing learning flows. Hence, teaching strategies should focus not only on cognitive interventions, but also on incentive and social interventions in order that the student's confusion (D' Mello, Lehman, Pekrun, & Graesser, 2014) may be steered in a such a way that IDT learning is fostered. In turn, an increase in teaching focus on these interventions gives meaning to the confusion in students' minds and leads to smooth IDT learning processes.

4.5.3 Key experiences (*research question 2*)

Table 4.3 shows the key experiences in IDT learning identified for the four FQM research phases (see chapter 4.4.1). The identified key experiences for the three dimensions indicate multiple interrelationships. To illustrate, the identified key experiences on the content dimension indicate that learning process characteristics such as combining different disciplinary knowledge into a visual presentation showing the relationships, and recognizing the ambiguity of interdisciplinary research are present during IDT learning. In line with these process characteristics, the identified key experiences on the incentive dimensions indicate learning process characteristics that reflect the ambiguity of finding and selecting the relevant disciplinary knowledge, and the linking of disciplinary knowledge in meaningful connections to advance the understanding towards a solution. Additionally, the interaction dimension indicate the process characteristics of interacting with the other disciplinary viewpoints and dealing with the time constraints, which are also inherent to interdisciplinary research (Sharp, 2015). Obviously, some key experiences reflect previously reported challenges in conducting interdisciplinary research (Golde & Alix Gallagher, 1999; Lach, 2014). For example, working across disciplines involves undertaking research in the absence of established frameworks, which results in the challenge to develop new analytical frameworks (see Table 4.3, incentive dimension, FQM phase 1).

Table 4.3 Overview of key learning experiences per FQM research phase and learning dimension

FQM research phase	Key learning experiences per learning dimension
	Content learning dimension
1	Understanding how to apply theoretical models or concepts to real-world situations
	Becoming aware of disciplinary contributions to the analysis of complex problems
2	Developing searching skills for acquiring disciplinary knowledge
	Designing conceptual models representing disciplinary interrelationships
3	Realizing the essence of all interdisciplinary research steps to be taken
	Recognizing changes due to advanced insights into the interdisciplinary research
4	Recognizing that answers can be based upon various uses of disciplinary knowledge
	Understanding the logic of interdisciplinary research and the pitfalls involved
	Incentive learning dimension
1	Frustrations in selecting and matching disciplinary knowledge to complex problems
	Feeling ambiguous about not having a clear view on how to frame complex problems
2	Irritation at the lack of the disciplinary knowledge to analyse complex problems
	Struggling to put different knowledge elements together in a meaningful way
3	Facing challenges in getting the exact information to diagnose complex problems
	Feeling relieved at what has been achieved compared to the intensive efforts
4	Mixed feelings about the integration of disciplinary solutions into one solution
	Feeling happy about the systematic manner and consistency in finding solutions
	Interaction learning dimension
1	Dealing with scheduled time for searching literature for various disciplines
	Socially engaging with peers to recognize similarities in perceptions and experiences
2	Dealing with lack of time in doing interdisciplinary research
	Socially engaging with teachers to receive feedback on being on the ‘right’ track or not
3	Dealing with the time needed to understand different viewpoints held by others
	Socially engaging with others to share the taken approach, arguments, and decisions
4	Interacting with literature to reach balanced disciplinary overviews
	Spending time on reviewing and finding arguments to construct a solid argument

4.6 Conclusions and further research

The present research concludes that short-term IDT learning processes for the FQM course in question can be divided into the content (194 out of 615 experiences), incentive (214 out of 615 experiences), and interaction (207 out of 615 experiences) dimensions *(research question 1)*. The present research concludes that the content, incentive, and interaction dimensions were equally addressed by the students during their learning processes. Additionally, the present research concludes that for the FQM course the cognitive part of the learning processes (content dimension) is more highly appreciated, relatively speaking, by the students than the emotional (incentive dimension) and social (interaction dimension) parts of the learning processes. Furthermore, the present research concludes that there are 24 key learning experiences featuring the IDT learning processes of students engaged in the FQM course *(research question 2)*. Lastly, the research concludes that the present use of the journaling research method seems to be suitable for its purpose of analytically characterizing learning processes aiming at the achievement of specific learning outcomes.

Further research is recommended to validate the results gained; replication studies are necessary in a wider context, which would lead to multiple researchers characterizing short-term IDT learning processes. Replication studies involving new cohorts of students on FQM courses or with other interdisciplinary courses are recommended in order to evaluate the representativeness of the results gained. Another research recommendation is that relationships between the analytical characterizations of IDT learning processes and the analytical characterizations of IDT learning outcomes be investigated. It is also recommended that research be extended on the relationships between IDT learning processes and instructional constructively aligned designs (e.g., Fiegel, 2013), and IDT learning processes and personality characteristics (e.g., Gardner, 2008; Morse, Nielsen-Pincus, Force, &

Wulfhorst, 2007; Repko, 2012), and IDT learning processes and solving complex problems (e.g., Hmelo-Silver & Azevedo, 2006). Lastly, the learning dimensions of Illeris's theory provided an univocal coding frame. The variations in coding (see chapter 4.4.3) are likely due to the existing dualism in coding (Schreier, 2012). This dualism relates to whether coding is based on the manifest or literal meaning (meaning that is obvious at first sight) or the latent meaning (meaning that is not immediately obvious). This dualism should also be further investigated.

4.7 Implications

The present exploration suggests the importance of tailoring the teaching to the three learning dimensions in order to enhance IDT learning. Generally speaking, teachers in HEE tend to focus more on the cognitive part of the learning processes rather than on the emotional and social parts of the learning processes. Table 4.4 presents a set of teaching strategies per learning dimension in accordance with the key experiences identified (Table 4.3). It is expected that these teaching strategies, as shown in Table 4.4, will help teachers to equally address the cognitive, emotional, and social parts of the IDT learning processes, so that the learning of students is enhanced.

Table 4.4 Overview of teaching strategies per FQM research phase and learning dimension

FQM research phase	Teaching strategies per learning dimension
	Content learning dimension
1	Facilitating students' linking of theory or disciplinary knowledge to practice
	Facilitating students' expansion of the disciplinary lenses to gain a wider perspective on complex problems
2	Facilitating students in gaining awareness of the various strategies to use in searching disciplinary knowledge
	Facilitating students in structuring and adequately conceptualizing all the disciplines used
3	Facilitating students in switching between the perspective of the research as a whole and the perspective of each research step
	Facilitating student awareness that interdisciplinary research changes due to disciplinary contributions
4	Facilitating students in creating multiple answers by integrating disciplinary knowledge in various ways
	Facilitating students in becoming aware of interdisciplinary research opportunities and limitations
	Incentive learning dimension
1	Facilitating students in recognizing opportunities for using disciplinary knowledge in interdisciplinary research
	Facilitating students in finding scientific and practical arguments to frame complex problems
2	Facilitating students in being creative in bridging the knowledge gap and explaining what has been done
	Facilitating students in listing items of disciplinary knowledge and then identifying relationships between these items
3	Facilitating students to deal with the uncertainty involved in data gathering across disciplines or departments
	Facilitating student awareness of the usefulness of each step or challenge in interdisciplinary research
4	Facilitating student recognition of the dynamics of real-world situations and causal loops
	Facilitating students' emotional releases by reflecting upon the 'bumpy' but worthwhile journeys undertaken
	Interaction learning dimension
1	Facilitating students in managing the scope and purpose of literature searches in order to steer the search activities
	Facilitating students in being open to learning from peer perceptions and experiences
2	Facilitating students in adopting a helicopter view of the interdisciplinary research and the disciplinary contributions
	Facilitating student discussion of whether the 'right track' exists or that 'it all depends'
3	Facilitating students' ability to switch easily between the various viewpoints of others in order to check their own viewpoint
	Facilitating students in being able to justify decisions made and to compare the issues and arguments raised
4	Facilitating students in zooming in and out of disciplinary focus at different levels of abstraction
	Facilitating students' ability to revise a viewpoint using logic and facts as a basis for reasoning

Chapter 5

Learning challenges, student strategies, and the outcomes of education in interdisciplinary thinking

Abstract

The teaching of interdisciplinary thinking (IDT) in higher education in engineering (HEE) is necessary to prepare students for working in interdisciplinary teams. While research on IDT teaching is steadily increasing, research on IDT learning is lagging behind. Therefore, the present research examined IDT learning processes with respect to the challenges, strategies, and outcomes involved, using two theoretical perspectives. The research context was an interdisciplinary graduate course on food quality management (FQM) in which students had to solve an authentic complex problem. A constructively aligned course design was implemented and reflection journals were developed to enable students to reflect upon their challenges, strategies, and outcomes during IDT learning. The results showed that students tend to report more on the *content*-related and *interaction*-related challenges than on the *incentive*-related challenges. Students also tend to report more on the disciplinary knowledge connections *technological conditions–human dynamics* and *technological conditions–administrative conditions* than on the *food dynamics–human dynamics* and *food dynamics–administrative conditions* disciplinary knowledge connections in FQM. Replication studies to validate these empirical results across HEE are recommended. The present research suggests the importance of the provision of pedagogical support in coping with challenges and with making disciplinary knowledge connections during IDT learning.

This chapter has been submitted for publication as:

Spelt, E. J. H., Luning, P. A., Van Boekel, M. A. J. S., & Mulder, M. (under review for publication). Learning challenges, student strategies, and the outcomes of education in interdisciplinary thinking

5.1 Introduction

The learning of interdisciplinary thinking (IDT) is necessary to prepare students in higher education in engineering (HEE) for their job requirements (Adams, 2007; Andrade et al., 2014; Chanan et al., 2012; Haase et al., 2013; Mascarelli, 2013; McGregor, O'Shea, Brewer, Abuodha, & Pharo, 2014; Redish & Smith, 2008; Schaefer et al., 2012; Vale et al., 2012), which are: complex problem-framing (Eisen et al., 2009; Pharo & Bridle, 2012), complex problem-solving (Fortuin et al., 2013), innovating new products and processes (Cantillon-Murphy, McSweeney, Burgoyne, O'Tuathaigh, & O'Flynn, 2015; Linnemann et al., 2011), and analysing phenomena (Repko, Newell, & Szostak, 2012). These requirements necessitate that engineers have skills in working in interdisciplinary teams and across disciplinary departments, and that engineers have skills in integrating disciplinary knowledge (Schmidt et al., 2012; Sharp, 2015). In other words, engineers need to be practitioners of IDT (Augsburg et al., 2013; Eisen et al., 2009; Lattuca et al., 2013). However, this practice is experienced as being challenging. The challenges include language barriers, epistemic differences, a lack of mutual respect, and a lack of willingness to learn from each other (Bossio, Loch, Schier, & Mazzolini, 2014; Davidson, 2015; Golde & Alix Gallagher, 1999; Lach, 2014; Morse et al., 2007; Nikitina, 2005; Nuijten, 2011; O'Rourke et al., 2013; Sill, 2001; Thompson, 2009; Turner, Benessaiah, Warren, & Iwaniec, 2015). Smooth interdisciplinary teamwork is fostered once engineers are capable of coping with these challenges (Bruce et al., 2004; Lyall & Meagher, 2012; Öberg, 2009). Learning how to cope with these challenges should therefore start early in HEE (Fortuin et al., 2013; Lund et al., 2006; MacKinnon et al., 2013; Tong, 2010).

However, student learning of IDT in HEE is yet not well understood due to limited empirical research (Lattuca et al., 2004). IDT has been defined as the ability to integrate knowledge of more than one discipline to produce a cognitive advancement that would have been impossible within a single discipline (Boix Mansilla et al., 2000). IDT learning outcomes are demonstrations of this integrative ability; they involve the demonstration of a complex cognitive skill (Van Merriënboer, 1997) constituting five subskills, namely: (1) knowledge of disciplines, (2) knowledge of disciplinary paradigms, (3) knowledge of interdisciplinarity, (4) higher-order cognitive skills, and (5) communication skills (Spelt et al., 2009). This means that students in HEE need to acquire particular kinds of knowledge and skills before they are able to practise IDT. The conceptual distance between the disciplinary knowledge determines the ease with which IDT is practised. Narrow IDT is the name given when the conceptual distance is relatively small and broad IDT when the conceptual distance is relatively great (Newell, 2007). Students in HEE need to learn broad IDT, specifically the ability to integrate disciplinary knowledge of natural and social sciences (Lund et al., 2006; Lyall & Meagher, 2012; Mobley et al., 2014; Schmidt et al., 2012; Spelt et al., 2010). This need necessitates the scientific understanding of student learning on broad IDT in HEE.

The distinction between the learning outcomes on multidisciplinary thinking and IDT is the integration of disciplinary knowledge (Klein, 2010). With multidisciplinary thinking, the disciplinary knowledge is summarized, and may be supplemented with an overview of similarities and differences in disciplinary knowledge, however, no integration of knowledge takes place, let alone advances understanding. The difference between multidisciplinary thinking and IDT is reflected in student learning outcomes in HEE. Student learning outcomes on multidisciplinary thinking (e.g., a report or a presentation) shows the knowledge of the disciplines one by one, without any attempt to link, to connect, and to integrate the knowledge (Klein, 2005). More specifically, the multidisciplinary thinking outcome involves the *analysis* element of cognitive endeavour, while the IDT outcome involves the *analysis* and the *synthesis* elements of cognitive endeavour. The synthesis element is concerned with (a) demonstrating the linkages between the disciplinary knowledge, (b) explaining the disciplinary knowledge connections, and (c) describing the advancements in understanding. Students in HEE require the opportunity to practise the *analysis* and *synthesis* cognitive endeavours during their learning to achieve the IDT learning outcomes.

The integration or synthesis cognitive endeavour is seen as the defining characteristic of interdisciplinary outcomes (Klein, 1990). The integration or synthesis of the disciplinary knowledge should provide a more holistic understanding or an enriched view of the particular phenomenon or the complex problem under study (Richards, 1996). Creativity is necessary to re-order the disciplinary information that was gained in the analytical cognitive endeavour. However, as a rule, students are taught to accept the order of disciplinary knowledge as it is given (Sill, 2001). In re-ordering the disciplinary information, epistemic or language conflicts may occur (Repko, 2012; Turner et al., 2015). The emergence of hybrid understanding manifests itself in the forging of new disciplinary knowledge connections. According to Defila and Di Giulio (2015), disciplinary knowledge connections can be made in various arrangements. For example, in a group of eight disciplinary knowledge elements, the options include connecting pairs of elements and connecting one element with each of the seven others. The best arrangement to apply in connecting the disciplinary knowledge depends on the purpose of the knowledge integration. In this respect, it is not a matter of 'the more disciplinary knowledge connections, the better', rather, it is a matter of the *sufficiency* of the gained advancement in understanding and the *characteristics* of the disciplinary knowledge connections made. The sufficiency and characteristics are constantly improved by revising and questioning the provisional integration made (Nikitina, 2005). Empirical research on making disciplinary knowledge connections by students in HEE has not yet started. Similarly, the phenomenon of disciplinary knowledge integration is also poorly researched (Defila & DiGiulio, 2015; Nikitina, 2005).

To date, research on IDT learning in higher education has focused mainly on long-term (curriculum-related) learning processes (Graybill et al., 2006; Haynes & Brown Leonard, 2010; Holley, 2013; Ivanitskaya et al., 2002). Little research is available on short-term (course-related) learning processes (e.g., Lattuca et al., 2004). For instance, Haynes and Brown Leonard (2010) characterized the long-term learning processes of an undergraduate curriculum using a cognitive-constructivist lens. In addition, previous research on IDT learning (e.g., Boix Mansilla, 2010; Bradbeer, 1999; Holley, 2013) has shown that students face challenges in crossing disciplinary boundaries. One challenge is to understand different disciplinary jargons (Woods, 2007). Another challenge is to understand the various relationships between factors affecting complex problems (Boix Mansilla, 2010). The making of disciplinary knowledge connections themselves is also experienced as challenging (Holley, 2013). The present research aim was to analyse these learning challenges, the student strategies, and the outcomes involved in short-term IDT learning in HEE. A greater understanding of the challenges, strategies, and outcomes would enable teachers in HEE to tailor their pedagogical support to enhance the learning (Haynes & Brown Leonard, 2010; Hmelo-Silver & Azevedo, 2006; Jacobson & Wilensky, 2006). The subject of the analysis was an interdisciplinary graduate course on food quality management (FQM). The FQM course teaches broad IDT outcomes involving the integration of the food technology and management-related disciplines (see chapter 5.2.2) for the purpose of solving food quality problems (Luning & Marcelis, 2006). The empirical research adopted a systematic research approach using two theoretical perspectives to analyse short-term IDT learning processes in HEE.

5.2 Theoretical perspectives

The theoretical perspective of Illeris (2002, 2007) was used to analyse the learning challenges and strategies, and the theoretical perspective of Luning and Marcelis (2006, 2007, 2009a, 2009b) was used to analyse the learning outcomes.

5.2.1 Perspective of Illeris's learning theory

No general framework for analysing the challenges and strategies involved in IDT learning yet exists. Therefore, the perspective of Illeris's learning theory (2002, 2007) was used, describing student learning in terms of three interrelated dimensions: content, incentive, and interaction. In this respect, the *content* dimension refers to the acquisition of disciplinary knowledge necessary to integrate the knowledge (cognitive processes). As Derry et al. (1998, pp. 33-34) has stated, every disciplinary term, for instance, the term 'model', must be clearly understood if the disciplinary knowledge is to be linked successfully. The *incentive* dimension refers to the dealing with emotional turbulence arising from interdisciplinary confusion (emotional processes). In this respect, Boix Mansilla et al. (2012, p. 8) have referred to the emotional turbulence as a 'surprise' or 'painful disorientation' that happens once new disciplinary knowledge conflicts with prior disciplinary knowledge. The *interaction* dimension refers to the multiple interactions with disciplinarians sharing disciplinary knowledge in an open manner in order to learn from each other and to come to a shared understanding (social processes). As Thompson (2009, p. 293) has noted, social processes of shared learning and language exchange in interdisciplinary teams affect the team's ability to communicate effectively in addressing interdisciplinary tasks. Figure 5.1 shows the three learning dimensions; the arrows illustrate the interrelationships between the cognitive, emotional, and social processes of learning.

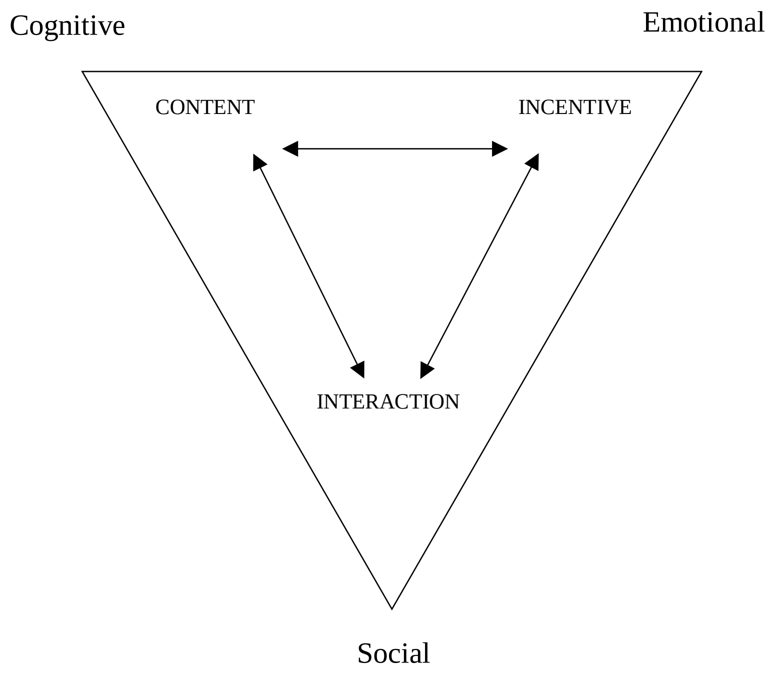


Figure 5.1 Triangle of learning dimensions, based on Illeris (2002, 2007)

The proposed 'socio-emotional-cognitive platform' of successful interdisciplinary collaborations in interdisciplinary teams (Boix Mansilla et al., 2012) resembles the three processes of learning of Illeris. In addition, the short-term IDT learning processes of students in HEE also resemble these three learning dimensions (Spelt, Luning, Van Boekel, & Mulder, under review). Hence, short-term IDT learning processes may also feature multiple challenges on these three learning dimensions. These challenges are then content-related, incentive-related, and interaction-related challenges. A content-related challenge is to connect disciplinary knowledge in a meaningful way, an incentive-related challenge is to release anxiety to cope with the ambiguity inherent to learning across disciplines and the interaction-related challenge is to discuss with disciplinary experts conflicting disciplinary knowledge. Illeris's theory considers the concept of learning to be constructivist in nature, which means that the learner him- or herself constructs his or her learning as mental structures, schemes, and patterns (Illeris, 2003). During IDT learning students are required to 'make meaning' of each new disciplinary knowledge element by adapting their existing mental structures and schemes.

5.2.2 Perspective of Luning and Marcelis's food quality management research principles

No general framework for analysing the disciplinary knowledge connections involved in achieving IDT learning outcomes yet exists. Therefore, the concepts underlying the research principles in FQM (Luning & Marcelis, 2006, 2007, 2009a, 2009b) were used to analyse the knowledge connections made between the food technology and management-related disciplines. To illustrate, disciplinary knowledge connections in FQM between food microbiology (a technology-related discipline) and education (a management-related discipline) need to be made when, for example, a hands-on training in microbial hygiene for factory operators is being designed. The integration of knowledge from technology and management-related disciplines is called the 'techno-managerial approach' (T-M approach) (Luning & Marcelis, 2006). As Milios et al. (2013, p. 1394) empirically found, management commitment (management-related) to food safety policies (technology-related) is essential for the proper implementation of food safety programs.

Luning and Marcelis (2007) have elaborated the T-M approach with a research paradigm in which food quality (*fq*) depends on the dynamics of the food systems, which in turn depend on the composition of the food products (food dynamics, *fd*) and the applied technological conditions (*tc*). In addition, food quality depends on the dynamics of human decision-making behaviour, which in turn depend on personal characteristics (human dynamics, *hd*) and the applied administrative conditions (*ac*). Figure 5.2 illustrates how this research paradigm can be applied to view FQM problems from four perspectives: food dynamics (*fd*) and technological conditions (*tc*), which are technology-related, and human dynamics (*hd*) and administrative conditions (*ac*), which are management-related. As a consequence of the T-M approach, four disciplinary knowledge connections are possible between the technology and management-related disciplines. The arrows in Figure 5.2 illustrate these four connections, which are between (1) food dynamics and human dynamics *(fd–hd)*, (2) food dynamics and administrative conditions *(fd–ac)*, (3) technological conditions and human dynamics *(tc–hd)*, and (4) technological conditions and administrative conditions *(tc–ac)*. Broad IDT learning outcomes in FQM should demonstrate these four kinds of connections.

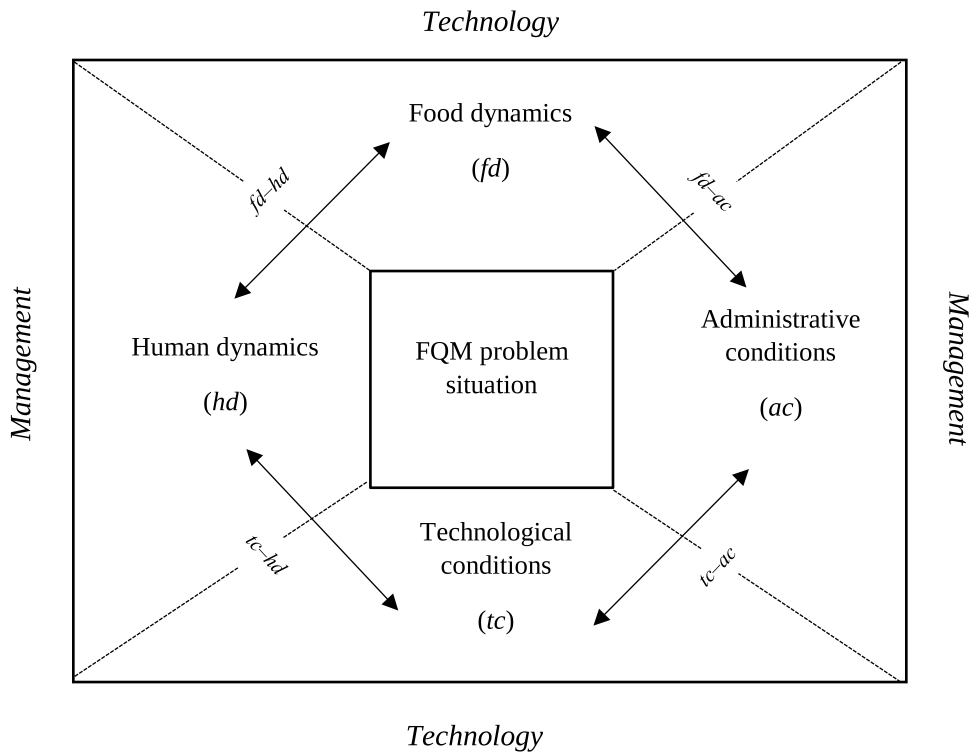


Figure 5.2 Square of knowledge connections, based on Luning and Marcelis (2007)

5.3 Research questions

The present research investigated four research questions:

1. What do students report as challenges (*content-related*, *incentive-related*, and *interaction-related*) in their IDT learning during the FQM course?
2. What do students report as learning strategies to overcome these challenges?
3. What do students report as disciplinary knowledge connections (*fd–hd*, *fd–ac*, *tc–hd*, *tc–ac*) in their IDT learning during the FQM course?
4. What justification do students give for having made these disciplinary knowledge connections?

The data was collected from two journals completed by each of the students, one journal to answer questions 1 and 2 and another to answer questions 3 and 4.

5.4 Method

5.4.1 Research context

The research context featured a constructively aligned instructional design for teaching broad IDT (Spelt et al., 2015). Figure 5.3 provides a simplified representation of this instructional design. The arrows in Figure 5.3 represent the constructive alignment between the four successive learning outcomes in IDT specific to this course, and the teaching, learning, and assessment elements. The four specific outcomes of IDT reflect the interdisciplinary research in FQM. This research involves four research phases (Luning & Marcelis, 2009b) and one specific learning outcome is related to each research phase. The four phases of the interdisciplinary FQM research are undertaken to analyse and solve FQM problems. The first phase is the problem appreciation phase; the second phase, the analysis phase, involves the problem analysis in more depth. In the third phase, the assessment phase, the problem situation is assessed in order to identify solutions, and the fourth phase, the evaluation phase, involves the evaluation of these solutions (Luning & Marcelis, 2009b). The course engaged students in an authentic and ill-structured FQM problem-solving task with particular assignments allocated to each of these four phases. In light of this, the students were engaged on multiple occasions in cognitive endeavours involving IDT analysis and synthesis. This resulted in multiple intermediate reports and in one final individual report. The problem-centred teaching on this course is one of the three pedagogical strategies (i.e., contextualizing, conceptualizing, and problem-centering) that have been identified as appropriate when delivering IDT (Nikitina, 2006).

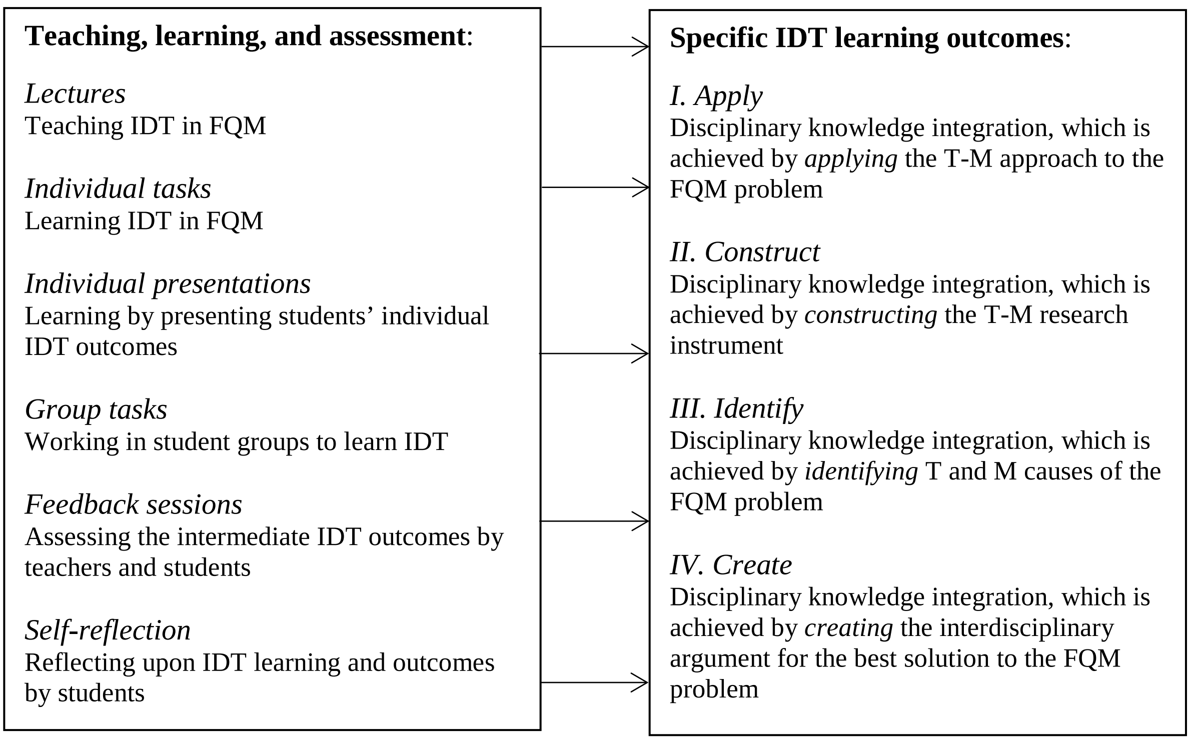


Figure 5.3 Aligned course design for the learning of IDT, based on Spelt et al. (2015)

The overall intended learning outcome of the course on broad IDT was: ‘At the end of this FQM course, students will be able to apply IDT to FQM problems by using the techno-managerial (T-M) approach in the four phases of the interdisciplinary research methodology’. This was a 12-week course taught by two teachers, one from the T-related disciplines (second author) and one from the M-related disciplines (not a member of the author team). This FQM course has a relatively long history as a mandatory course in the interdisciplinary graduate program on FQM. This program is provided at a European university that delivers education in the domain of healthy food and a healthy living environment. This university is reputed to be outstanding in education and research in its multidisciplinary domain. The present design-based research (e.g., Edelson, 2002; McKenney & Reeves, 2012) examined the learning of novice learners using multiple lenses and data. However, the present research did not examine the effectiveness (i.e., is there a systematic effect and why?) or practicality (i.e., what is happening?) of the implemented instructional design (e.g., Nieveen, 2007; Penuel, Confrey, Maloney, & Rupp, 2014; Shavelson et al., 2003), neither the theoretical, nor the methodological issues of design-based research (e.g., Brown, 1992; Collins et al., 2004; Dede, 2004; Kelly, 2004; Penuel, Fishman, Cheng, & Sabelli, 2011; Shavelson et al., 2003).

5.4.2 Data collection

The data collection took place via two reflective journals. One journal was intended to collect data on challenges and strategies. This journal was written by the students during the course, on five occasions occurring at almost regular intervals. Students were asked to reflect on their challenges and strategies during their learning of broad IDT. The journaling activity was based on Brookfield's critical incident method (1995). This method involves critical reflection on incidents that individuals encounter in order that they might learn from these ‘incidents’, ‘difficulties’ or ‘challenges’. The journal format was an author-devised data-collection form structured in two parts: part A, the description of the challenge, and part B, the description of strategies pursued to overcome the challenge faced. The latter description took the form of five statements.

The other reflective journal was intended to collect data on disciplinary knowledge connections. This journal was completed on one occasion at the end of the course. Students were asked to reflect on two disciplinary knowledge connections as described in their final reports. The journaling activity was based on the evaluation criterion ‘usefulness’ that is recommended for the critical evaluation of research activities conducted in the FQM research phases (Luning & Marcelis, 2009b). This criterion considers three sub-criteria: (1) relevance, (2) reliability, and (3) validity. The journal format was an author-devised form structured in two parts: part A, the description of the disciplinary knowledge connection made, and B, the critical evaluation of the connection. The evaluation took the form of four statements.

In completing both journals, students were free in their choice of which challenges and connections they wished to report. Instruction on the added value of reflection was provided on two occasions during the course with respect to reflection in general (Boud, 2001; Langer, 2002), reflection in interdisciplinary research (Morse et al., 2007; Repko, 2012), reflection during IDT learning (Boix Mansilla & Duraising, 2007; Nardone & Lee, 2011; Woods, 2007), and reflection in becoming a capable professional (Groen, 2011; Shön, 1987). The population of 30 students ranged in age from 23 to 41-years-old, where 22 students were women and eight were men, and 13 nationalities were represented. All 30 students were novice IDT learners. The data collection yielded 150 journals with respect to the challenges and strategies and 30 journals with respect to the outcomes. All journals were processed digitally and anonymously.

5.4.3 Data analysis

The data analysis featured a content analysis which, in accordance with Hsieh and Shannon (2005, p. 1278), was considered as a research method for the subjective interpretation of the content of textual data. This content analysis involved the systematic categorization of the data, thereby enabling the identification of patterns. Two types of content analysis were performed: directed content analysis and conventional content analysis (Hsieh & Shannon, 2005). The goal of the directed content analysis approach was to validate and to conceptually extend the theoretical perspectives presented (see chapter 5.2). This analysis involved the use of predetermined codes derived from these theoretical perspectives. This analysis was done by the first author who coded all 150 reported challenges and all 60 reported knowledge connections. The codes with respect to the challenges were based on the three dimensions of Illeris (2002, 2007) and included the categories *content*-related challenge, *incentive*-related challenge, and *interaction*-related challenge. The codes with respect to the knowledge connections were based on the concepts of Luning and Marcelis (2007) and included the categories: *fd–hd*, referring to food dynamics and human dynamics, *fd–ac*, referring to food dynamics and administrative conditions, *tc–hd*, referring to technological conditions and human dynamics, and *tc–ac*, referring to technological conditions and administrative conditions.

After the directed content analysis, the conventional content analysis was conducted for each data set. For the data set on learning challenges, the goal of the conventional content analysis was to identify the subcategories of challenges and the strategies. For the data set on knowledge connections, the goal was to identify the subcategories of justification given by the students. The inductive analysis method was kept as simple as possible and started with identifying similar kinds of expressions, clustering them, and subsequently labelling each cluster (Silverman, 2013). The analysis was done twice to make sure that an optimal fit was achieved between subcategories and the data set.

5.5 Results and discussion

5.5.1 Learning challenges (*research question 1*)

Table 5.1 provides two examples of the reported challenges per category of challenge.

Table 5.1 An illustration of the reported learning challenges per category of challenge

Category of challenge	The experienced challenge is:
Content-related	*"How to integrate both T[echnological] and M[anagerial] factors. Though the idea that T[echnological] and M[anagerial] elements are always linked together is clear to me, I do not know [how] to demonstrate it in my assignment. I am easily to lose [easily loose] the balance when using them"* *"The most difficult thing I experienced was putting […] the T[echnological] & M[anagerial] strategies (solutions) [and solutions] together and comparing them with another"*
Incentive-related	*"I was quite certain which factors had an influence, but uncertain where [how] to categorise them. I was also doubting whether or not I had unilaterally T[echnological] and M[anagerial] concepts"* *"I found a lot of models that are relevant to my case [FQM problem]. I was confused which to use, many of them fits to my [FQM] situation, I had to choose 'the best'"*
Interaction-related	*"To manage my time between researching the M[anagerial] factors and T[echnological] factors"* *"To find relevant information to help me to judge the best solutions"*

Students reflected on the challenge of connecting the disciplinary knowledge in a meaningful way (*content*), on the confusion arising from crossing disciplinary boundaries due to the overwhelming amount of disciplinary knowledge and number of possibilities involved in demarcating complex problems (*incentive*), and they reflected on the need for collaborating with peers and for finding adequate information to be able to reason in a consistent way during their interdisciplinary research (*interaction*). Empirical research (D' Mello & Graesser, 2012; D' Mello et al., 2014) on the affective states during complex learning has shown that confusion can be beneficial to learning, once the confusion (*incentive*) is successfully resolved. The attempt to achieve resolution is likely to lead to engagement and flow. Should, however, the attempt fail, confusion is likely to lead to frustration and then boredom. This mechanism illustrates the importance of the successful resolution of the reported confusion during IDT learning.

The results showed that students reflected more often on the challenge categories of content (106 times) and interaction (38 times) than on the challenge category of incentive (six times). Possible explanations for this difference in frequency are: students do not consider their emotions to be part of their learning processes, students do not regard emotions as learning challenges, students prefer not to reflect on this kind of challenge, students do not face incentive-related challenges during IDT learning, students were not triggered to report on this kind of challenge due to the manner of interrogation, students might not be able to reflect on their emotions because their emotional intelligence is as yet insufficiently developed (Goleman, 1996), and students might not dare to reflect on their emotions since they might perceive this to be too personal.

Table 5.2 presents the subcategories of each category of challenges. All the identified subcategories relate to the achievement of the IDT learning outcomes. For example, the making of meaningful connections is considered as challenging (*content*-related), because it involves the cognitively embedding of new ideas into existing ideas (Richter & Paretti, 2009), and because it involves the recognition of relationships between disciplinary knowledge elements that have different scales or units (Defila & DiGiulio, 2015; Eisen et al., 2009; Morse et al., 2007). Additionally, IDT may prompt the need to define the rules and boundaries of study and this may give rise to the challenge of feeling uncertain (*incentive*-related), whereas disciplinary thinking occurs in a context with predefined rules and boundaries of study (Lach, 2014). Furthermore, the time-management involved in doing interdisciplinary research is a known challenge (*interaction*-related), because working across disciplines takes time (Sharp, 2015) and learning to work across disciplines also takes time (Lyall, Bruce, Tait, & Meagher, 2011).

Table 5.2 Overview of subcategories of challenges per category of challenge

Category of challenge	Subcategories of challenges
Content-related	- Analysing the complex problem situations by viewing the multiple perspectives in an appropriate manner - Linking, connecting, and integrating the disciplinary knowledge and practical information in reasonable combinations - Maintaining an appropriate balance between the disciplinary knowledge elements in number and specificity
Incentive-related	- Coping with the uncertainty of selecting and categorizing the disciplinary knowledge
Interaction-related	- Finding relevant literature per discipline for the particular research phase - Managing time between researching the relevant disciplines

5.5.2 Learning strategies to overcome the learning challenges (*research question 2*)

Table 5.3 illustrates the kind of learning strategies that were reported per category of challenge.

Table 5.3 An illustration of the reported strategies per category of challenge

Category of challenge	To overcome the experienced challenge:
Content-related: *connecting the disciplines*	*"[I] will draw a flow chart. This simple method allows me to have a clear view on the situation. Problem in the middle and possible causes from both [technological and managerial] perspectives. Flowchart allows to define the problem and, step by step find out concrete managerial and technological issues causing problems"*
Incentive-related: *confusion on selecting the disciplinary knowledge*	*"I read carefully my previous assignments (1st-5th), come [read] back to [the] description of the CMC case [company] and combine it with the literature about the TQM [Total Quality Management] approach"*
Interaction-related: *searching for adequate disciplinary knowledge*	*"[I] spend much time searching for literature in order to find ways to make a linkage between T[echnological] and M[anagerial] issues with the respective consequences. Additionally, I discussed with my peers about the problem I was facing and it appears that I am not the only one. Together we tried to solve the difficulty by searching literature"*

At first sight, the reported strategies seemed to be effective strategies for coping with the challenges of IDT learning. Table 5.4 shows the subcategories of each learning strategy per category of challenge. This table shows that strategies for coping with the challenges involved in IDT learning include the following: using all the available information to gain a good understanding of the problem situation, rethinking all technological and managerial knowledge elements to find connections, putting thoughts on paper to foster reflection on the reasoning (*content*-related), being more open-minded and trying to be creative (*incentive*-related), listening carefully to the lectures and student presentations; discussing with peers, and searching for literature and handbooks that describe the disciplinary connections (*interaction-related*). The impact of these strategies to overcome the challenges should be investigated to identify which learning strategies good IDT students use and which factors affect their choice of strategy.

Table 5.4 Overview of subcategories of learning strategies per category of challenge

Category of challenge	Subcategories of learning strategies
Content-related	- Gaining a good picture of what is happening in the problem situation by linking the disciplinary knowledge and practical information - Rethinking of the problem situation and organizing the connections between T and M-related disciplinary knowledge, using flow diagrams - Writing down in one's own words the thoughts and gathered information and reflect upon the logical reasoning
Incentive-related	- Being more open-minded about what interdisciplinary research actually involves - Being creative in the use of search terms across the disciplines
Interaction-related	- Re-reading all information, asking, and listening to teachers, and discussing with peer students to learn their ‘tips and tricks’ - Searching for literature that already connects the disciplinary knowledge and for literature that aids the recognition of these connections

5.5.3 Disciplinary knowledge connections (*research question 3*)

Table 5.5 illustrates the kind of disciplinary knowledge connections that were reported per category of disciplinary knowledge connection. The example provided for the *fd–hd* category shows how the interaction between the knowledge of operators (*hd*, human dynamics) and the ripeness of tomatoes (*fd*, food dynamics) impacts decision-making concerning the quality of the tomatoes to be used as ingredients. The results showed that the *tc–hd* and *tc–ac* knowledge connections were reported more frequently, 26 and 28 times respectively, than the *fd–hd* and *fd–ac* knowledge connections, reported four and two times respectively. The students themselves chose the knowledge connections they wished to report, allowing for the constraint of reporting one knowledge connection in research phase III and one knowledge connection in research phase IV (see chapter 5.4.2).

Table 5.5 An illustration of reported knowledge connections per category of knowledge connection

Category of knowledge connection	The made disciplinary knowledge connection is:
fd–hd	*"On page 19, I explained how the combination between* ***lack of knowledge of employees*** *(managerial) and* ***variability in ripeness of incoming tomatoes*** *(technological), can lead to a situation where employees will let through the unripe tomatoes for using them in the company CMC meals"*
fd–ac	*"****As the Industry Guide for Beef Aging stated, to improve the consistency of beef tenderness, post-mortem aging should be managed with respect to both individual muscle and USDA Quality Grade.*** *USDA Select beef muscles required approximately 20 days or more of post-mortem aging to complete a majority of the aging response. […]".*
tc–hd	*"The R&D department need to find the* ***best gas composition in modified atmosphere packaging*** *for pork to meet their customer demand. On the other hand,* ***people in marketing department need to improve their knowledge*** *on measuring colour performance of the customers, so that they can know which colour is their customer's demand, then communicate with R&D department via information system, so that R&D department can design the best gas composition in the modified atmosphere packaging"*
tc–ac	*"According to the literature the reason that company* ***CMC lab does not have suitable equipment*** *may be because there are not enough finances made available to the* ***incoming material control lab*** *in order to acquire the best suitable equipment. Thus another solution will have to be found to* ***increase the finances available to the lab by making the people in control of the finances aware*** *of the need for suitable equipment and convincing them of the impact the suitable equipment will have on the sales of the final product and evidently contributing to a* ***more positive financial situation for the company CMC in the long term****"*

Note: the text addressing the four perspectives (*fd, tc, hd,* s *ac*) is bold printed.

In view of this freedom of choice, it seems that students prefer to reflect on the *tc–hd* and *tc–ac* knowledge connections more than on the *fd–hd* and *fd–ac* knowledge connections, or it might be that during research phases III and IV, the students needed to make more *tc–hd* and *tc–ac* knowledge connections than in research phases I and II, or it might be that reflection on *tc–hd* and *tc–ac* knowledge connections is more obvious to students, or it might be that the teachers provided more examples of these particular kinds of knowledge connections. Further research should clarify whether students tend to make some types of knowledge connections rather than others and whether they tend to reflect on some types of knowledge connection rather than others.

5.5.4 Justification of the knowledge connections made (*research question 4*)

Table 5.6 shows the subcategories of justifications given per category of IDT subskill. The identified subcategories show similarities with the three assessment criteria applied to student interdisciplinary work (Boix Mansilla & Duraising, 2007, p. 223), namely: (a) disciplinary grounding, (b) critical awareness, and (c) advancement in student understanding through integration. As shown in Table 5.6, the subcategories of justifications within the category of having disciplinary knowledge were: in depth-disciplinary and factual reasoning. Students produced in-depth reasoning that justified the disciplinary knowledge connections made by explaining the disciplinary facts and practical information used to make the connection. An example is *"Thus if the packaging properties is [are] not sufficient to maintain the [modified atmosphere] gas composition, the gas composition of the package altered. This will then result in the [negative] effects of modified atmosphere composition being reversed and thus revering [reverting to] the normal atmospheric composition. This reversing process will create an optimal environment for spoilage microbes like Pseudomonas fluorescens and Candida sake to grow as no more hurdles are present to inhibit their growth [references]."*

This example shows the disciplinary reasoning supporting the use of a modified atmosphere packaging that requires particular packaging properties; without these properties, the induced gas composition of modified atmosphere packaging is going to change, leading to the undesired growth of single-cell organisms that will cause spoilage. By providing this kind of justification, students show their disciplinary understanding (subskill 1 and criteria a).

Table 5.6 Overview of subcategories of justifications per category of subskill

Category of subskill	Subcategories of justifications
1. Having knowledge of disciplines	- In-depth disciplinary reasoning - In-depth factual reasoning
2. Having knowledge of disciplinary paradigms	- Theoretical source information and assumptions derived - Practical source information and assumptions derived
3. Having knowledge of interdisciplinarity	- The interrelationships between the disciplinary knowledge - The reasoning behind the interrelationships
4. Having higher-order cognitive skills	- The activities conducted in connecting the disciplinary knowledge - The weighing of disciplinary knowledge involved
5. Having communication skills	- The reflective manner of communicating the advancement in understanding - The influence of individual disciplinary background

In addition, in the subcategories of justifications within the category of having knowledge of disciplinary paradigms reference was made to the sources and the assumptions derived from them in order to justify the connection (see Table 5.6). To illustrate, *"The description of CMC case [company] shows that its products are mainly sold to the North-west Europe. Germany, the Netherlands, Switzerland, and Belgium have banned to use chlorine to wash ready-to-eat* *food [reference]. Also, [reference] reports that equipment for ozonation [ozonated] washing need [needs] higher anticorrosive and initial investment [reference]. So, I think CMC will take these regulations and requirement of equipment into account when it makes decision of use of antimicrobial agent."* This example illustrates a meta-level of reasoning (Boix Mansilla & Duraising, 2007) with respect to particular sources and explains how assumptions were derived in view of these sources. By providing this kind of justification, students show their understanding of disciplinary paradigm knowledge (subskill 2 and criteria a). The subcategories of justifications within the category of having knowledge of interdisciplinarity deal with explaining the interrelationships between the disciplinary knowledge elements (see Table 5.6). For instance, *"It [the connection] shows how the setting of product and process parameter specifications and managerial issues such as operator training and organisation culture influence operator[s'] decision[s]. Thus showing [the connection shows that] decisions are not just depended [dependent] on technological conditions but also on people characteristics and administrative conditions."* This example explains the interdependency between technology-related and management-related factors (see chapter 5.2.2) and shows the student's critical awareness of interdisciplinarity (subskill 3 and criteria b).

With respect to the category of having higher-order cognitive skills, the subcategories of justifications concern the construction of the knowledge connection and the contribution of each discipline to this knowledge connection (see Table 5.6). The following excerpt is a student reflection on how the connection is constructed: *"Two main factors, logical reasoning and underpinning [with] literature. Logical reasoning derived from the combination of three critical points; crucial facts (provided by the CMC [company] description), my previous educational background, and finally the detailed analysis of my operational research instrument. Additionally, the useful support of literature was very important for extracting data on the set of key questions."* By providing this kind of justification, students show their critical awareness of how to construct the disciplinary knowledge connections (subskill 4 and criteria b). With respect to the category of having communication skills, the subcategories of justifications showed the student’s awareness of his or her influence on the making of the disciplinary knowledge connections and, in particular, the influence of the researcher’s disciplinary background (see Table 5.6). An example is: *”Despite the fact that I was firstly biased on analysing different factors and try [to] find solutions more from a technological prospective because of my background, in the end I underpinned my argumentation based on managerial prospective which was supported from [by] technological factors as the disinfectant agents and the microbiological tests.”* By providing this type of justification, students demonstrate the ability to reflect on disciplinary bias in interdisciplinary research (subskill 5 and criteria c). Further research is required to determine whether having a justification for each subcategory is a prerequisite for making disciplinary knowledge connections. Suppose this were the case, then the question becomes whether it would be possible to teach students in HEE to formulate all five kinds of justifications identified.

5.6 Critical considerations and further research

One issue to be critically considered is the current use of research methods. Firstly, the IDT learning outcomes were empirically investigated by means of the analysis of the disciplinary knowledge connections. However, this means that the gain in IDT ability by students has not yet been investigated. Secondly, the self-reflection method was used to investigate the challenges, strategies, and outcomes. Presumably, the ability to self-reflect differs per student and per nationality, and it is likely that this was the first time that these students had been required to reflect in this way. However, the self-reflection method is a common formative method used to evaluate the practicality of newly developed instructional designs (Linn, Palmer, Baranger, Gerard, & Stone, 2015; Nieveen & Folmer, 2013). The use of the self-reflection method in this research has advanced understanding of both IDT learning processes and the practicality of the implemented instructional design.

A second consideration is the potential added value design-based research brings to an examination of the learning processes. This is because (1) the learning is examined within a particular 'engineered' context (Cobb et al., 2003; Sandoval & Bell, 2004), (2) the investigation environment is naturalistic (Barab & Squire, 2004; Tabak, 2004), (3) usable knowledge about how students learn is produced through the methodological alignment of existing theories and implemented instructional designs (Hoadley, 2004), (4) the achievement of goals between the researchers' goals, designers' goals and practitioners' goals is facilitated (Joseph, 2004), and (5) design refinements are made possible by means of teaching, learning, and assessment conjectures (Sandoval, 2004, 2014). Design-based research to examine the teaching and learning of IDT is therefore encouraged in line with Gouvea et al. (2013).

Another consideration is the way in which the systematic analysis of student learning has been conducted using the perspective provided by the integrated learning theory of Illeris (2002, 2007) and the adoption of the naturalistic research paradigm (Hsieh & Shannon, 2005). As Saljö (2009) has discussed, when researchers studying and making claims about learning, researchers clarify the theoretical perspective they are using. They also clarify the unit of analysis being used, which depends on the chosen theory. This reduces the complexity of learning. This reductionist step was taken in the present research by separating the learning into cognitive, emotional, and social processes (Illeris, 2002, 2007). Obviously, the tension between capturing the complexity of learning, on the one hand, and conducting a rigorous systematic research methodology, on the other hand, was also present in this research. This reductionist approach may have limited the gain in understanding concerning the learning processes.

Further research directions are numerous: (1) replication studies to validate the present results and to verify that the present findings can be generalized (Babbie, 2010), (2) experimental studies to develop pedagogical support for students contending with the challenges of IDT learning, (3) learning studies to further analyse short-term learning processes. This would involve extending the investigation to individual students to better understand how students learn IDT, (4) design-based research studies to investigate the impact of constructively aligned designs on IDT learning, (5) design studies of assessment instruments (Boix Mansilla, Duraising, Wolfe, & Haynes, 2009; Engström, 2014; Hackett & Rhoten, 2009; Lattuca et al., 2013). Ideally, these design studies would focus on an individual's performance. Table 5.7 presents an initial version of an assessment instrument for assessing an individual's IDT performance.

5.7 Conclusions and implications

In extending the understanding of student IDT learning in HEE, the present research concludes that empirical evidence was found to support the learning theory of Illeris (2002, 2007) and the FQM concepts of Luning and Marcelis (2007) with respect to short-term IDT learning processes. In particular, the present research concludes that students face challenges on all three learning dimensions of Illeris during IDT learning in the FQM course. In this respect, students tend to report *content*-related and *interaction*-related challenges more frequently than *incentive*-related challenges. Furthermore, the present research concludes that during IDT learning, students make every one of the four types of disciplinary knowledge connection that are possible in FQM. In this respect, students tend to report *tc–hd* and *tc–ac* disciplinary knowledge connections more frequently than *fd–hd* and *fd–ac* disciplinary knowledge connections. Overall, it can be concluded that research in ‘designing for learning’ by means of design-based research promotes scientific understanding of the teaching and learning of IDT in HEE and enables the refinement of instructional designs for IDT.

Table 5.7 Initial rubric on the development of competence in IDT

Category of subskill	An individual competent in IDT:
Having knowledge of disciplines	- asks open questions to understand the reasoning involved in disciplines - draws tables or figures showing the relevant disciplinary knowledge for the particular research purpose
Having knowledge of disciplinary paradigms	- distinguishes differences and similarities between disciplinary perspectives and knowledge elements - explains the disciplinary perspectives that are used to interpret the knowledge elements
Having knowledge of interdisciplinarity	- explains on a meta-level the interdisciplinary approach that was taken in order to achieve the interdisciplinary research purpose
Having higher-order cognitive skills	- shows creativity in making meaningful connections between the relevant disciplinary knowledge with a view to producing a cognitive advancement - tests the plausibility of the connections and the sufficiency of the cognitive advancement
Having communication skills	- is able to communicate the advancement in understanding to disciplinarians and interdisciplinarians - is able to communicate how the knowledge connections were made as well as their benefits and shortcomings

The present research suggests the importance of providing pedagogical support for students in dealing with challenges and making disciplinary knowledge connections. In this respect, Table 5.8 presents a pedagogical tool that includes questions to formatively assess the making of disciplinary knowledge connections and to enhance creativity in making these connections (Dowds, 1998; Ng et al., 2011; Nicol & Macfarlane-Dick, 2006; Quinton & Smallbone, 2010). This pedagogical tool can be used by teachers and students. Furthermore, the results suggest the need to adjust IDT teaching to the content, learning, and incentive dimensions (Illeris, 2002, 2007). Moreover, the results indicate the need to have an interdisciplinary framework (see chapter 5.2.2), which represents the connections between disciplines, embedded in the course design. This framework provides students with a platform from which to learn how to make these connections.

Table 5.8 Supportive questions to formatively assess the disciplinary knowledge integration

Category of subskill	Supportive questions on making knowledge connections:
Having knowledge of disciplines	How relevant is the connection? *Asking for the meaningfulness of connecting these disciplines*
Having knowledge of disciplinary paradigms	How reliable is the connection? *Asking for the epistemic and system level differences that might influence the reliability of the connections*
Having knowledge of interdisciplinarity	How accurate is the connection? *Asking for the continuously revision of the connections due to the advancements in understanding of the problem under study*
Having higher-order cognitive skills	How is the connection constructed? *Asking for details of the construction of the connections and the disciplinary knowledge used*
Having communication skills	How is the connection communicated? *Asking for the manner of communicating the connections and the advancement in understanding*

The final implication is the clarification of the IDT learning outcomes and the alignment of these outcomes with the teaching, learning, and assessment activities (Borrego & Cutler, 2010; Gharaibeh et al., 2013; Yang, 2009). With particular relevance to IDT learning, the constructive alignment principle facilitates the better alignment of subject matter via the formulation of intended learning outcomes beyond the disciplinary subjects. In addition, the alignment brings consistency to IDT learning environments. As Fischer has claimed (1980, p. 480), the development of skills are induced by the environment, and only the skills that are induced most consistently will typically be developed at the highest level that the individual is capable of. So, once the constructive alignment principle has been implemented for the intended learning outcome of IDT, students in HEE have the opportunity to learn IDT at the highest level they are capable of, induced by consistent learning environments.

Chapter 6

General discussion

6.1 Research overview and results

Each chapter of this thesis is a step towards answering the main research question: *"Which teaching and learning aspects need to be taken into account in order to teach engineering students interdisciplinary thinking (IDT) with respect to complex problem solving?"* This main research question originated in the *actual problem situation*, as represented in Figure 6.1, on the need for improving the education practice in order to enhance student learning on IDT in higher education in engineering (HEE).

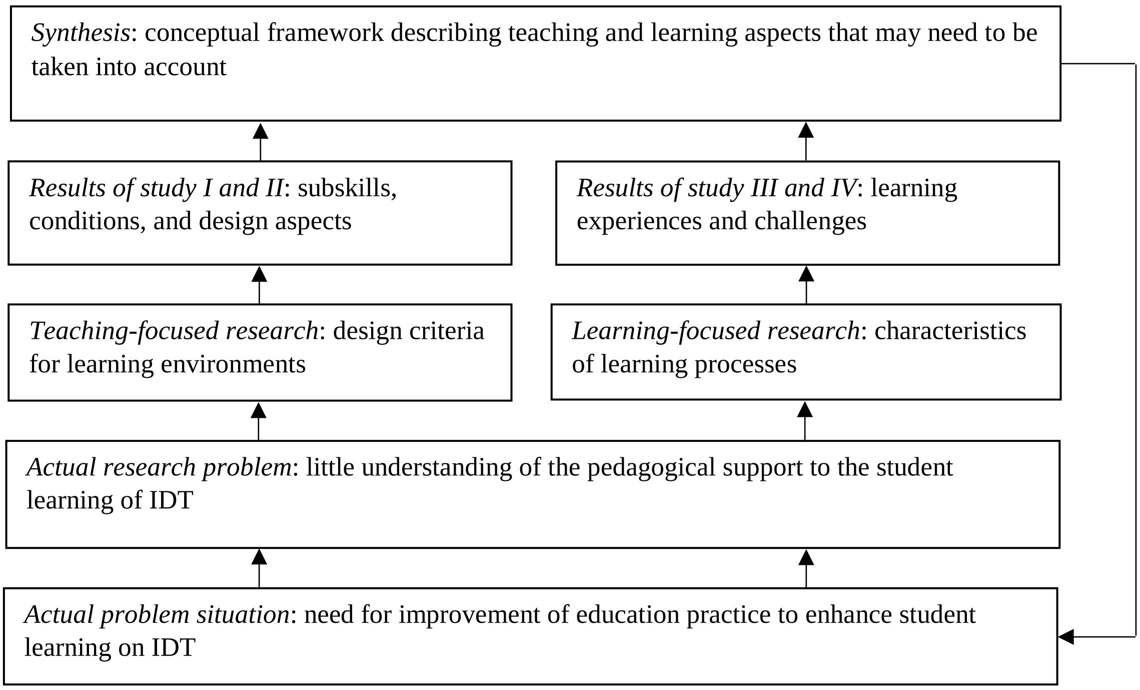


Figure 6.1 Overview of conducted thesis research

After literature exploration, the actual problem situation led to the identification of the *actual research problem* (Figure 6.1), which was little scientific understanding on the pedagogically support to the learning of IDT by engineering students. Therefore, *teaching-focused research* (Figure 6.1) was conducted to investigate *subskills* of IDT, enabling *conditions* and design *aspects* for learning environments (chapters 2 and 3). In addition, *learning-focused research*

(Figure 6.1) was conducted to investigate *learning experiences*, and *challenges* (chapters 4 and 5). The *synthesis of these results* has led to a conceptual framework describing the teaching and learning aspects that may need to be taken into account to improve education practice on IDT, which was the starting point of this thesis research.

In order to answer the main research question, four sub research questions were investigated in the present research. The first sub research question dealt with the inventory of main subskills of IDT and enabling conditions to teach and to learn IDT in interdisciplinary higher education (Figure 1.4, ***study I***). Chapter two, dealing with this sub research question, showed that theoretical evidence was found for five main subskills and 26 main enabling conditions for interdisciplinary higher education (see Table 2.1). The second sub research question dealt with the inventory of key design criteria that need to be taken into account to teach engineering students IDT in HEE (Figure 1.4, ***study II***). Chapter three, dealing with this sub research question, showed that empirical evidence was found for eight key design aspects for the food quality management (FQM) course in question (see Table 3.6). The third sub research question dealt with the inventory of key learning experiences that need to be taken into account to teach engineering students IDT in HEE (Figure 1.4, ***study III***). Chapter four, dealing with this sub research question, showed that empirical evidence was found for 24 key learning experiences for the FQM course in question (see Table 4.3). The fourth sub research question dealt with the inventory of typical learning challenges that need to be taken into account to teach engineering students IDT in HEE (Figure 1.4, ***study IV***). Chapter five, dealing with this sub research question, showed that empirical evidence was found for six typical learning challenges for the FQM course in question (see Table 5.2). All aforementioned main results (Tables 2.1, 3.6, 4.3, and 5.2) are used in chapter 6.2 to extend the existing models of teaching and learning, which were explained in chapter 1, and applied to the present thesis research (chapters 2 – 5).

6.2 Extension of the used teaching and learning models

The present thesis research aim was to gain insight in the pedagogical content knowledge for IDT to enhance student learning across HEE. In accordance to Boix Mansilla (2010) and Shulman (1987), pedagogical content knowledge was considered in the present research as an understanding of the unique teaching and learning demands to ensure quality student learning processes. To achieve the aim of gaining insight in these teaching and learning demands, the understanding of design criteria of IDT learning environments (*teaching-focus*) and the understanding of IDT learning process characteristics (*learning-focus*) were considered as necessary. Considering the *teaching-focus*, the constructive alignment theory of Biggs and Tang was applied to advance the understanding on teaching and learning IDT. Based upon the main results of chapter 2 (Table 2.1), the original 3P model of teaching and learning (see Figure 1.1) can be extended for each component: *student*, *learning environment*, *learning process*, and *learning outcomes*. Figure 6.2 presents the extended 3P model of teaching and learning of IDT in higher education. As shown by this extended model for the component student, it can be reasoned that the student characteristics of ‘curiosity’, ‘respect’, ‘openness’, ‘patience’, ‘diligence’, ‘self-regulation’, ‘prior social experiences’, and ‘prior educational experiences’ would likely lead to better IDT learning processes and outcomes. Additionally, for the component learning environment, it can be reasoned that the learning environment characteristics divided into four different categories, ‘curriculum’, ‘teacher’, ‘pedagogy’, and ‘assessment’ would likely lead to better IDT learning processes and outcomes. Furthermore, as shown in Figure 6.2 for the component learning processes, it can be reasoned that ‘phased with gradual advancement’, ‘linear’, ‘iterative’, ‘milestones with encountering questions’, ‘learning activities aimed at achieving interdisciplinarity’ and ‘learning activities aimed at achieving reflection’ would likely lead to better IDT learning processes and outcomes.

Moreover, for the component of IDT learning outcomes, it can be reasoned that the acquisition of particular knowledge, 'knowledge of disciplines', 'knowledge of disciplinary paradigms', and 'knowledge of interdisciplinarity' together with particular skills, 'higher-order cognitive skills' and 'communication skills', would likely lead to better IDT learning processes and outcomes.

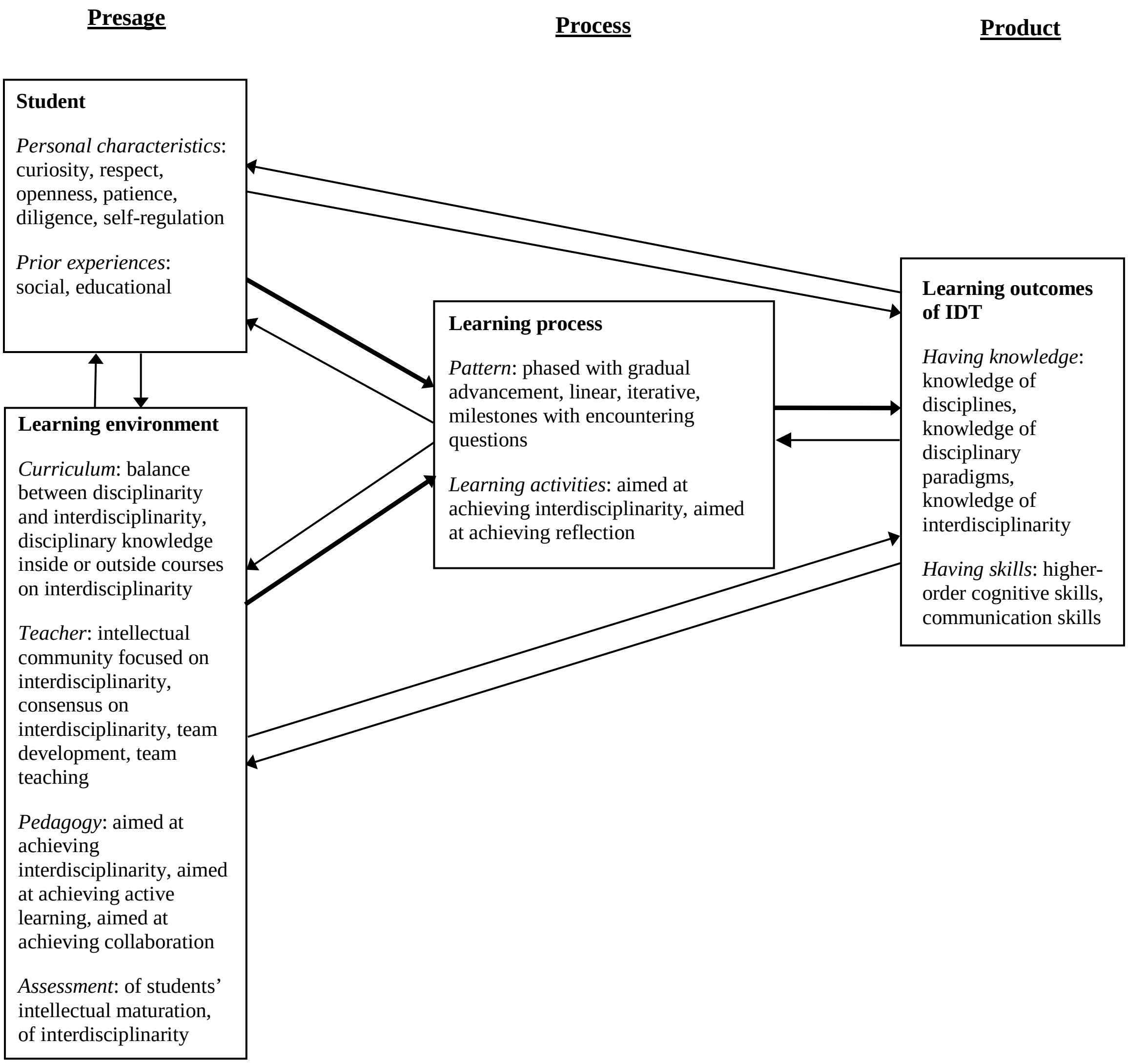


Figure 6.2 Extended 3P model of teaching and learning of IDT in higher education based upon the systematic review findings (***study I***)

Based upon the main results of chapter 3 (Table 3.6), the original outcome-based design model (Figure 1.2) can be extended for each part of the model: *the intended learning outcomes, teaching and learning activities, and assessment tasks*. Figure 6.3 presents the extended outcome-based design model for interdisciplinary learning environments.

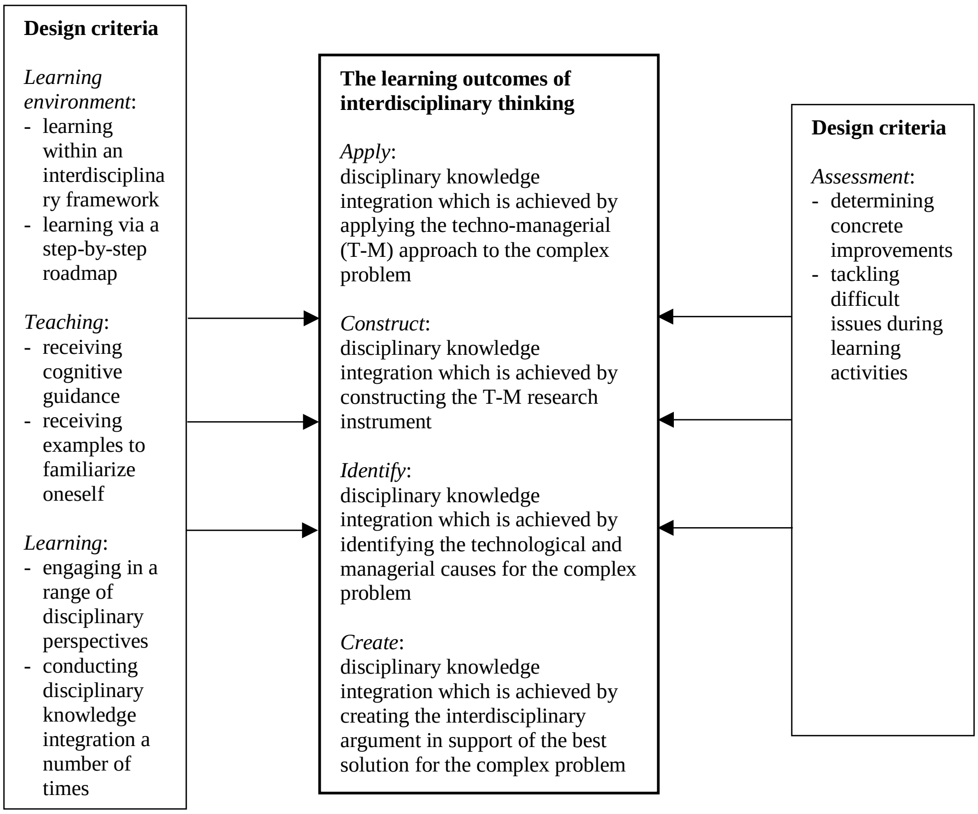


Figure 6.3 Extended outcome-based design model for IDT based upon the critical evaluation findings (***study II***)

From this extended model for the part of intended learning outcomes, it can be reasoned that four different IDT learning outcomes would help students in their IDT learning processes and outcomes with respect to complex problem solving. Additionally, for the part of teaching and learning activities, it can be reasoned that design criteria with respect to the learning environment such as ‘learning within an interdisciplinary framework’ and ‘learning via a step-by-step roadmap’, with respect to teaching, such as ‘receiving cognitive guidance’ and

’receiving examples to familiarize oneself’, and with respect to learning such as ‘engaging in a range of disciplinary perspectives’ and ‘conducting disciplinary knowledge integration a number of times’ would help students in their IDT learning processes and outcomes. Furthermore, as shown in Figure 6.3 for the part of assessment tasks, it can be reasoned that design criteria with respect to assessment such as ‘determining concrete improvements’ and ‘tackling difficult issues during learning activities’ would help students in their IDT learning processes and outcomes. It is hypothesized that by constructively aligning these design criteria in education practice on learning how to solve complex problems in an interdisciplinary manner, the IDT learning processes and outcomes by engineering students would be better.

Considering the *learning-focus* of the present thesis research (see Figure 6.1), the learning theory of Illeris was applied to advance the understanding on teaching and learning IDT. Based upon the main results of chapter 4 (Table 4.3), the original model of the three dimensions of learning (see Figure 1.3) can be extended for each dimension of learning: *content*, *incentive*, and *interaction*. Figure 6.4 presents the extended learning dimensions model for IDT learning with the identified key learning experiences (Table 4.3). As shown in Figure 6.4, the identified key experiences for the content dimension are, for example, ‘understanding how to apply theoretical models or concepts to real-world situations’ and ‘becoming aware of disciplinary contributions to the analysis of complex problems’. In addition, the identified key experiences for the incentive dimension are, for instance, ‘frustrations in selecting and matching disciplinary knowledge to complex problems’ and ‘feeling ambiguous about not having a clear view on how to frame complex problems’. Moreover, two illustrations of the key experiences identified for the interaction learning dimension are: ‘dealing with the scheduled time for searching literature’ and ‘socially engaging with peers to recognize similarities in perceptions and experiences’. Considering the key experiences as presented in Figure 6.4, it can be reasoned that once engineering students gain experience during their learning processes on these particular experiences, the IDT learning processes and outcomes would be better.

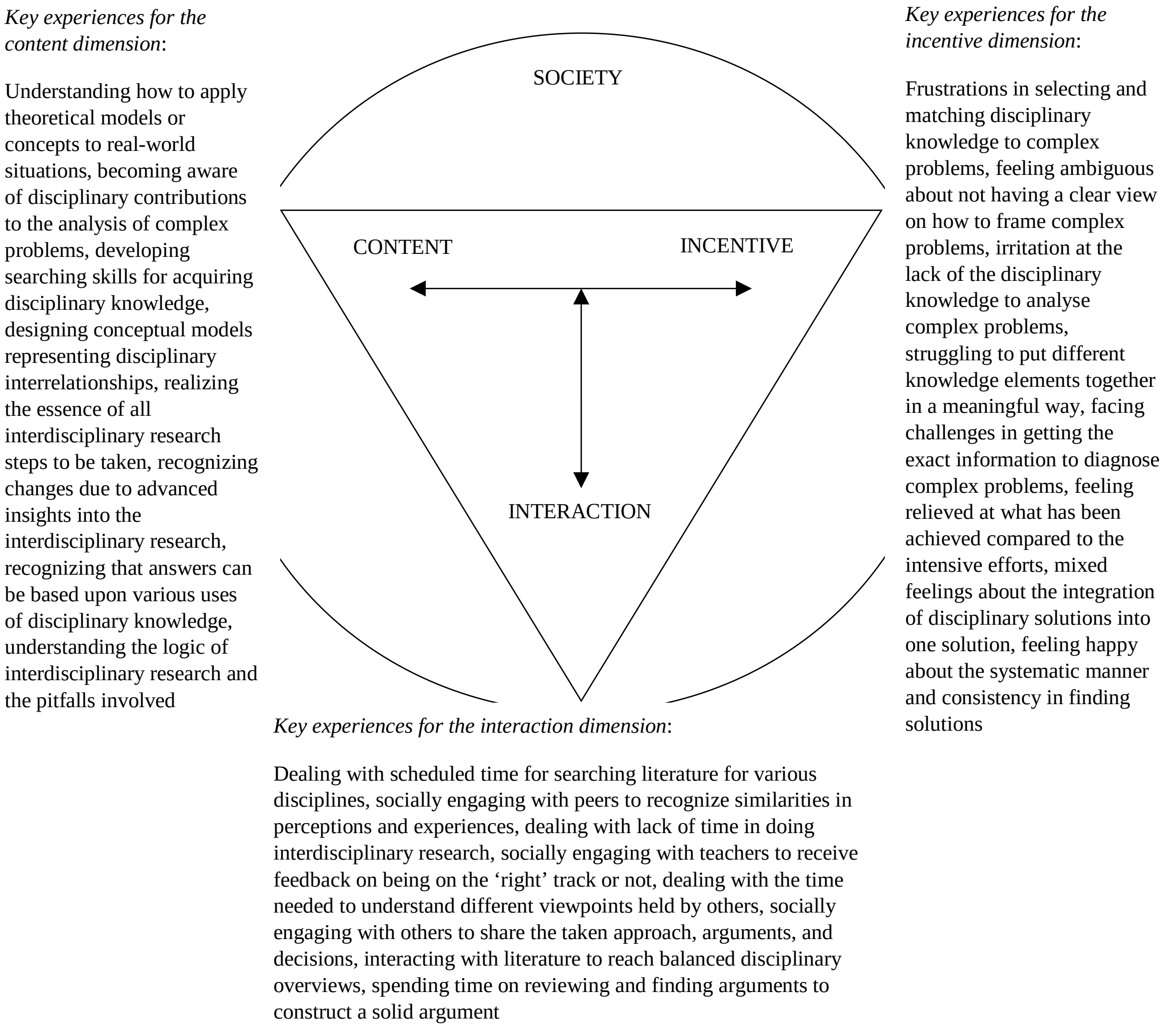


Figure 6.4 Extended model of learning dimensions for IDT learning with respect to key learning experiences identified (***study III***)

Based upon the main results of chapter 5 (Table 5.2), the original learning model of Illeris (see Figure 1.3) can be extended. Figure 6.5 presents the extended learning dimensions model for IDT learning with respect to the identified typical challenges (Table 5.2). As can be derived from Figure 6.5, a typical content-related challenge is 'analysing the complex problem situations by viewing the multiple perspective in an appropriate manner', a typical incentive-related challenge is 'coping with the uncertainty of selecting and categorizing the disciplinary knowledge', and a typical interaction-related challenge is 'finding relevant literature per discipline for the particular research phase'. Considering the typical challenges as presented in Figure 6.5, it can be reasoned that once engineering students, engaged in solving complex problems in an interdisciplinary manner, are able to cope with these challenges, their IDT learning processes and outcomes would be better.

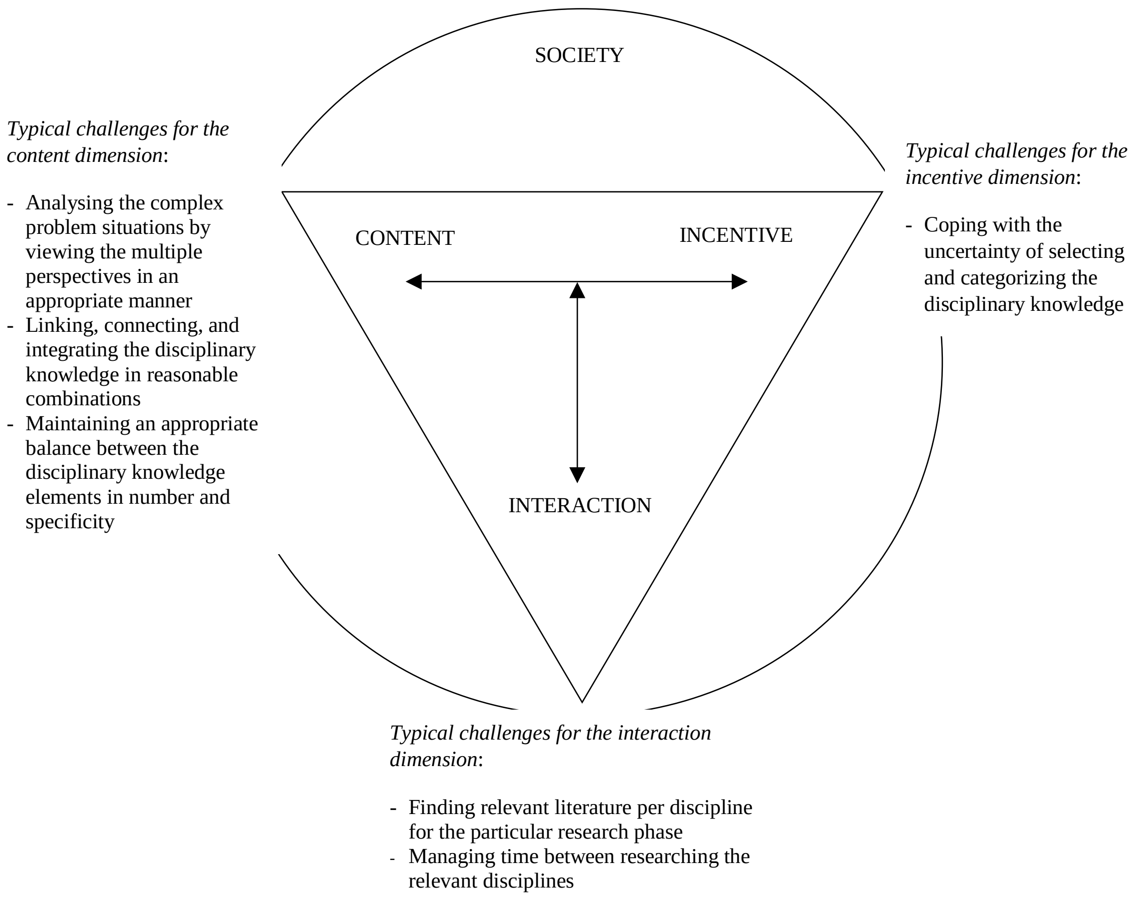


Figure 6.5 Extended model of learning dimensions for IDT learning with respect to typical learning challenges (***study IV***)

The hypotheses of this thesis research referred to the application of two theories (see chapter 1.4). The first hypothesis referring to the application of the constructive alignment theory of Biggs and Tang (2007, 2011) is ‘This constructive alignment theory is suitable to identify design criteria for interdisciplinary learning environments’ and has been accepted by this thesis research (see chapters 2 and 3). The second hypothesis referring to the application of the learning theory of Illeris (2007, 2011) is ‘This learning theory is suitable to characterize the learning of IDT in HEE’ and has been accepted by this thesis research (see chapters 4 and 5). Needless to say, the present thesis research design did not embrace studies to test the counterpart.

6.3 Integration of teaching and learning results

The integration of the teaching and learning results, as described in chapter 6.2, led to the identification of IDT teaching and learning aspects that may need to be taken into account in HEE. Figure 6.6 shows the developed conceptual framework representing these aspects. Of central in this conceptual framework are the short-term learning processes on IDT leading to IDT learning outcomes to be achieved by engineering students (chapter 3), and leading to the acquisition of IDT sub skills to be learnt by engineering students (chapter 2). The upper section of the conceptual framework represents the results of the *teaching-focus o*f the present thesis research (chapters 2 and 3). For example, the parts of education practice, that is ‘teaching’, ‘learning’, and ‘assessing’, are displayed. The lower section of the conceptual framework represents the results of the *learning-focus* of the present thesis research (chapters 4 and 5). For instance, the processes of learning, that is ‘content, ‘incentive’, and ‘interaction’, are presented. On the left hand side of Figure 6.6, the results on the student factors (chapter 2) that may foster the IDT learning processes are represented.

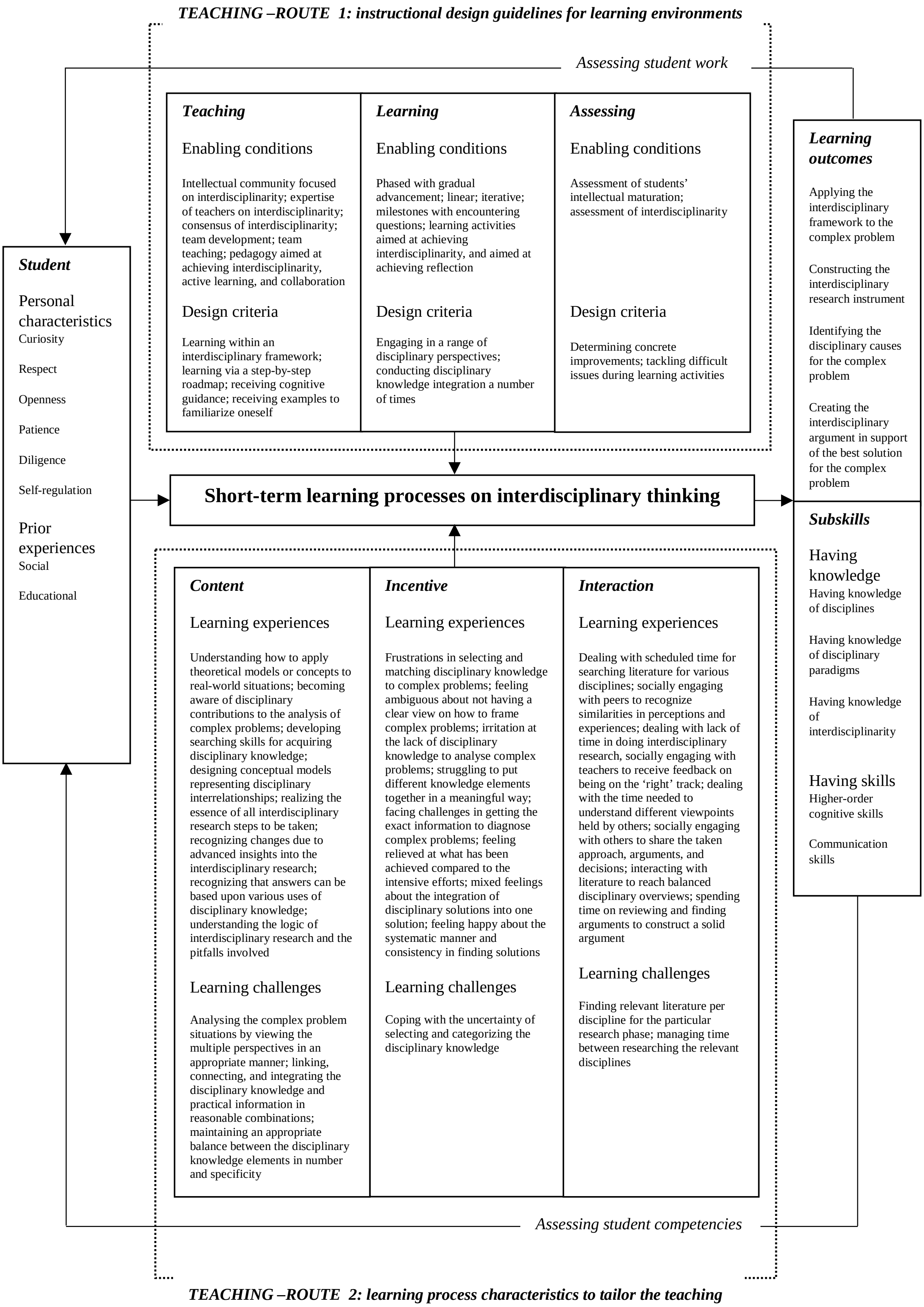


Figure 6.6 Conceptual framework on teaching and learning aspects for IDT

In order to enhance short-term learning processes on IDT, teachers in HEE can follow two different teaching-routes (see Figure 6.6). The *first* teaching-route is designated to design and to keep a learning environment that fosters IDT learning processes leading to student work with specific IDT outcomes. By way of example, the design criteria with respect to the learning part of the ’engagement of students in a range of disciplinary perspectives’ would likely foster IDT learning processes leading to student work with specific IDT outcomes. The *second* teaching-route is designated to guide the learning by students to foster IDT learning processes leading to the development of the IDT subskills. To illustrate, pedagogical support of the learning processes characteristics on the incentive dimension of ‘frustrations in selecting and matching disciplinary knowledge to complex problems’ would likely contribute to the enhancement of student IDT learning processes, leading to the development of the IDT subskills. The difference between these two teaching routes is that the first teaching-route involves the learning environment affecting student learning and the second teaching-route involves the student learning itself.

During the short-term IDT learning processes, it seems that teachers in HEE need to alternate between these teaching-routes while continuously diagnosing the student learning outcomes and subskills development. For example, a student report can be assessed by a teacher who provides, handwritten or typewritten, feedforward support to the student. While discussing this feedforward support to the particular student in a teacher-student chat, the teacher needs to diagnose the current developmental stage of the IDT subskills to determine whether the student is able to address the raised feedback. It is hypothesized that by switching between these teaching routes, teachers would provide the pedagogical support to students in HEE to achieve the desired IDT learning outcomes. Logically, this switching between these teaching-routes requires that teachers in HEE have an understanding of the pedagogical content knowledge for IDT as initially gained in this thesis research, and that they are able to demonstrate this particular kind of knowledge.

The developed framework (Figure 6.6) centralizes the student learning processes. In particular, it centralizes the learning processes of typically problem-focused interdisciplinary research as described by Lyall et al. (2011). The centralization of student learning processes is novel compared to existing instructional design models, such as that of Van Merriënboer (1997), that majorly focus on the design of learning environments. The centralization of student learning processes is also novel to related pedagogies, such as that of Repko et al. (2014) and Hursh et al. (1983), that majorly focus on the conduct of the interdisciplinary research process.

6.4 Research limitations

Several research limitations affected the development of the initial basis on the pedagogical content knowledge for IDT as schematically represented in Figure 6.6. It is difficult to estimate the impact of each of these limitations on the identification of the teaching and learning aspects.

6.4.1 Use of theoretical perspectives

The use of theoretical perspectives provided focus to the identification of teaching and learning aspects (Figure 6.6) and demarcated the research activities. The use of modelling for theory building in qualitative research was described by Briggs (2007) as valuable method for education. However, the focus hinders the inductive way of researching that may result in discovering teaching and learning aspects outside the adopted theoretical perspectives, because of the theoretical bias in approaching the research object and the data (Hsieh &

Shannon, 2005). By way of example, the provided focus by the use of the constructive alignment theory in the present thesis research may have led to a relatively more ‘passive’ embedding of the assessment part in the course design (Table 3.1), compared to the teaching and learning parts, in enhancing the learning processes. It is therefore suggested to change the wording of assess*ment* in assess*ing* (see Figure 6.6) to emphasize the feed forward purpose of the assess*ing* part, thereby providing an equal weight to the teaching, the learning, and the assessment part in the enhancement of student learning processes.

6.4.2 Interdisciplinary and transdisciplinary research

The interdisciplinary and transdisciplinary research led to the identification of teaching and learning aspects (Figure 6.6) which have their origin in disciplinary paradigms and education practice. The novelty of this way of doing research necessitated to stick to the fundamental science pillars of ‘logic’ and ‘facts’ as described by Luyten and Hoefnagel (1995). However, the decision-making process in the present research was still complicated, because it was experienced that the logic by taking one disciplinary viewpoint could be different from another disciplinary viewpoint. Similarly, it was experienced that the logic from theoretical perspective was different from practical perspective. In these cases, the approach of pragmatism was often taken as suggested by Nuijten (2011). However, it can be questioned whether the approach of pragmatism leads to repeatable research results. It is therefore suggested to provide guidelines to educational psychologists that will facilitate the conduct of inter- and transdisciplinary research in education.

6.4.3 Pioneering research work

The few available scientific literature, expertise, and experience on the teaching and learning of IDT, as recently confirmed by Morrison (2015), resulted in frequently pioneering during the practise of this thesis research work. The few availability of scientific knowledge provided the opportunity to make a contribution to the scientific field. On the contrary, it also meant that the intended empirical validation of the found subskills of IDT and enabling conditions across higher education (chapter 2) had to be postponed. Instead, an instructional design for one course in FQM was developed (chapter 3) using the literature review insights gained. As a consequence, the fundament of the developed framework (Figure 6.6) is, in fact, one case-study which means an in-depth knowledge basis, instead of a wide knowledge basis by examination of, for instance, multiple courses. To counter this limitation, a broad variety of scientific publications and various disciplinary experts has been consulted during the research, so that the framework can be considered as starting point for the further development of a more generic framework in the future.

6.4.4 Dual focus on teaching and learning

The dual focus on teaching and learning was necessary to gain a comprehensive understanding on the pedagogical content knowledge for IDT (Figure 6.6). This resulted in a dual investigation on teaching and on learning with trade-offs on both sides. In turn, these trade-offs led to results which are not always specific enough for the teaching and the learning of IDT. For example, the enabling condition with respect to the learning part of ‘phased with gradual advancement’ (see Figure 6.6) can likely be attributed to every complex cognitive skill. It would be interesting to know what should be phased with gradual advancement particular for the complex cognitive skill of IDT. Should the five subskills of interdisciplinary be taught among engineering students one by one, or should all five subskills being taught at the same time? In this research, it was chosen to teach all five subskills at the same time and to create a linear and iterative pattern in the teaching of these five subskills to meet the other enabling conditions with respect to the learning part of 'linear' and 'iterative' as well (see Figure 6.6).

6.4.5 Self-devised research methods

The self-devised research methods of studies II, III, and IV (see Figure 1.4) which were embedded in the instructional course design resulted in naturally occurring data from education practice. This naturally occurring data was in line with the adopted transdisciplinary research approach and resulted in an ecological valid research context. However, the internal validity of each self-devised research method, that is the extent to which the empirical measures adequately reflect the real meaning of the concepts under study as defined by Babbie (2010, p. 160), was not tested. Despite this lack of testing, it is still expected that the internal validity of the research methods was sufficient to its purpose, because all students reports were considered as plausible at first sight; after scrutiny of the reports, no 'outliers' could be identified. In addition, the self-devised critical appraisal form being used in the literature review (chapter 2) comprised a general part based upon critical appraisal examples as provided by, for instance, Gough et al., (2012) and a tailor-made part for the theoretical purpose of the review study. The need for more validation of this research method is also recognized.

6.4.6 Small size of data sets

Each study featured a relatively small size of data which has been qualitatively analysed via the use of generally acknowledged handbooks (e.g., Miles et al., 2013). The qualitative analyses were done as accurate as possible, being identified as most suitable for the particular study to construct meaning of the data collected. Following the definition of Hsieh and Shannon for qualitative content analysis (2005, p. 1278), it considers a subjective interpretation of the content of text data through the systematic classification process of coding and identifying themes or patterns compared to quantitative data analysis. To counter the subjectivity, the interpretations were multiply discussed with peers, tested in own teaching practice, and were continuously evaluated as described by Postholm and Moen (2011) with their research and development (R&D) model for the continuous improvement of education practice. The relatively small data set of the FQM course seemed to be sufficient for its purpose to start building theory on pedagogical content knowledge for IDT. However, this theory building should be continued with larger data sets across HEE, and patterns should be determined by means of a validated coding scheme as described by Schreier (2012).

6.5 Further research and implications

In extending the scientific research on the teaching and the learning of IDT, multiple research directions could be identified. First, further development of the pedagogical content knowledge for IDT, as represented in Figure 6.6, via research replication coupled with experiments is recommended. For example, relationships between the teaching and learning aspects, the learning processes, and learning outcomes should be investigated. Second, empirical validation of the literature results (chapter 2) by, for instance, comparing and contrasting various instructional designs, learning processes, and learning outcomes is recommended. This could be done once the education practice shows relevant and comparable cases. Third, extension of the design-based research approach, as recommended by Gouvea et al. (2013), to continuously improve education practice on IDT. Fourth, instead of cohort student analysis like being done for the present research, the individual student analysis of learning challenges, strategies, and outcomes could be conducted to reveal individual patterns of learning. Fifth, the analysis of learning activities to start understanding the subskills development of IDT, thereby using the publication of Schwartz (2009) as starting point.

Lastly, the elaboration of student-centred research with teacher-centred research (e.g., Pharo & Bridle, 2012): “What do teachers experience as challenging in teaching IDT and what do they perceive as contributing to their own learning processes and to the student learning processes?” are interesting research questions.

The thesis results as schematically represented in Figure 6.6 suggest the importance of (a) a joint focus of teaching and learning by teachers and designers of HEE to improve the learning on IDT, (b) an understanding of the constructive alignment theory of Biggs and Tang and the learning theory of Illeris by teachers and designers of HEE, (c) the realization of consistent learning environments on IDT, in which students are triggered to develop IDT on the highest level depending on their individual capabilities as claimed by Fischer (1980), and (d) the realization of an integrated pedagogical support on IDT, in which students receive guidance on the cognitive, emotional, and social processes during IDT learning.

6.6 Conclusions

The present research aim was to gain insight in the pedagogical content knowledge for IDT to enhance student learning across HEE. This thesis concludes that the identified teaching and learning aspects (Figure 6.6) involve an initial basis of the pedagogical content knowledge for IDT, which needs validation across HEE. In addition, the present thesis research concludes that the constructive alignment theory of Biggs and Tang and the learning theory of Illeris are indeed suitable to develop pedagogical content knowledge for a particular complex cognitive skill such as IDT (Figures 6.2 – 6.5). Furthermore, the present research concludes that the research methodology of design-based research is beneficial to jointly investigate design criteria and learning process characteristics (chapters 3 – 5).

References

Adams, J. U. (2007). Interdisciplinary research: Building bridges, finding solutions. *Science 23*, 1315-1318.

Anderman, E. M. (2011). Educational psychology in the twenty-first century: Challenges for our community. *Educational Psychologist, 46*(3), 185-196.

Andrade, K., Corbin, C., Diver, S., Eitzel, M. V., Williamson, J., Brashares, J., & Fortmann, L. (2014). Finding your way in the interdisciplinary forest: Notes on education future conservation practitioners. *Biodiversity and Conservation, 23,* 3405-3423.

Augsburg, T. (2006). *Becoming interdisciplinary: An introduction to interdisciplinary studies*. Dubuque, IA: Kendall/Hunt.

Augsburg, T., Bekken, B. M., Hovland, K., Klein, J. T., Luckie, D. B., Madison, B. L., . . . Vaz, R. (2013). Insights on interdisciplinary teaching and learning. White paper. In A. M. McCright & W. Eaton (Eds.), (pp. 1-36): East Lansing, MI: Michigan State University.

Aziz, A. A., Yusof, K. M., & Yatim, J. M. (2012). Evaluation on the effectiveness of learning outcomes from students' perspectives. *Procedia - Social and Behavioral Sciences, 56*, 22-30.

Babbie, E. R. (2010). *The practice of social research* (12th ed.). Belmont: Cengage Learning.

Bajada, C., & Trayler, R. (2013). Interdisciplinary business education: Curriculum through collaboration. *Education and Training, 55*(4/5), 385-402.

Barab, S., & Squire, K. (2004). Design-based research: Putting a stake in the ground. *The Journal of the Learning Sciences, 13*(1), 1-14.

Biggs, J. B. (1993). From theory to practice: A cognitive systems approach. *Higher Education Research and Development, 12*(1), 73-86.

Biggs, J. B. (1999a). *Teaching for quality learning at university: what the student does* (1st ed.). Buckingham: Open University Press.

Biggs, J. B. (1999b). What the student does: Teaching for enhancing learning. *Higher Education Research & Development, 18*(1), 57-75.

Biggs, J. B. (2003). *Teaching for quality learning at university: What the student does* (2nd ed.). Berkshire: Open University Press.

Biggs, J. B. (2012). What the students does: Teaching for enhanced learning. *Higher Education Research & Development, 31*(1), 39-55.

Biggs, J. B., & Collis, K. F. (Eds.). (1982). *Evaluating the quality of learning: the SOLO taxonomy (Structure of the Observed Learning Outcome)*: New York: Academic Press.

Biggs, J. B., & Tang, C. (2007). *Teaching for quality learning at university: What the student does* (3rd ed.). Berkshire: Open University Press.

Biggs, J. B., & Tang, C. (2011). *Teaching for quality learning at university* (4th ed.). Berkshire: Open University Press.

Boeije, H. R. (2010). *Analysis in qualitative research*. London: Sage.

Boix Mansilla, V. (2010). Learning to synthesize: The development of interdisciplinary understanding. In R. Frodeman, J. T. Klein, & C. Mitcham (Eds.), *The Oxford handbook of interdisciplinarity* (pp. 288-306). New York: Oxford University Press.

Boix Mansilla, V., & Duraising, E. D. (2007). Targeted assessment of students' interdisciplinary work: An empirically grounded framework proposed. *The Journal of Higher Education 78*(2), 215-237.

Boix Mansilla, V., Duraising, E. D., Wolfe, C. R., & Haynes, C. (2009). Targeted assessment rubric: An empirically grounded rubric for interdisciplinary writing. *The Journal of Higher Education, 80*(3), 334-353.

Boix Mansilla, V., Lamont, M., & Sato, K. (2012). *Successful interdisciplinary collaborations: The contributions of shared socio-emotional-cognitive platforms to* *interdisciplinary synthesis*. 4S Annual Meeting. Vancouver, Canada. Retrieved from http://nrs.harvard.edu/urn-3:HUL.InstRepos:10496300

Boix Mansilla, V., Miller, W. C., & Gardner, H. (2000). On disciplinary lenses and interdisciplinary work. In S. Wineburg & P. Grossman (Eds.), *Interdisciplinary curriculum: Challenges of implementation* (pp. 17-38). New York: Teachers College Press.

Boni, A. A., Weingart, L. R., & Evenson, S. (2009). Innovation in an academic setting: Designing and leading a business through market-focused, interdisciplinary teams. *Academy of Management Learning & Education, 8*(3), 407-417.

Borrego, M., & Cutler, S. (2010). Constructive alignment of interdisciplinary graduate curriculum in engineering and science: An analysis of successful IGERT proposals. *Journal of Engineering Education, 99*(4), 355-369.

Borrego, M., & Newswander, L. K. (2010). Definitions of interdisciplinary research: Toward graduate-level interdisciplinary learning outcomes. *The Review of Higher Education, 34*(1), 61-84.

Bossio, D., Loch, B., Schier, M., & Mazzolini, A. (2014). A roadmap for forming successful interdisciplinary education research collaborations: A reflective approach. *Higher Education Research & Development, 33*(2), 198-211.

Boud, D. (2001). Using journal writing to enhance reflective practice. *New Directions for Adult and Continuing Education, 90*, 9-17.

Bradbeer, J. (1999). Barriers to interdisciplinarity: Disciplinary discourses and student learning. *Journal of Geography in Higher Education, 23*(3), 381-396.

Brand, B. R., & Triplett, C. F. (2012). Interdisciplinary curriculum: An abondoned concept? *Teachers and Teaching Practice: Theory and Practice, 18*(3), 381-393.

Briggs, A. R. J. (2007). The use of modelling for theory building in qualitative analysis. *British Educational Research Journal, 33*(4), 589-603.

Brookfield, S. D. (1995). *Becoming a critically reflective teacher*. San Francisco: Jossey-Bass.

Brown, A. L. (1992). Design experiments: Theoretical and methodological challenges in creating complex interventions in classroom settings. *The Journal of the Learning Sciences*, *2*(2), 141-178.

Bruce, A., Lyall, C., Tait, J., & Williams, R. (2004). Interdisciplinary integration in Europe: The case of the Fifth Framework programme. *Futures, 36*(4), 457-470.

Cantillon-Murphy, P., McSweeney, J., Burgoyne, L., O'Tuathaigh, C., & O'Flynn, S. (2015). Addressing biomedical problems through interdisciplinary learning: A feasibility study. *International Journal of Engineering Education*, *31*(1), 282-291.

Chanan, A., Vigneswaran, S., & Kandasamy, J. (2012). Case study research: Training interdisciplinary engineers with context-dependent knowledge. *European Journal of Engineering*, *37*(1), 97-104.

Chandramohan, B., & Fallows, S. (Eds.). (2009). *Interdisciplinary learning and teaching in higher education: Theory and practice*. New York: Routledge.

Chen, S., Hsu, I. C., & Wu, C. M. (2009). Evaluation of undergraduate curriculum reform for interdisciplinary learning. *Teaching in Higher Education*, *14*(2), 161-173.

Cobb, P., Confrey, J., diSessa, A., Lehrer, R., & Schauble, L. (2003). Design experiments in educational research. *Educational Researcher, 32*(1), 9-13.

Collins, A., Joseph, D., & Bielaczyc, K. (2004). Design research: Theoretical and methodological issues. *The Journal of the Learning Sciences, 13*(1), 15-42.

D' Mello, S., & Graesser, A. (2012). Dynamics of affective states during complex learning. *Learning and Instruction*, *22*, 145-157.

D' Mello, S., Lehman, B., Pekrun, R., & Graesser, A. (2014). Confusion can be beneficial for learning. *Learning and Instruction*, *29*, 153-170.

Davidson, R. A. (2015). Integrating disciplinary contributions to achieve community resilience to natural disasters. *Civil Engineering and Environmental Systems, 32*(1-2), 55-67.

Davies, M., Devlin, M., & Tight, M. (Eds.). (2010). *International perspectives on higher education research: Interdisciplinary higher education: Perspectives and practicalities* (Vol. 5). Bingley: Emerald Group Publishing Limited.

Dede, C. (2004). If design-based resarch is the answer, what is the question? A commentary on Collins, Joseph, and Bielaczyc; Di Sessa and Cobb; and Fishman, Marx, Blumenthal, Krajcik, and Soloway in the JLS special issue on design-based research. *The Journal of the Learning Sciences*, *13*(1), 105-114.

Defila, R., & DiGiulio, A. (2015). Integrating knowledge: Challenges raised by the "Inventory of Synthesis". *Futures, 65*(1), 123-135.

Derry, S. J., DuRussel, L. A., & O'Donnel, A. M. (1998). Individual and distributed cognitions in interdisciplinary teamwork: A developing case study and emerging theory. *Educational Psychology Review, 10*(1), 25-56.

Dowds, B. N. (1998). Helping students make connections across disciplines. *Creativity Research Journal*, *1998*(11), 1.

Eckstein, B. (1976). Overcoming non-cognitive problems in interdisciplinary engineering work. *European Journal of Engineering Education, 1*(3), 217-221.

Edelson, D. C. (2002). Design research: What we learn when we engage in design. *The Journal of the Learning Sciences, 11*(1), 105-121.

Eisen, A., Hall, A., Soon Lee, T., & Zupko, J. (2009). Teaching water: Connecting across disciplines and into daily life to address complex societal issues. *College Teaching, 57*(2), 99-104.

Engström, H. (2014). A model for conducting and assessing interdisciplinary undergraduate dissertations. *Assessment & Evaluation in Higher Education,* http://dx.doi.org/10.1080/02602938.2014.950552.

Fernandez, J. M., Van Hattum-Janssen, N., Ribeiro, A. N., Fonte, V., Santos, L. P., & Sousa, P. (2012). An integrated approach to develop professional and technical skills for informatics engineering students. *European Journal of Engineering Education, 37*(2), 167-177.

Fiegel, G. L. (2013). Incorporating learning outcomes into an introductory geotechnical engineering course. *European Journal of Engineering Education, 38*(3), 238-253.

Field, M., & Lee, R. (1992). Assessment of interdisciplinary programmes. *European Journal of Education, 27*(3), 277-283.

Fischer, K. W. (1980). A theory of cognitive development: The control and construction of hierarchies of skills. *Psychological Review, 87*(6), 477-531.

Fortuin, K. P. J., Van Koppen, C. S. A., & Kroeze, C. (2013). The contribution of systems analysis to training students in cognitive interdisciplinary skills in environmental science education. *Journal of Environmental Studies and Sciences, 3*(2), 139-152.

Fortuin, K. P. J., Van Koppen, C. S. A., & Leemans, R. (2011). The value of conceptual models in coping with complexity and interdisciplinarity in environmental sciences education. *Bioscience, 61*(10), 802-814.

Franks, D., Dale, P., Hindmarsh, R., Fellows, C., Buckridge, M., & Cybinski, P. (2007). Interdisciplinary foundations: Reflecting on interdisciplinarity and three decades of teaching and research at Griffith University, Australia. *Studies in Higher Education, 32*(2), 167-185.

Froyd, J. E., & Ohland, M. W. (2005). Integrated engineering curricula. *Journal of Engineering Education, 94*(1), 147-164.

Gardner, H. (2008). *Five minds for the future*. Boston: Harvard Business School Publishing.

Gero, A. (2013). Interdisciplinary program on aviation weapon systems as a means of improving high school students attitudes towards physics and engineering. *International Journal of Engineering Education, 29*(4), 1047-1054.

Gharaibeh, K., Harb, B., Salameh, H. B., Zoubi, A., Shamali, A., Murphy, N., & Brennan, C. (2013). Review and redesign of the curriculum of a Masters programme in telecommunications engineering - Towards an outcome-based approach. *European Journal of Engineering Education, 38*(2), 194-210.

Gilkey, M. B., & Earp, J. A. L. (2006). Effective interdisciplinary training: Lessons from the University of North Carolina's Student Health Action Coalition. *Academic Medicine, 81*(8), 749-758.

Golde, C. M., & Alix Gallagher, A. (1999). The challenges of conducting interdisciplinary research in traditional doctoral programs. *Ecosystems, 2*, 281-285.

Goleman, D. (1996). *Emotionele intelligentie: Emoties als sleutel tot succes [Emotional intelligence: Emotions a key to success]*. Amsterdam / Antwerpen: Contact.

Goodman, B. E., & Huckfeldt, V. E. (2013). The rise and fall of a required interdisciplinary course: Lessons learned. *Innovative Higher Education, 39*(1), 75-88.

Gough, D., Oliver, S., & Thomas, J. (2012). *An introduction to systematic reviews*. Thousand Oaks, California: Sage.

Gouvea, J. S., Sawtelle, V., Geller, B. D., & Turpen, C. (2013). A framework for analyzing interdisciplinary tasks: Implications for student learning and curricular design. *CBE-Life Sciences Education, 12*(2), 187-205.

Graybill, J. K., Dooling, S., Shandas, V., Withey, J., Greve, A., & Simon, G. L. (2006). A rough guide to interdisciplinarity: Graduate student perspectives. *Bioscience, 56*(9), 757-763.

Groen, M. (2011). *Reflecteren: de basis, op weg naar bewust en bekwaam handelen [Reflecting: the basis, the roadmap to conscious and competent performance]*. Groningen, Houten: Noordhoff Uitgevers.

Guo, T. L., & Liu, J. (2011). Multi-disciplinary education for product design and development. *Advanced Materials Research, 156-157*, 681-684.

Haase, S., Chen, H. L., Sheppard, S., Kolmos, A., & Mejlgaard, N. (2013). What does it take to become a good engineer? Identifying cross-natural engineering student profiles according to perceived importance of skills. *International Journal of Engineering Education, 29*(3), 698-713.

Hackett, E. J., & Rhoten, D. R. (2009). The snowbird charrette: Integrative interdisciplinary collaboration in environmental research design. *Minerva, 47*(4), 407-440.

Harden, R. M., Crosby, J. R., & Davis, M. H. (1999). AMEE guide no. 14: Outcome-based education: Part 1 - An introduction to outcome-based education *Medical Teacher, 21*(1), 7-14.

Harrison, G. P., Macpherson, D. E., & Williams, D. A. (2007). Promoting interdisciplinarity in engineering teaching. *European Journal of Engineering Education, 32*(3), 285-293.

Haynes, C. (Ed.). (2002). *Innovations in interdisciplinary teaching*: Westport, CT : ACE/Oryx Press.

Haynes, C., & Brown Leonard, J. (2010). From surprise parties to mapmaking: Undergraduate journeys toward interdisciplinary understanding. *The Journal of Higher Education 81*(5), 645-666.

He, P., Chen, N., & Wu, J. (2011). Study of interdisciplinary specialized mechanical engineering education. *Advanced Materials Research 199-200*, 1676-1679.

Hersam, M. C., Luna, M., & Light, G. (2004). Implementation of interdisciplinary group learning and peer assessment in a nanotechnology engineering course. *Journal of Engineering Education, 93*(1), 49-57.

Hmelo-Silver, C. E., & Azevedo, R. (2006). Understanding complex systems: Some core challenges. *The Journal of the Learning Sciences*, *15*(1), 53-61.

Hoadley, C. M. (2004). Methodological alignment in design-based research. *Educational Psychologist*, *39*(4), 203-212.

Holley, K. A. (2009). *Understanding interdisciplinary challenges and opportunities in higher education*. San Francisco: Wiley Company.

Holley, K. A. (2013). Doctoral education and the development of an interdisciplinary identity. *Innovations in Education and Teaching International*, *http://dx.doi.org/10.1080/14703297.2013.847796*.

Hooker, H. D., Deutschman, W. A., & Avery, B. J. (2014). The biology and chemistry of brewing: An interdisciplinary course. *Journal of Chemical Education, 91*, 336-339.

Hsieh, H. F., & Shannon, S. E. (2005). Three approaches to qualitative content analysis. *Qualitative Health Research, 15*(9), 1277-1288.

Hursh, B., Haas, P., & Moore, M. (1983). An interdisciplinary model to implement general education. *Journal of Higher Education, 54*(1), 42-59.

Illeris, K. (2002). *The three dimensions of learning: Contemporary learning theory in the tension field between the cognitive, the emotional, and the social*. Frederiksberg: Roskilde University Press.

Illeris, K. (2003). Towards a contemporary and comprehensive theory of learning. *International Journal of Lifelong education, 22*(4), 396-406.

Illeris, K. (2007). *How we learn: Learning and non-learning in school and beyond*. New York: Routledge.

Ivanitskaya, L., Clark, D., Montgomery, G., & Primeau, R. (2002). Interdisciplinary learning: Process and outcomes. *Innovative Higher Education, 27*(2), 95-111.

Jacobson, M. J., & Wilensky, U. (2006). Complex systems in education: Scientific and educational importance and implications for the learning sciences. *The Journal of the Learning Sciences, 15*(1), 11-34.

Johannes, M. N., & Kasteren, V. (1996). Interdisciplinary teaching within engineering education. *European Journal of Engineering Education, 21*(4), 387-392.

Johnson, R. B., & Onwuegbuzie, A. J. (2004). Mixed methods research: A research paradigm whose time has come. *Educational Researcher, 33*(7), 14-26.

Joseph, D. (2004). The practice of design-based research: Uncovering the interplay between design, research, and the real-world context. *Educational Psychologist, 39*(4), 235-242.

Kelly, A. E. (2004). Design research in education: Yes, but is it methodological? *The Journal of the Learning Sciences, 13*(1), 115-128.

Klein, J. T. (1990). *Interdisciplinarity: History, theory, and practice*. Detroit: Wayne State University Press.

Klein, J. T. (1996). *Crossing Boundaries: Knowledge, disciplinarities and interdisciplinarities*. Charlottesville and London: University Press of Virginia.

Klein, J. T. (2005). Integrative learning and interdisciplinary studies. *Peer Review, 7*(4), 8-10.

Klein, J. T. (2008). Evaluation of interdisciplinary and transdisciplinary research. *American Journal of Preventive Medicine, 35*(2), S116-S123.

Klein, J. T. (2010). A taxonomy of interdisciplinarity. In R. Frodeman, J. T. Klein, & C. Mitcham (Eds.), *The Oxford handbook of interdisciplinarity* (pp. 15-30). Oxford: Oxford University Press.

Knight, D. B., Lattuca, L. R., Kimball, E. W., & Reason, R. D. (2013). Understanding interdisciplinarity: Curricular and organizational features of undergraduate interdisciplinary programs. *Innovative Higher Education, 38*(2), 143-158.

Kockelmans, J. J. (Ed.). (1979). *Interdisciplinarity and higher education*. University Park and London: The Pennsylvania State University Press.

Lach, D. (2014). Challenges of interdisciplinary research: Reconciling qualitative and quantitative methods for understanding human-landscape systems. *Environmental Management*, *53*(1), 88-93.

Langer, A. M. (2002). Reflecting on practice: Using learning journals in higher and continuing education. *Teaching in Higher Education*, *7*(3), 337-351.

Lattuca, L. R., Knight, D., & Bergom, I. (2013). Developing a measure of interdisciplinary competence. *International Journal of Engineering Education, 29*(3), 726-739.

Lattuca, L. R., Voigt, L. J., & Fath, K. Q. (2004). Does interdisciplinarity promote learning? Theoretical support and researchable questions. *The Review of Higher Education, 28*(1), 23-48.

Liebert, W. J. (2013). Preparing to understand and use science in the real world: Interdisciplinary study concentrations at the technical university of Darmstadt. *Science and Engineering Ethics*, *19*(4), 1533-1550.

Linn, M. C., Lee, H. S., Tinker, R., Husic, F., & Chiu, J. L. (2006). Teaching and assessing knowledge integration in science. *Science, 313*, 1049-1050.

Linn, M. C., Palmer, E., Baranger, A., Gerard, E., & Stone, E. (2015). Undergraduate research experiences: Impacts and opportunities. *Science, 347*(6222), 627.

Linnemann, A. R., Schroën, C. G. P. H., & Van Boekel, M. J. A. S. (Eds.). (2011). *Food product design: An integrated approach*. Wageningen: Wageningen Academic Publishers.

Lok, C. (2008). Interdisciplinary science: Harvard under review. *Nature, 454*, 686-689.

Lund, V., Coleman, G., Gunnarsson, S., Calvert Appleby, M., & Karkinen, K. (2006). Animal welfare science - working at the interface between the natural and social sciences. *Applied Animal Behaviour Science, 97*, 37-49.

Luning, P. A., & Marcelis, W. J. (2006). A techno-managerial approach in food quality management research. *Trends in Food Science & Technology, 17*(7), 378-385.

Luning, P. A., & Marcelis, W. J. (2007). A conceptual model of food quality management functions based on a techno-managerial approach. *Trends in Food Science & Technology, 18*(3), 159-166.

Luning, P. A., & Marcelis, W. J. (2009a). *Food Quality Management - Technological and managerial principles and practices*. Wageningen: Wageningen Academic Publishers.

Luning, P. A., & Marcelis, W. J. (2009b). A food quality management research methodology integrating technological and managerial theories. *Trends in Food Science & Technology, 20*(1), 35-44.

Luyten, J., & Hoefnagel, B. (Eds.). (1995). *Het oog van de de wetenschapsfilosofie*. Amsterdam: Boom.

Lyall, C., Bruce, A., Tait, J., & Meagher, L. (2011). *Interdisciplinary research journeys: Practical strategies for capturing creativity*. New York: Bloomsbury Publishing

Lyall, C., & Meagher, L. R. (2012). A masterclass in interdisciplinarity: Research into practice in training the next generation of interdisciplinary researchers. *Futures*, *44*(6), 608-617.

MacKinnon, P. J., Hine, D., & Barnard, R. T. (2013). Interdisciplinary science research and education. *Higher Education Research & Development*, *32*(3), 407-419.

MacPhail, A., Tannehill, D., & GocKarp, G. (2013). Preparing physical education preservice teachers to design instructionally aligned lessons through constructivist pedagogical practices. *Teaching and teachers education, 33*, 100-112.

Manathunga, C., Lant, P., & Mellick, G. (2006). Imagining an interdisciplinary doctoral pedagogy. *Teaching in Higher Education*, *11*(3), 365-379.

Martin, R., Maytham, B., Case, J., & Fraser, D. (2005). Engineering graduates' perceptions of how well they were prepared for work in industry. *European Journal of Engineering Education, 30*(2), 167-180.

Mascarelli, A. (2013). Environmental puzzle solvers: Sustainability training is on the rise, and institutions are working out how best to translate it into marketable skills. *Nature*, *494*, 507-509.

McFadden, K. L., Chen, S.-J., Munroe, D. J., Naftzger, J. R., & Selinger, E. M. (2011). Creating an innovative interdisciplinary graduate certificate program. *Innovative Higher Education, 36*(3), 161-176.

McGregor, H. V., O'Shea, B., Brewer, C., Abuodha, P., & Pharo, E. J. (2014). Internationalization of the curriculum through student-led climate change teaching activity. *Journal of Geoscience, 62*(3), 353-363.

McKenney, S., & Reeves, T. C. (2012). *Conducting educational design research*. London: Routledge.

Miles, M. B., Huberman, A. M., & Saldaña, J. (2013). *Qualitative data analysis* (third ed.). Thousand Oaks: Sage.

Milios, K., Zoiopoulos, P. E., Pantouvakis, A., Mataragas, M., & Drosinos, E. H. (2013). Techno-managerial factors related to food safety management system in food businesses. *British Food Journal, 115*(9), 1381-1399.

Mingers, J., & Brocklesby, J. (1997). Multimethodology: Towards a framework for mixing methodologies. *Omega, 25*(5), 489-509.

Misra, S., Harvey, R. H., Stokols, D., Pine, K. H., Fuqua, J., Shokair, S. M., & Whiteley, J. M. (2009). Evaluating an interdisciplinary undergraduate training program in health promotion research. *American Journal of Preventive Medicine, 36*(4), 358-365.

Mobley, C., Lee, C., Morse, J. C., Allen, J., & Murphy, C. (2014). Learning about sustainability: An interdisciplinary graduate seminar in biocomplexity. *International Journal of Sustainability in Higher Education, 15*(1), 16-33.

Morrison, D. (2015). *The underdetermination of interdisciplinarity: Theory and curriculum design in undergraduate higher education.* University of Glasgow, Glasgow.

Morse, W. C., Nielsen-Pincus, M., Force, J. E., & Wulfhorst, J. D. (2007). Bridges and barriers to developing and conducting interdisciplinary graduate-student team research. *Ecology and Society, 12*(2), art. 8.

Mulder, M., & Kintu, D. K. (2013). Curriculum development in the floriculture sector in Uganda: A design-based validation research study. In T. Plomp & N. Nieveen (Eds.), *Educational design research: Introduction and illustrative cases* (pp. 881-904). Enschede: SLO Netherlands institute for curriculum development.

Nardone, C. F., & Lee, R. G. (2011). Critical Inquiry across the disciplines: Strategies for student-generated problem posing. *College Teaching, 59*(1), 13-22.

Newell, W. H. (1992). Academic disciplines and undergraduate interdisciplinary education: Lessons from the school of interdisciplinary studies at Miami University, Ohio. *European Journal of Education, 27*(3), 211-221.

Newell, W. H. (2007). Decision making in interdisciplinary studies. In G. Morçöl (Ed.), *Handbook of decision making* (pp. 245-263). New York: CRC Press.

Newell, W. H. (2010a). Educating for a complex world: Integrative learning and interdisciplinary studies. *Liberal Education, 96*(4).

Newell, W. H. (2010b). Undergraduate general education. In R. Frodeman, J. T. Klein, & C. Mitcham (Eds.), *The Oxford handbook of interdisciplinarity*. New York: Oxford University Press.

Ng, B. L. L., Yap, K. C., & Hoh, Y. K. (2011). Students' perception of interdisciplinary, problem-based learning in a food biotechnology course. *Journal of Food Science Education, 10*(1), 4-8.

Nicol, D. J., & Macfarlane-Dick, D. (2006). Formative assessment and self-regulated learning: A model and seven principles of good feedback practice. *Studies in Higher Education, 31*(2), 199-218.

Nieveen, N. (2007). Formative evaluation in educational design research. In T. Plomp & N. Nieveen (Eds.), *An introduction to educational design research* (pp. 89-101). Enschede: SLO Netherlands Institute for Curriculum Development.

Nieveen, N., & Folmer, E. (2013). Formative evaluation in educational design research. In T. Plomp & N. Nieveen (Eds.), *Educational design research part A: An introduction* (pp. 152-169). Enschede: SLO: Netherlands Institute for Curriculum Development.

Nikitina, S. (2005). Pathways of interdisciplinary cognition. *Cognition & Instruction, 23*(3), 389-425.

Nikitina, S. (2006). Three strategies for interdisciplinary teaching: Contextualizing, conceptualizing, and problem-centring. *Journal of Curriculum Studies 38*(3), 251-271.

Nuijten, E. (2011). Combining research styles of the natural and social sciences in agricultural research. *NJAS- Wageningen Journal of Life Sciences, 57*(3-4), 197-205.

O'Byrne, D., Dripps, W., & Nicholas, K. A. (2015). Teaching and learning sustainability: An assessment of the curriculum content and structure of sustainability degree programs in higher education. *Sustainability Science, 10*(1), 43-59.

O'Rourke, M., Crowley, S., Eigenbrode, S. D., & Wulfhorst, J. D. (2013). *Enhancing communication and collaboration in interdisciplinary research*. Thousand Oaks: Sage

Öberg, G. (2009). Facilitating interdisciplinary work: Using quality assessment to create common ground. *Higher Education, 57*(4), 405-415.

Ollis, D. F. (2004). Basic elements of multidisciplinary design courses and projects. *International Journal of Engineering Education, 20*(3), 391-397.

Penuel, W. R., Confrey, J., Maloney, A., & Rupp, A. A. (2014). Design decisions in developing learning trajectories-based assessments in mathematics: A case-study. *The Journal of the Learning Sciences, 23*(1), 47-95.

Penuel, W. R., Fishman, B. J., Cheng, B. H., & Sabelli, N. (2011). Organizing research and development at the intersection of learning, implementation, and design. *Educational Researcher, 40*(7), 331-337.

Perry jr., W. G. (1999). *Forms of ethical and intellectual development in the college years*. San Francisco: Jossey-Bass Publishers.

Pharo, E., & Bridle, K. (2012). Does interdisciplinarity exist behind the facade of traditional disciplines? A study of natural resource management teaching. *Journal of Geography in Higher Education, 36*(1), 65-80.

Pharo, E., Davison, A., McGregor, H., Warr, K., & Brown, P. (2014). Using communities of practice to enhance interdisciplinary teaching: Lessons from four Australian institutions. *Higher Education and Development, 33*(2), 341-354.

Pharo, E., Davison, A., Warr, K., Nursey-Bray, M., Beswick, K., Wapstra, E., & Jones, C. (2012). Can teacher collaboration overcome barriers to interdisciplinary learning in a disciplinarity university? A case study using climate change. *Teaching in Higher Education, 17*(5), 497-507.

Plomp, T., & Nieveen, N. (2013). *Educational design research: Introduction and illustrative cases*. Enschede: SLO Netherlands Institute for Curriculum Development.

Postholm, M. B., & Moen, T. (2011). Communities of development: A new model for R&D work. *Journal of Educational Change*, *12*(4), 385-401.

Quinton, S., & Smallbone, T. (2010). Feeding forward: Using feedback to promote student reflection and learning - a teaching model. *Innovations in Education and Teaching International*, *47*(1), 125-135.

Redish, E. F., & Smith, K. A. (2008). Looking beyond content: Skill development for engineers. *Journal of Engineering Education*, *97*(3), 295-307.

Reid, H. M. (2014). *Introduction to statistics: Fundamental concepts and procedures of data analysis*. Thousand Oaks, California: Sage.

Repko, A. F. (2012). *Interdisciplinary research: Process and theory*. Thousand Oaks: Sage.

Repko, A. F., Newell, W. H., & Szostak, R. (2012). *Case studies in interdisciplinary research*. Thousand Oaks, California: Sage.

Repko, A. F., Szostak, R., & Philips Buchberger, M. (2014). *Introduction to interdisciplinary studies*. Thousands Oaks, California: Sage.

Rhee, J., Cordero, E. C., & Quill, L. R. (2010). Pilot implementation of an interdisciplinary course on climate solutions. *International Journal of Engineering Education, 26*(2), 391-400.

Richards, D. G. (1996). The meaning and relevance of synthesis in interdisciplinary studies. *The Journal of General Education 45*, 114-128.

Richter, D. M., & Paretti, M. C. (2009). Identifying barriers to and outcomes of interdisciplinarity in the engineering classroom. *European Journal of Engineering Education, 34*(1), 29-45.

Rives-East, D., & Lima, O. K. (2013). Designing interdisciplinary science/humanities courses: Challenges and solutions. *College Teaching, 61*(3), 100-106.

Roehler, L., Fear, K., & Herrmann, B. A. (1998). Connecting and creating for learning: Integrating subject matter across the curriculum and the school. *Educational Psychology Review, 10*(2), 201-225.

Saldaña, J. (2009). *The coding manual for qualitative researchers*. Thousand Oaks, California: Sage.

Saljö, R. (2009). Learning, theories of learning, and units of analysis in research. *Educational Psychologist, 44*(3), 202-208.

Sandoval, W. A. (2004). Developing learning theory by refining conjectures embodied in educational designs. *Educational Psychologist, 39*(4), 213-223.

Sandoval, W. A. (2014). Conjecture mapping: An approach to systematic educational design research. *The Journal of the Learning Sciences, 23*(1), 18-36.

Sandoval, W. A., & Bell, P. (2004). Design-based research methods for studying learning in context: Introduction. *Educational Psychologist, 39*(4), 199-201.

Schaefer, D., Panchal, J. H., Thames, J. L., Haroon, S., & Mistree, F. (2012). Educating engineers for the near tomorrow. *International Journal of Engineering Education, 28*(2), 381-396.

Schmidt, A. H., Robbins, A. S. T., Combs, J. K., Freeburg, A., Jesperson, R. G., Rogers, H. S., . . . Wheat, E. (2012). A new model for training graduate students to conduct interdisciplinary, interorganizational and international research. *Bioscience*, *62*(3), 296-304.

Schreier, M. (2012). *Qualitative content analysis in practice*. London: Sage.

Schwartz, M. (2009). Cognitive development and learning: Analyzing the building of skills in classrooms. *Mind, Brain and Education, 3*(4), 198-208.

Sharp, E. (2015). Interdisciplinary experiences: A postgraduate geographer's perspective. *Journal of Geography in Higher Education, 39*(2), 220-225.

Shavelson, R. J., Philips, D. C., Towne, L., & Feuer, M. J. (2003). On the science of education design studies. *Educational Researcher, 32*(1), 25-28.

Shön, D. A. (1987). *Educating the reflective practitioner: Toward a new design for teaching and learning in the professions*. San Francisco: Jossey-Bass Inc. Publishers.

Shulman, L. S. (1987). Knowledge and teaching: Foundations of the new reform. *Harvard Educational Review, 57*(1), 1-21.

Sill, D. J. (2001). Integrative thinking, synthesis, and creativity in interdisciplinary studies. *The Journal of General Education, 50*(4), 288-311.

Silverman, D. (2013). *Doing qualitative research* (fourth ed.). London: Sage.

Smith, C. (2008). Design-focused evaluation. *Assessment & Evaluation in Higher Education, 33*(6), 631-645.

Smith, J. A., & Carey, G. (2007). Those who are crossing boundaries need less talk, more help and flexibility. *Nature, 447*, 638.

Spady, W. G. (1994). *Outcome-based education: Critical issues and answers*. Arlington: American Association of School Administrators.

Spelt, E. J. H., Biemans, H. J. A., Luning, P. A., Tobi, H., & Mulder, M. (2010). Interdisciplinary thinking in the agricultural and life sciences higher education. *Communications in Agricultural and Applied Biological Sciences, 75*(1), 73-79.

Spelt, E. J. H., Biemans, H. J. A., Tobi, H., Luning, P. A., & Mulder, M. (2009). Teaching and learning in interdisciplinary higher education: A systematic review. *Educational Psychology Review*, *21*(4), 365-378.

Spelt, E. J. H., Luning, P. A., Van Boekel, M. A. J. S., & Mulder, M. (2015). Constructively aligned teaching and learning in higher education in engineering: What do students perceive as contributing to the learning of interdisciplinary thinking? *European Journal of Engineering Education*, *40*(5), 459-475.

Spelt, E. J. H., Luning, P. A., Van Boekel, M. A. J. S., & Mulder, M. (under review). Characterization of short-term learning processes on interdisciplinary thinking in higher education in engineering

Stam, C. (2011). Bètatesten van ontwerpstellingen [Betatesting of design principles]. In J. Van Aken & D. Andriessen (Eds.), *Handboek ontwerpgericht wetenschappelijk onderzoek: wetenschap met effect [Handbook of design-oriented science research: science with effect]* (pp. 231-247). Den Haag: Boom Lemma uitgevers [Boom Lemma publishers].

Stefani, L. A. J. (2009). Assessment in interdisciplinary and interprofessional programs: Shifting paradigms. In B. Chandramohan & S. Fallows (Eds.), *Interdisciplinary learning and teaching in higher education: Theory and practice* (pp. 44-57). New York: Routledge.

Szostak, R. (2003). Classifying natural and social scientific theories. *Current Sociology, 51*(1), 27-49.

Tabak, I. (2004). Reconstructing context: Negotiating the tension between exogenous and endogenous educational design. *Educational psychologist, 39*(4), 225-233.

Ten Dam, G., Van Hout, H., Terlouw, C., & Willems, J. (2004). *Onderwijskunde hoger onderwijs*. Assen: Koninklijke Van Gorcum.

Thompson, J. L. (2009). Building collective communication competence in interdisciplinary research teams. *Journal of Applied Communication, 37*(3), 278-297.

Tong, C. H. (2010). Let interdisciplinary research begin in undergraduate years. *Nature, 463*, 157.

Turner, V. K., Benessaiah, K., Warren, S., & Iwaniec, D. (2015). Essential tensions in interdisciplinary scholarship: navigating challenges in affect, epistemologies, and structure in environment-society research centers. *Higher Education,* *http://dx.doi.org/10.1007/s10734-015-9859-9*.

Tynjälä, P., Slotte, V., Nieminen, J., Lonka, K., & Olkinuora, E. (2006). From university to working life: Graduates' workplace skills in practice In P. Tynjälä, J. Välimaa, & G. Boulton-Lewis (Eds.), *Higher education and working life: Collaborations, confrontations and challenges*. Amsterdam: Elsevier.

Vale, R. D., DeRisi, J., Philips, R., Mullins, R. D., Waterman, C., & Mitchison, T. J. (2012). Interdisciplinary graduate training in teaching labs. *Science, 338*(6114), 1542-1543.

Van Boekel, M. J. A. S. (2009). Innovation as science. In H. R. Moskowitz, I. S. Saguy, & T. Straus (Eds.), *An integrated approach to new product development* (pp. 37-52). Boca Raton: Taylor & Francis.

Van Boxtel, C. (Ed.). (2009). *Vakintegratie in de mens- en maatschappijvakken*. Amsterdam: Landelijke Expertisecentrum Mens-en Maatschappijvakken en Landelijk Expertisecentrum Economie van Hnadel.

Van Merriënboer, J. J. G. (1997). *Training complex cognitive skills: A four-component instructional design model for technical training*. Englewood Cliffs (N.J.): Educational Technology.

Van Mil, H. G. J., Foegeding, E. A., Windhab, E. J., Perrot, N., & Van der Linden, E. (2014). A complex system approach to address world challenges in food and agriculture. *Trends in Food Sciences & Technology 40*, 20-32.

Van Zonneveld, H. (1996). Interdisciplinary problem-oriented higher education at the University of Amsterdam: Development at the interfaculty department of environmental science of University of Amsterdam 1976-95. *European Journal of Engineering Education*, *21*(2), 175-183.

Vedeld, P., & Krogh, E. (2005). Crafting interdisciplinary in an M.Sc. programme in management of natural resources and sustainable agriculture. *The Forestry Chronicle, 81*(3), 330-336.

Wagner, H. H., Murphy, M. A., Holderegger, R., & Waits, L. (2012). Developing an interdisciplinary, distributed graduate course for twenty-first century scientists. *Bioscience*, *62*(2), 182-188.

Wang, X., Su, Y., Cheung, S., Wong, E., & Kwong, T. (2013). An exploration of Biggs' constructive alignment in course design and its impact on students' learning approaches. *Assessment & Evaluation in Higher Education, 38*(4), 477-491.

Warren, K. (2006). Postgraduate veterinary training in conservation medicine: an interdisciplinary program at Murdoch University, Australia. *EcoHealth 3*(1), 57-65.

Wolman, M. G. (1977). Interdisciplinary education: A continuing experiment. *Science, 198*(4319), 800-804.

Woods, C. (2007). Researching and developing interdisciplinary teaching: Towards a conceptual framework for classroom communication. *Higher Education, 54*(6), 853-866.

Wright, S. P. (2005). Fostering intellectual development of students in professional schools through interdisciplinary coursework. *Innovative Higher Education, 16*(4), 251-261.

Yang, M. (2009). Making interdisciplinary subjects relevant to students: An interdisciplinary approach. *Teaching in Higher Education, 14*(6), 597-606.

Summary

Interdisciplinary thinking (IDT) is of importance for engineers to analyse and solve complex problems such as climate change and food quality management. The problem analysis and solution development are done in collaboration with other engineers of different disciplines. In this respect, the ability of IDT is required to connect the different disciplinary knowledge in such a way that an advance in understanding occurs. Higher education in engineering (HEE) teaches IDT among future engineers to prepare them to work in interdisciplinary teams. However, a comprehensive understanding on the teaching and learning of IDT in HEE is, to date, lacking. This thesis contributed to the research of teaching and learning of IDT in higher education by investigating the teaching and learning aspects that may need to be taken into account to teach future engineers IDT with respect to complex problem solving.

In **chapter 2** scientific literature on teaching and learning of IDT was systematically reviewed. In this respect, a search strategy and critical appraisal form were developed. In critically analysing the selected 13 publications, five main sub skills of IDT were identified: ‘having knowledge of disciplines, having knowledge of disciplinary paradigms, having knowledge of interdisciplinarity, higher-order cognitive skills, and communication skills’. In addition, 26 main enabling conditions for the development of IDT could be identified for eight different categories of conditions: ‘personal characteristics, prior experiences, curriculum, teacher, pedagogy, assessment, pattern, and learning activities’.

Chapter 3 described the development and implementation of a constructively aligned design in the interdisciplinary field of food quality management (FQM). The design was chiefly based on the constructive alignment theory of Biggs and Tang (2007, 2011), the systematic review on teaching and learning of IDT in higher education, and the course content for FQM. The implemented course design was evaluated with a design-focused evaluation among the participating students. The student perceptions showed that the implementation of the constructively aligned design seems to be adequate for the redesigned FQM course in

enhancing the IDT teaching and learning. Eight key design aspects were identified: ‘learning within an interdisciplinary framework, learning via a step-by-step roadmap, receiving cognitive guidance, receiving examples to familiarize oneself, engaging in a range of disciplinary perspectives, conducting disciplinary knowledge integration a number of times, determining concrete improvements, and tackling difficult issues during learning activities’.

In **chapter 4** the learning processes of 30 students engaged in the newly designed FQM course were analytically characterized. In this respect, the learning theory of Illeris (2002, 2007) was identified as having the potential to characterize these learning processes. Illeris’s theory has an integrated viewpoint to learning in terms of three interrelated dimensions: content, incentive, and interaction. A journaling activity was embedded in the instructional design leading to 150 reflective journals with, in total 615, positive and negative experiences. The results showed that the learning processes can be divided into the content (194 out of 615 experiences), incentive (214 out of 615 experiences), and interaction (207 out of 615 experiences) dimensions. Twenty-four key learning experiences such as ‘becoming aware of disciplinary contributions to the analysis of complex problems’ were identified for IDT learning with respect to complex problem solving in FQM.

Chapter 5 described the analysis of learning challenges, student strategies, and outcomes of the newly designed FQM course. For the analysis of learning challenges and student strategies, the learning dimensions of Illeris (2002, 2007) were used and for the analysis of learning outcomes, the concepts underlying the research principles in FQM of Luning and Marcelis (2006, 2009b) were used. Two journaling activities were embedded in the instructional design, one journaling activity during the learning to collect data on learning challenges and strategies, and one journaling activity at the end of the course to collect data on the learning outcomes. Six typical challenges for all three dimensions were identified. The results also showed that students tend to report more on the content-related and interaction-

related challenges than on the incentive-related challenges. Additionally, students tend to report more on the disciplinary knowledge connections technological conditions–human dynamics and technological conditions–administrative conditions than on the food dynamics–human dynamics and food dynamics–administrative conditions in the FQM course.

In **chapter 6** the integration of the gained teaching and learning results, described in chapters 2 – 4, led to the advancement in understanding on the teaching and learning aspects that may need to be taken into account in order to teach engineering students IDT with respect to complex problem solving. To this end, the used teaching and learning models were extended and merged into one conceptual framework showing two teaching-routes with aspects related to the learning environment (*teaching-route 1*) and with aspects related to the learner (*teaching-route 2*). The thesis results suggest the importance of (a) a joint focus of teaching and learning, (b) an understanding of the constructive alignment theory of Biggs and Tang and the learning dimensions of Illeris, (c) the realization of consistent interdisciplinary learning environments, and (d) the realization of an integrated pedagogical support to IDT learning. This thesis concludes that the identified teaching and learning aspects involve an initial basis of the pedagogical content knowledge for IDT, which needs validation across HEE.

Acknowledgements

I would like to thank everyone who had a direct or indirect contribution to the writing of this thesis. During the writing, I gained much in understanding of sciences, research, education, life, and my own life. I look forward to discovering new aspects on all of these five dimensions!

Dankwoord (in Dutch)

Ik wil graag iedereen bedanken die een directe of indirecte bijdrage heeft geleverd aan het schrijven van dit proefschrift. Tijdens het schrijven heb ik veel geleerd over wetenschap, onderzoek, onderwijs, het leven en mijn leven. Ik ben benieuwd wat er nog meer te leren valt op deze vijf aspecten!

Elsbeth

About the author

Elsbeth Spelt received in 1996, cum laude, her 'propedeuse' in the field of food and health and in 2001, cum laude, her master degree in the fields of food physics and food quality management at Wageningen University, the Netherlands. After a year of working as dairy product developer, she returned back to the university to continue her research interest in interdisciplinarity. She worked at Wageningen University as teacher in the field of integrated food sciences (2002 – 2003) in the chair group of Product Design and Quality Management, as designer on E-learning at the department of Educational Staff Development (2003 – 2005), as PhD researcher (0.8 fte) on interdisciplinary teaching and learning in the chair group of Education and Competence Studies (2006 – 2011) and as adviser (0.2 fte) on interdisciplinary teaching and learning in the chair group of Food Quality and Design (2010 – 2011). She also advised on interdisciplinary teaching and learning at the lectorate Food and Health of Van Hall Larenstein University of Professional Education, the Netherlands, as part of her PhD.

During her PhD thesis research (2006 – 2015), she completed two graduate programs: in social sciences at the Wageningen School of Social Sciences (WASS) and in educational sciences at the Interuniversity Center for Educational Sciences (ICO) in the Netherlands (2005 – 2011). Her first publication on teaching and learning in interdisciplinary higher education yielded an invitation to Harvard Graduate School of Education and Harvard School of Engineering and Applied Sciences (2010 and 2011). From 2012 – 2015, she worked as teacher (0.2 fte) at the interdisciplinary bachelor program Liberal, Arts and Sciences at Utrecht University in Utrecht, the Netherlands. From 2012 onwards, she works as teacher (0.8 fte) at the interdisciplinary master program Food Quality Management in the chair group of Food Quality and Design at Wageningen University. Recently, she started as teacher (0.2 fte) at the interdisciplinary master program Learning and Innovating at STOAS Vilentum University of Applied Sciences, Wageningen, the Netherlands.

List of publications

Publications in peer-reviewed journals

Spelt, E. J. H., Biemans, H. J. A., Tobi, H., Luning, P. A., & Mulder, M. (2009). Teaching and learning in interdisciplinary higher education: A systematic review. *Educational Psychology Review, 21*(4), 365-378.

Spelt, E. J. H., Luning, P. A., Van Boekel, M. A. J. S., & Mulder, M. (2015). Constructively aligned teaching and learning in higher education in engineering: What do students perceive as contributing to the learning of interdisciplinary thinking? *European Journal of Engineering Education, 40*(5), 459-475.

Submitted publications in peer-reviewed journals

Spelt, E. J. H., Luning, P. A., Van Boekel, M. A. J. S., & Mulder, M. (under review for publication). Characterization of short-term learning processes on interdisciplinary thinking in higher education in engineering

Spelt, E. J. H., Luning, P. A., Van Boekel, M. A. J. S., & Mulder, M. (under review for publication). Student learning challenges, strategies, and outcomes of interdisciplinary thinking in higher education in engineering

Publication in non-peer reviewed journals

Spelt, E. J. H., Biemans, H. J. A., Luning, P. A., Tobi, H., & Mulder, M. (2010). Interdisciplinary thinking in the agricultural and life sciences higher education. *Communications in Agricultural and Applied Biological Sciences, 75*(1), 73-79.

Conference abstracts and proceedings

Spelt, E. J. H. (2013). *What do engineering students experience in learning interdisciplinary thinking? An analytical characterization of the learning processes*. Paper presented at The 35th annual conference of the Association for Interdisciplinary Studies, Oxford, Ohio, USA.

Spelt, E.J.H. (2012, invited). Interdisciplinair denken in de agri-business – Onderzoeksproject. Paper presented at the Seminarie 21th Century Skills and Interdisciplinariteit, Vlaamse ministerie van Onderwijs en Vorming, Antwerpen, België.

Spelt, E. J. H. (2011). *Competence development on interdisciplinary thinking in engineering higher education*. Paper presented at The 33th annual conference of the Association for Interdisciplinary Studies, Grand Rapids, Michigan, USA.

Spelt, E. J. H., Biemans, H. J. A., Tobi, H., Luning, P. A., & Mulder, M. (2011, invited). *Teaching and learning of interdisciplinary thinking in higher education: Conceptual course design*. Paper presented at the International Network for Interdisciplinarity and Transdisciplinarity (INIT), Utrecht, the Netherlands.

Spelt, E. J. H., Biemans, H. J. A., Luning, P. A., Tobi, H., & Mulder, M. (2011). *Leren van interdisciplinair denken in het hoger onderwijs: Leeruitdagingen, -activiteiten, en -uitkomsten*. Paper presented at the Onderwijs Research Dagen, Maastricht, the Netherlands.

Spelt, E. J. H., Biemans, H. J. A., Tobi, H., Luning, P. A., & Mulder, M. (2011). *Teaching and learning of interdisciplinary thinking in higher education: Curriculum design analysis*. Paper presented at The annual PhD day of Wageningen School of Social Sciences, Wageningen, the Netherlands.

Spelt, E. J. H. (2010). *Teaching and learning of interdisciplinary thinking in life sciences higher education*. Paper presented at The 32th annual conference of the Association for Interdisciplinary Studies, San Diego, California, USA.

Spelt, E. J. H., Biemans, H. J. A., Luning, P. A., Tobi, H., & Mulder, M. (2010). *Het leren van interdisciplinair denken in life sciences hoger onderwijs*. Paper presented at the Onderwijs Research Dagen, Enschede, the Netherlands.

Spelt, E. J. H., Biemans, H. J. A., Luning, P. A., Tobi, H., & Mulder, M. (2010). *Interdisciplinary thinking in agricultural and life sciences higher education*. Paper presented at the Doctoral and postdoctoral professional development in agricultural and life sciences - Challenges for the next decade, Gent, Belgium.

Spelt, E. J. H. (2009). *A teaching and learning framework for interdisciplinary higher education proposed*. Paper presented at The 31th annual conference of the Association for Interdisciplinary Studies, Tuscaloosa, Alabama, USA.

Spelt, E. J. H., Biemans, H. J. A., Tobi, H., Luning, P. A., & Mulder, M. (2008). *Teaching and learning in interdisciplinary higher education: A systematic review*. Paper presented at the ICO winter school, Jyvaskyla, Finland.

Spelt, E. J. H., Biemans, H. J. A., Tobi, H., Luning, P. A., & Mulder, M. (2007). *Interdisciplinary teaching and learning in higher education: A systematic review*. Paper presented at the ICO toogdag Amsterdam, the Netherlands.

Spelt, E. J. H., Biemans, H. J. A., Luning, P. A., Mulder, M., & Tobi, H. (2007). *Factors influencing interdisciplinary thinking within the context of higher education in the life sciences*. Paper presented at The 29th annual conference of the Association for Interdisciplinary Studies, Tempe, Arizona, USA.

Spelt, E. J. H., Biemans, H. J. A., Luning, P. A., Mulder, M., & Tobi, H. (2007). *Factors influencing interdisciplinary thinking within the context of higher education*. Paper presented at The Junior Researchers of EARLI conference, Budapest, Hungarian.

Spelt, E. J. H., Biemans, H. J. A., Luning, P. A., Mulder, M., & Tobi, H. (2007). *Factoren van invloed op interdisciplinair bèta-gamma denken in het hoger onderwijs op het gebied van life sciences*. Paper presented at the Onderwijs Research Dagen, Groningen, the Netherlands.

Completed training and supervision plan
Elsbeth Spelt
Wageningen School of Social Sciences (WASS)

Name of the learning activity	Department/Institute	Year	ECTS*
Research methodology:			
- Information literacy	WUR Library	2006	1
- Writing a research proposal	WASS	2006	6
- Methodology of research and design	Twente University	2006-2007	8
- Research and education meetings	Education and Competence Studies, ICO Educational Committee	2006-2011	1
Qualitative analysis:			
- Qualitative research methods	WASS	2006	3
- Qualitative analysis: theory and practice	Utrecht University	2010	1
- ATLAS.ti a hands-on practical	WASS	2011	0.5
Interdisciplinary research:			
- WASS introduction course	WASS	2006	1
- Interdisciplinary research: crucial knowledge and skills	www.Elroy.com via WASS	2010	1.1
- Harvard Graduate School of Education: interdisciplinary research Project Zero	WASS junior research grant	2010	2
- WASS seminar: '*Challenges of Multidisciplinary Research*'	WASS	2011	1
Presenting scientific work:			
- Conference contributions	AIS and ORD conferences	2007-2013	2
'Factors influencing interdisciplinary thinking within the context of higher education in the life sciences'	AIS conference, Tempe, USA	2007	
'Leren van interdisciplinair denken in het hoger onderwijs: Leeruitdagingen, -activiteiten, en -uitkomsten'	ORD conference, Maastricht, NL	2011	
- Scientific publishing	WUR graduate schools	2009	0.3
- Scientific writing C1	Wageningen in'to languages	2012	1.7
University teaching:			
- Teaching and supervising thesis students	WUR Educational Staff Development	2006	1
- Food quality management research principles I and II	WUR Food Quality Design Group	2010+2011	1
- Communication skills	WUR Educational Staff Development	2011	1
Total			**32.6**

*One credit according to ECTS is on average equivalent to 28 hours of study load

ICO dissertation series

In the ICO dissertation series dissertations are published of graduate students from faculties and institutes on educational research within the ICO Partner Universities: Eindhoven University of Technology, Leiden University, Maastricht University, Open University of the Netherlands, University of Amsterdam, University of Twente, Utrecht University, VU University Amsterdam, and Wageningen University, and formerly University of Groningen (until 2006), Radboud University Nijmegen (until 2004), and Tilburg University (until 2002). The University of Groningen, University of Antwerp, University of Ghent, and the Erasmus University Rotterdam have been ‘ICO ‘Network partner’ in 2010 and 2011. From 2012 onwards, these ICO Network partners are full ICO partners, and from that period their dissertations will be added to this dissertation series.

List update February, 2015 (the list will be updated every year in January)

1. Tartwijk, J.W.F. van (28-09-1993). *Docentgedrag in beeld: De interpersoonlijke betekenis van nonverbaal gedrag van docenten in de klas*. Utrecht: Utrecht University.

2. Machiels-Bongaerts, M.I.A. (23-12-1993). *Mobilizing prior knowledge in text processing: The selective- attention hypothesis versus the cognitive set-point hypothesis*. Maastricht: Maastricht University.

3. Keursten, P. (04-02-1994). *Courseware-ontwikkeling met het oog op implementatie: De docent centraal*. Enschede: University of Twente.

4. Deursen, P.F.A. van (18-03-1994). *Tekstbestudering met analogieën: Effecten van zelf-gegenereerde en gepresenteerde analogieën op de verwerking van tekstinformatie*. Utrecht: Utrecht University.

5. Aarntzen, B.M.H. (22-04-1994). *Audio in interactive tutorial courseware: Methodological and design guidelines*. Enschede: University of Twente.

6. Dolmans, D.H.J.M. (31-04-1994). *How students learn in a problem-based curriculum*. Maastricht: Maastricht University.

7. Admiraal, W.F. (17-06-1994). *Reacties van docenten op aandachtseisende situaties in de klas*. Utrecht: Utrecht University.

8. Ros, A.A. (07-07-1994). *Samenwerking tussen leerlingen en effectief onderwijs: De invloed van de leerkracht*. Groningen: University of Groningen.

9. Goei, S.L. (01-09-1994). *Mental models and problem solving in the domain of computer numerically controlled programming*. Enschede: University of Twente.

10. Lazonder, A.W. (16-09-1994). *Minimalist computer documentation: A study on constructive and corrective skills development*. Enschede: University of Twente.

11. Willemsen, Th.F.W.P. (22-09-1994). *Remediële rekenprogramma's voor de basisschool: Een effectstudie*. Groningen: University of Groningen.

12. Luyten, J.W. (02-12-1994). *School effects: Stability and malleability*. Enschede: University of Twente.

13. Custers, E.J.F.M. (01-06-1995). *The development and function of illness scripts: Studies on the structure of medical diagnostic knowledge.* Maastricht: Maastricht University.

14. Ladhani, A.N. (01-09-1995). *Modelling and using performance knowledge for courseware design*. Enschede: University of Twente.

15. Theunissen, M.W.G. (19-09-1995). *Samen nascholen, maar hoe?: Een onderzoek naar samenwerkingsvormen van lerarenopleidingen basisonderwijs en schoolbegeleidingsdiensten bij nascholing van leerkrachten basisonderwijs.* Nijmegen: Radboud University Nijmegen.

16. Weide, M.G. (28-09-1995). *Effectief basisonderwijs voor allochtone leerlingen*. Groningen: University of Groningen.

17. Gielen, E.W.M. (06-10-1995). *Transfer of training in a corporate setting.* Enschede: University of Twente.

18. Pal, J. van der (21-10-1995). *The balance of situated action and formal instruction for learning conditional reasoning*. Enschede: University of Twente.

19. Brand-Gruwel, F.L.J.M. (14-11-1995). *Onderwijs in tekstbegrip: Een onderzoek naar het effect van strategisch lees- en luisteronderwijs bij zwakke lezers*. Nijmegen: Radboud University Nijmegen.

20. Schellings, G.L.M. (24-11-1995). *An educational approach to selecting main points in texts: Motives, methods, tasks, and individual differences*. Amsterdam: University of Amsterdam.

21. Lokman, A.H. (30-11-1995). *Dag … onderwijs: Een onderzoek naar uitstroombeslissingen van meao- leerlingen*. Groningen: University of Groningen.

22. Couzijn, M. (18-12-1995). *Observation of writing and reading activities: Effects on learning and transfer.* Amsterdam: University of Amsterdam.

23. Wijgh, I.F. (23-02-1996). *Gespreksvaardigheid in de vreemde taal begripsbepaling en toetsing*. Utrecht: Utrecht University.

24. Heeren, E. (28-03-1996). *Technology support for collaborative distance learning*. Enschede: University of Twente.

25. Mulder-Schulten, H.B.G. (01-05-1996). *Training in leesstrategieën: Vorm en rendement. Een onderzoek naar het effect van vier trainingsvarianten op de leesvaardigheid Frans als vreemde taal*. Utrecht: Utrecht University.

26. Heyl, E. (12-09-1996). *Het docentennetwerk: Structuur en invloed van collegiale contacten binnen scholen*. Enschede: University of Twente.

27. Wetterling, J.M. (11-10-1996). *Decision making and educational media: Estima – a computer-based support tool.* Enschede: University of Twente.

28. Zhu, Z.T. (22-10-1996). *Cross-cultural portability of educational software: A communication-oriented approach*. Enschede: University of Twente.

29. Zhang, J.P. (22-10-1996). *Investigating the portability of multimedia learning resources: Design for a "Teaching Models Toolkit"*. Enschede: University of Twente.

30. Lam, J.F. (28-11-1996). *Tijd en kwaliteit in het basisonderwijs: Ontwikkeling van een onderzoeksinstrumentarium*. Enschede: University of Twente.

31. Vaatstra, H.F. (23-12-1996). *Expertise in accountancy: Empirisch onderzoek naar de kennisontwikkeling van student tot ervaren accountant.* Maastricht: Maastricht University.

32. Veerkamp, W.J.J. (23-01-1997). *Statistical methods for computerized adaptive testing*. Enschede: University of Twente.

33. Roes, M.G. (21-02-1997). *Nascholing op basis van lesvoorbeelden in de context van curriculumvernieuwing.* Enschede: University of Twente.

34. Biemans, H.J.A. (03-03-1997). *Fostering activation of prior knowledge and conceptual change*. Nijmegen: Radboud University Nijmegen.

35. Bechger, T.M. (04-07-1997). *Methodological aspects of comparison of educational achievement: The case of reading literacy.*Amsterdam: University of Amsterdam.

36. Wiel, M.W.J. van de (12-09-1997). *Knowledge encapsulation: Studies on the development of medical expertise.* Maastricht: Maastricht University.

37. Peters, C.M.T. (17-09-1997). *De professionaliteit van schoolleiders: Een taakspecifieke benadering.* Nijmegen: Radboud University Nijmegen.

38. Wessum, L. van (12-09-1997). *De sectie als eenheid: Samenwerking en professionaliteitsopvattingen van docenten in het voortgezet onderwijs.* Utrecht: Utrecht University.

39. Glaudé, M.Th. (17-10-1997). *Werkplek-opleiden als innovatie.* Utrecht: Utrecht University.

40. Genseberger, R.J. (01-11-1997). *Interesse-georienteerd natuur- en scheikundeonderwijs.* Utrecht: Utrecht University.

41. Hattum, M.J.C. van (02-11-1997). *Pesten: Een onderzoek naar beleving, visie en handelen van leraren en leerlingen.* Amsterdam: University of Amsterdam.

42. Bastiaens, Th.J. (12-11-1997). *Leren en werken met electronic performance support systems: Een effectevaluatie.* Enschede: University of Twente.

43. Severiens, S.E. (13-11-1997). *Gender and learning: Learning styles, ways of knowing, and patterns of reasoning.* Amsterdam: University of Amsterdam.

44. Sontag, L. (08-12-1997). *Vormgeving en effecten van onderwijs aan vier- tot zevenjarige leerlingen.* Amsterdam: University of Amsterdam.

45. Nieveen, N.M. (11-12-1997). *Computer support for curriculum developers: A study on the potential of computer support in the domain of formative curriculum evaluation.* Enschede: University of Twente.

46. Dolk, M.L.A.M. (16-12-1997). *Onmiddellijk onderwijsgedrag: Over denken en handelen van leraren in onmiddellijke onderwijssituaties.* Utrecht: Utrecht University.

47. Vos, W.A. de (06-03-1998). *Het methodegebruik op basisscholen.* Utrecht: Utrecht University.

48. Verwijs, C.A. (20-03-1998). *A mix of core and complementary media: New perspectives in media- decision making.* Enschede: University of Twente.

49. Vos, H. de (03-04-1998). *Educational effects: A simulation-based analysis.* Enschede: University of Twente.

50. Teelken, J.Ch. (09-06-1998). *Market mechanisms in education: A comparative study of school choice in the Netherlands, England and Scotland.* Amsterdam: University of Amsterdam.

51. Hoek, D.J. (11-06-1998). *Social and cognitive strategies in co-operative groups: Effects of strategy instruction in secondary mathematics.* Amsterdam: University of Amsterdam.

52. Til, C.T. van (03-07-1998). *Voortgang in voortgangstoetsing: Studies naar de aansluiting van de voortgangstoets op probleemgestuurd onderwijs.* Maastricht: Maastricht University.

53. Savelsbergh, E.R. (04-09-1998). *Improving mental representations in physics problem solving.* Enschede: University of Twente.

54. Boerman, P.L.J. (14-10-1998). *Decentrale besluitvorming en organisatie-effectiviteit: Een organisatiekundige analyse van instellingen voor middelbaar beroepsonderwijs.* Amsterdam: University of Amsterdam.

55. Krabbe, E.T.W. (22-10-1998). *Tussen intuïtie en rationaliteit: Een onderzoek naar mogelijkheden tot standaardisatie van leerplanontwikkeling.* Enschede: University of Twente.

56. Swaak, J. (05-11-1998). *What-if: Discovery simulations and assessment of intuitive knowledge.* Enschede: University of Twente.

57. Hooge, E.H. (26-11-1998). *Ruimte voor beleid. Autonomiebergroting en beleidsuitvoering door basisscholen.* Amsterdam: University of Amsterdam.

58. Louman, J.M. (07-01-1998). *De sleutelzinmethode: Een geheugenstrategie onderzocht bij het leren van Engels vocabulaire*. Tilburg: Tilburg University.

59. Meijer, P.C. (14-01-1999). *Teachers' practical knowledge: Teaching reading comprehension in secondary education*. Leiden: Leiden University.

60. Doolaard, S. (18-02-1999). *Schools in change or schools in chains?* Enschede: University of Twente.

61. Kwakman, C.H.E. (16-03-1999). *Leren van docenten tijdens de beroepsloopbaan: Studies naar professionaliteit op de werkplek in het voortgezet onderwijs*. Nijmegen: Radboud University Nijmegen.

62. Bimmel, P.E. (19-03-1999). *Training en transfer van leesstrategieën.* Utrecht: Utrecht University.

63. Verkroost, M.J. (03-05-1999). *Onderzoekend handelen in het leeronderzoek*. Groningen: University of Groningen.

64. Croock, M.B.M. de (18-06-1999). *The transfer paradox: Training design for troubleshooting skills*. Enschede: University of Twente.

65. Visscher-Voerman, J.I.A. (08-10-1999). *Design approaches in training and education: A reconstructive study*. Enschede: University of Twente.

66. Hurk, M.M. van den (29-10-1999). *Individual study in problem-based learning: Studies on the relation between individual study and curriculum characteristics*. Maastricht: Maastricht University.

67. Vermetten, Y.J.M. (19-11-1999). *Consistency and variability of student learning in higher education*. Tilburg: Tilburg University.

68. Rikers, R.M.J.P. (24-11-1999). *Solving non-routine problems in medicine*. Maastricht: Maastricht University.

69. Slaats, J.A.M.H. (08-12-1999). *Reproduceren en construeren: Leerstijlen van leerlingen in het middelbaar beroepsonderwijs*. Tilburg: Tilburg University.

70. Thijs, A.M. (10-12-1999). *Supporting science curriculum reform in Botswana: The potential of peer coaching*. Enschede: University of Twente.

71. Boxtel, C.A.M. van (03-05-2000). *Collaborative concept learning: Collaborative learning tasks, student interaction, and the learning of physics concepts*. Utrecht: Utrecht University.

72. Klerks, M.C.J.L. (12-05-2000). *Veranderingscapaciteiten en basisvorming*. Utrecht: Utrecht University.

73. Veerman, A.L. (26-05-2000). *Computer-supported collaborative learning through argumentation*. Utrecht: Utrecht University.

74. Broek, J.F.L. van den (21-11-2000). *Achterstandsbestrijding door circuitonderwijs: Onderzoek naar de institutionalisering en effecten van het OVB-circuitmodel in het basisonderwijs*. Nijmegen: Radboud University Nijmegen.

75. Huizen, P.H. van (15-12-2000). *Becoming a teacher: Development of a professional identity by prospective teachers in the context of university-based teacher education.* Utrecht: Utrecht University.

76. Huibregtse, W.P. (02-02-2001). *Effecten en didactiek van tweetalig voortgezet onderwijs in Nederland*. Utrecht: Utrecht University.

77. Limbach, R. (08-03-2001). *Supporting instructional designers: Towards an information system for the design of instructional discovery learning environments*. Enschede: University of Twente.

78. Winnips, J.C. (09-03-2001). *Scaffolding-by-design: A model for WWW-based learner support*. Enschede: University of Twente.

79. Bros, E.M.M. (14-03-2001). *Reproductie of emancipatie? Loopbanen van de Enschedese schoolgeneratie 1964.* Amsterdam: University of Amsterdam.

80. Veen, H. van der (31-05-2001). *Successful Turkish and Moroccan students in the Netherlands*. Amsterdam: University of Amsterdam.

81. Moonen, B.H. (31-05-2001). *Teacher learning in inservice networks on internet use in secondary education*. Enschede: University of Twente.

82. Zanting, A. (05-06-2001). *Mining the mentor's mind: The elicitation of mentor teachers' practical knowledge by prospective teachers*.Leiden: Leiden University.

83. Hulshof, C.D. (07-06-2001). *Discovery of ideas and ideas about discovery: The influence of prior knowledge on scientific discovery learning in computer-based simulations*. Enschede: University of Twente.

84. Maslowski, R. (08-06-2001). *School culture and school performance: An explorative study into the organizational culture of secondary schools and their effects*. Enschede: University of Twente.

85. Schoot, E. van der (30-08-2001). *De invloed van het curriculum op de brede inzetbaarheid van afgestudeerden in de verzorging en verpleging*. Enschede: University of Twente.

86. Fox, G.J.A. (07-09-2001). *Multilevel IRT: A Bayesian perspective on estimating parameters and testing statistical hypotheses*. Enschede: University of Twente.

87. Brok, P.J. den (21-09-2001). *Teaching and student outcomes: A study on teachers' thoughts and actions from an interpersonal and a learning activities perspective*. Utrecht: Utrecht University.

88. McKenney, S.E. (12-10-2001). *Computer-based support for science education materials developers in Africa*. Enschede: University of Twente.

89. Oosterheert, I.E. (15-11-2001). *How student teachers learn: A psychological perspective on knowledge construction in learning to teach*. Groningen: University of Groningen.

90. Stoyanov, S.T. (16-11-2001). *Mapping in the educational and training design*. Enschede: University of Twente.

91. Eysink, T.H.S. (07-12-2001). *Signs for logic teaching*. Enschede: University of Twente.

92. Geijsel, F.P. (13-12-2001). *Schools and innovations: Conditions fostering the implementation of educational innovations*. Nijmegen: Radboud University Nijmegen.

93. Fukkink, R.G. (02-02-2002). *Instructing primary school children in deriving word meaning from written context*. Amsterdam: University of Amsterdam.

94. Vosse, A.J.M. (10-04-2002). *Evaluatie van het tutorleren in Nederland: Een onderzoek naar de cognitieve en sociaal-emotionele effecten van een tutorprogramma voor rekenen-wiskunde in het basisonderwijs*. Amsterdam: University of Amsterdam.

95. Jager, B. de (25-04-2002). *Teaching reading comprehension: The effects of direct instruction and cognitive apprenticeship on comprehension skills and metacognition*. Groningen: University of Groningen.

96. Veldhuis-Diermanse, E.A. (26-04-2002). *CSCLearning? Participation, learning activities and knowledge construction in computer-supported collaborative learning in higher education*. Wageningen: Wageningen University.

97. Crombach, M.J. (02-05-2002). *Sixth and seventh graders' appraisal processes of curricular tasks: Development of a model to explain students' willingness to invest effort*. Nijmegen: Radboud University Nijmegen.

98. Kruiter, J.H. (13-05-2002). *Groningen community schools: Influence on child behaviour problems and education at home*. Groningen: University of Groningen.

99. Braaksma, M.A.H. (21-05-2002). *Observational learning in argumentative writing*. Amsterdam: University of Amsterdam.

100. Lankhuijzen, E.S.K. (24-05-2002). *Learning in self-managed management career: The relation between managers' HRD-patterns, psychological career contracts and mobility perspectives*. Utrecht: Utrecht University.

101. Gellevij, M.R.M. (06-06-2002). *Visuals in instruction: Functions of screen captures in software manuals*. Enschede: University of Twente.

102. Vos, F.P. (26-06-2002). *Like an ocean liner changing course: The grade 8 mathematics curriculum in the Netherlands, 1995-2000*.Enschede: University of Twente.

103. Sluijsmans, D.M.A. (28-06-2002). *Student involvement in assessment: The training of peer assessment skills*. Heerlen: Open University of the Netherlands.

104. Tabbers, H.K. (13-09-2002). *The modality of text in multimedia instructions: Refining the design guidelines*. Heerlen: Open University of the Netherlands.

105. Verhasselt, E. (14-11-2002). *Literacy rules: Flanders and the Netherlands in the international adult literacy survey*. Groningen: University of Groningen.

106. Beekhoven, S. (17-12-2002). *A fair chance of succeeding: Study careers in Dutch higher education*. Amsterdam: University of Amsterdam.

107. Veermans, K.H. (09-01-2003). *Intelligent support for discovery learning: Using opportunistic learner modeling and heuristics to support simulation based discovery learning*. Enschede: University of Twente.

108. Tjepkema, S. (10-01-2003). *The learning infrastructure of self-managing work teams*. Enschede: University of Twente.

109. Snellings, P.J.F. (22-01-2003). *Fluency in second language writing: The effects of enhanced speed of lexical retrieval*. Amsterdam: University of Amsterdam.

110. Klatter, E.B. (23-01-2003). *Development of learning conceptions during the transition from primary to secondary education*. Nijmegen: Radboud University Nijmegen.

111. Jellema, F.A. (21-02-2003). *Measuring training effects: The potential of 360-degree feedback*. Enschede: University of Twente.

112. Broekkamp, H.H. (25-02-2003). *Task demands and test expectations: Theory and empirical research on students' preparation for a teacher-made test*. Amsterdam: University of Amsterdam.

113. Odenthal, L.E. (21-03-2003). *Op zoek naar balans: Een onderzoek naar een methode ter ondersteuning van curriculumvernieuwing door docenten*. Enschede: University of Twente.

114. Kuijpers, M.A.C.T. (21-03-2003). *Loopbaanontwikkeling: Onderzoek naar 'competenties'*. Enschede: University of Twente.

115. Jepma, I.J. (01-07-2003). *De schoolloopbaan van risico-leerlingen in het primair onderwijs*. Amsterdam: University of Amsterdam.

116. Sotaridona, L.S. (05-09-2003). *Statistical methods for the detection of answer copying on achievement tests*. Enschede: University of Twente.

117. Kester, L. (05-09-2003). *Timing of information presentation and the acquisition of complex skills*. Heerlen: Open University of the Netherlands.

118. Waterreus, J.M. (05-09-2003). *Lessons in teacher pay: Studies on incentives and the labor market for teachers*. Amsterdam: University of Amsterdam.

119. Toolsema, B. (23-10-2003). *Werken met competenties*. Enschede: University of Twente.

120. Taks, M.M.M.A. (20-11-2003). *Zelfsturing in leerpraktijken: Een curriculumonderzoek naar nieuwe rollen van studenten en docenten in de lerarenopleiding*. Enschede: University of Twente.

121. Driessen, C.M.M. (21-11-2003). *Analyzing textbook tasks and the professional development of foreign language teachers*. Utrecht: Utrecht University.

122. Hubers, S.T.T. (24-11-2003). *Individuele leertheorieën en het leren onderzoeken in de tweede fase*. Eindhoven: Eindhoven University of Technology.

123. Sun, H. (04-12-2003). *National contexts and effective school improvement: An exploratory study in eight European countries*.Groningen: University of Groningen.

124. Bruinsma, M. (09-12-2003). *Effectiveness of higher education: Factors that determine outcomes of university education*. Groningen: University of Groningen.

125. Veneman, H. (01-07-2004). *Het gewicht van De Rugzak: Evaluatie van het beleid voor leerlinggebonden financiering*. Groningen: University of Groningen.

126. Annevelink, E. (27-08-2004). *Class size: Linking teaching and learning*. Enschede: University of Twente.

127. Emmerik, M.L. van (22-09-2004). *Beyond the simulator: Instruction for high performance tasks*. Enschede: University of Twente.

128. Vries, B. de (15-10-2004). *Opportunities for reflection: E-mail and the Web in the primary classroom*. Enschede: University of Twente.

129. Veenhoven, J. (05-11-2004). *Begeleiden en beoordelen van leerlingonderzoek: Een interventiestudie naar het leren ontwerpen van onderzoek in de tweede fase van het voortgezet onderwijs*. Utrecht: Utrecht University.

130. Strijbos, J.W. (12-11-2004). *The effect of roles on computer-supported collaborative learning*. Heerlen: Open University of the Netherlands.

131. Hamstra, D.G. (22-11-2004). *Gewoon en anders: Integratie van leerlingen met beperkingen in het regulier onderwijs in Almere*. Groningen: University of Groningen.

132. Lubbers, M.J. (09-12-2004). *The social fabric of the classroom: Peer relations in secondary education*. Groningen: University of Groningen.

133. Nijman, D.J.J.M. (10-12-2004). *Supporting transfer of training: Effects of the supervisor*. Enschede: University of Twente.

134. Dewiyanti, S. (25-02-2005). *Learning together: A positive experience. The effect of reflection on group processes in an asynchronous computer-supported collaborative learning environment.* Heerlen: Open University of the Netherlands.

135. Stoof, A. (04-03-2005). *Tools for the identification and description of competencies*. Heerlen: Open University of the Netherlands.

136. Groot, R.W.A. de (10-03-2005). *Onderwijsdecentralisatie en lokaal beleid*. Amsterdam: University of Amsterdam.

137. Salden, R.J.C.M. (22-04-2005). *Dynamic task selection in aviation training.* Heerlen: Open University of the Netherlands.

138. Huong, N.T. (23-05-2005). *Vietnamese learners mastering English articles.* Groningen: University of Groningen.

139. Gijlers, A.H. (23-09-2005). *Confrontation and co-construction: Exploring and supporting collaborative scientific discovery learning with computer simulations.* Enschede: University of Twente.

140. Stevenson, M.M.C. (27-09-2005). *Reading and writing in a foreign language: A comparison of conceptual and linguistic processes in Dutch and English.* Amsterdam: University of Amsterdam.

141. Saab, N. (14-10-2005). *Chat and explore: The role of support and motivation in collaborative scientific discovery learning.* Amsterdam: University of Amsterdam.

142. Löhner, S. (11-11-2005). *Computer-based modeling tasks: The role of external representation.* Amsterdam: University of Amsterdam.

143. Beers, P.J. (25-11-2005). *Negotiating common ground: Tools for multidisciplinary teams.* Heerlen: Open University of the Netherlands.

144. Tigelaar, E.H. (07-12-2005). *Design and evaluation of a teaching portfolio.* Maastricht: Maastricht University.

145. Van Drie, J.P., (20-12-2005). *Learning about the past with new technologies. Fostering historical reasoning in computer-supported collaborative learning*. Utrecht: Utrecht University.

146. Walrecht, E.S. (09-01-2006). *Brede innovatie, passende strategie?: De Groninger Vensterschool als casus van onderzoek naar strategie en invoering.* Groningen: University of Groningen.

147. De Laat, M. (03-02-2006). *Networked learning*. Utrecht: Utrecht University.

148. Prince, C.J.A.H. (21-04-2006). *Problem-based learning as a preparation for professional practice.* Maastricht: Maastricht University.

149. Van Gog, T. (28-04-2006). *Uncovering the problem-solving process to design effective worked examples.* Heerlen: Open University of the Netherlands.

150. Sins, P.H.M. (18-05-2006). *Students' reasoning during computer-based scientific modeling.* Amsterdam: University of Amsterdam.

151. Mathijsen, I.C.H. (24-05-2006). *Denken en handelen van docenten.* Utrecht: Utrecht University.

152. Akkerman, S.F. (23-06-2006). *Strangers in dialogue: Academic collaboration across organizational boundaries.* Utrecht: Utrecht University.

153. Willemse, T.M. (21-08-2006). *Waardenvol opleiden: Een onderzoek naar de voorbereiding van aanstaande leraren op hun pedagogische opdracht.* Amsterdam: VU University Amsterdam.

154. Kieft, M. (19-09-2006). *The effects of adapting writing instruction to students' writing strategies.* Amsterdam: University of Amsterdam.

155. Vreman-de Olde, G.C. (27-09-2006). *Look experiment design: Learning by designing instruction.* Enschede: University of Twente.

156. Van Amelsvoort, M. (13-10-2006). *A space for debate: How diagrams support collaborative argumentation-based learning.* Utrecht: Utrecht University.

157. Oolbekking-Marchand, H. (9-11-2006). *Teachers' perspectives on self-regulated learning: An exploratory study in secondary and university education.* Leiden: Leiden University.

158. Gulikers, J. (10-11-2006). *Authenticity is in the eye of the beholder: Beliefs and perceptions of authentic assessment and the influence on student learning*. Heerlen: Open University of the Netherlands.

159. Henze, I. (21-11-2006). *Science teachers' knowledge development in the context of educational innovation.* Leiden: Leiden University.

160. Van den Bossche, P. (29-11-2006). *Minds in teams: The influence of social and cognitive factors on team learning.* Maastricht: Maastricht University.

161. Mansvelder-Longayroux, D.D. (06-12-2006). *The learning portfolio as a tool for stimulating reflection by student teachers.* Leiden: Leiden University.

162. Visschers-Pleijers, A.J.S.F. (19-01-2007). *Tutorial group discussion in problem-based learning: Studies on the measurement and nature of learning-oriented student interactions.* Maastricht: Maastricht University.

163. Poortman, C.L. (16-02-2007). *Workplace learning processes in senior secondary vocational education.* Enschede: University of Twente.

164. Schildkamp. K.A. (15-03-2007). *The utilisation of a self-evaluation instrument for primary education.* Enschede: University of Twente.

165. Karbasioun, M. (20-04-2007). *Towards a competency profile for the role of instruction of agricultural extension professionals in Asfahan.*Wageningen: Wageningen University.

166. Van der Sande, R.A.W. (04-06-2007). *Competentiegerichtheid en scheikunde leren: Over metacognitieve opvattingen, leerresultaten en leeractiviteiten.* Eindhoven: Eindhoven University of Technology.

167. Pijls, M. (13-06-2007). *Collaborative mathematical investigations with the computer: Learning materials and teacher help.* Amsterdam: University of Amsterdam.

168. Könings, K. (15-06-2007). *Student perspectives on education: Implications for instructional design.* Heerlen: Open University of the Netherlands.

169. Prangsma, M.E. (20-06-2007). *Multimodal representations in collaborative history learning.* Utrecht: Utrecht University.

170. Niemantsverdriet, S. (26-06-2007). *Learning from international internships: A reconstruction in the medical domain.* Maastricht: Maastricht University.

171. Van der Pol, J. (03-07-2007). *Facilitating online learning conversations: Exploring tool affordances in higher education.* Utrecht: Utrecht University.

172. Korobko, O.B. (07-09-2007). *Comparison of examination grades using item response theory: A case study*. Enschede: University of Twente.

173. Madih-Zadeh, H. (14-09-2007). *Knowledge construction and participation in an asynchronous computer-supported collaborative learning environment in higher education.* Wageningen: Wageningen University.

174. Budé, L.M. (05-10-2007). *On the improvement of students' conceptual understanding in statistics education.* Maastricht: Maastricht University.

175. Meirink, J.A. (15-11-2007). *Individual teacher learning in a context of collaboration in teams.* Leiden: Leiden University.

176. Niessen, T.J.H. (30-11-2007). *Emerging epistemologies: Making sense of teaching practices.* Maastricht: Maastricht University.

177. Wouters, P. (07-12-2007). *How to optimize cognitive load for learning from animated models.* Heerlen: Open University of the Netherlands.

178. Hoekstra, A. (19-12-2007). *Experienced teachers' informal learning in the workplace.* Utrecht: Utrecht University.

179. Munneke-de Vries, E.L. (11-01-2008). *Arguing to learn: Supporting interactive argumentation through computer-supported collaborative learning*. Utrecht: Utrecht University.

180. Nijveldt, M.J. (16-01-2008). *Validity in teacher assessment. An exploration of the judgement processes of assessors*. Leiden: Leiden University.

181. Jonker, H.G. (14-02-2008). *Concrete elaboration during knowledge acquisition*. Amsterdam: VU University Amsterdam.

182. Schuitema, J.A. (14-02-2008). *Talking about values. A dialogue approach to citizenship education as an integral part of history classes*. Amsterdam: University of Amsterdam.

183. Janssen, J.J.H.M. (14-03-2008). *Using visualizations to support collaboration and coordination during computer-supported collaborativelearning*. Utrecht: Utrecht University.

184. Honingh, M.E. (17-04-2008). *Beroepsonderwijs tussen publiek en privaat: Een studie naar opvattingen en gedrag van docenten en middenmanagers in bekostigde en niet-bekostigde onderwijsinstellingen in het middelbaar beroepsonderwijs.* Amsterdam: University of Amsterdam.

185. Baartman, L.K.J. (24-04-2008). *Assessing the assessment: Development and use of quality criteria for competence assessment programmes*. Utrecht: Utrecht University.

186. Corbalan Perez, G. (25-04-2008). *Shared control over task selection: Helping students to select their own learning tasks*. Heerlen: Open University of the Netherlands.

187. Hendrikse, H.P. (22-05-2008). *Wiskundig actief: Het ondersteunen van onderzoekend leren in het wiskunde onderwijs*. Enschede: University of Twente.

188. Moonen, M.L.I. (26-09-2008). *Testing the multi-feature hypothesis: Tasks, mental actions and second language acquisition*. Utrecht: Utrecht University.

189. Hooreman, R.W. (18-11-2008). *Synchronous coaching of the trainee teacher: An experimental approach*. Eindhoven: Eindhoven University of Technology.

190. Bakker, M.E.J. (02-12-2008). *Design and evaluation of video portfolios: Reliability, generalizability, and validity of an authentic performance assessment for teachers*. Leiden: Leiden University.

191. Kicken, W. (12-12-2008). *Portfolio use in vocational education: Helping students to direct their learning*. Heerlen: Open University of the Netherlands.

192. Kollöffel, B.J. (18-12-2008). *Getting the picture: The role of external representations in simulation- based inquiry learning*. Enschede: University of Twente.

193. Walraven, A. (19-12-2008). *Becoming a critical websearcher: Effects of instruction to foster transfer.* Heerlen: Open University of the Netherlands.

194. Radstake, H. (14-05-2009).*Teaching in diversity: Teachers and pupils about tense situations in ethnically heterogeneous classes*.Amsterdam: University of Amsterdam.

195. Du Chatenier, E. (09-09-2009). *Open innovation competence: Towards a competence profile for inter- organizational collaboration in innovation teams*. Wageningen: Wageningen University.

196. Van Borkulo, S.P. (26-06-2009). *The assessment of learning outcomes of computer modelling in secondary science education*.Enschede: University of Twente.

197. Handelzalts, A. (17-09-2009). *Collaborative curriculum development in teacher design teams*. Enschede: University of Twente.

198. Nievelstein, F.E.R.M. (18-09-2009). *Learning law: Expertise differences and the effect of instructional support*. Heerlen: Open University of the Netherlands.

199. Visser-Wijnveen, G.J. (23-09-2009). *The research-teaching nexus in the humanities: Variations among academics*. Leiden: Leiden University.

200. Van der Rijst, R.M. (23-09-2009). *The research-teaching nexus in the sciences: Scientific research dispositions and teaching practice*.Leiden: Leiden University.

201. Mainhard, M.T. (25-09-2009). *Time consistency in teacher-class relationships*. Utrecht: Utrecht University.

202. Van Ewijk, R. (20-10-2009). *Empirical essays on education and health*. Amsterdam: University of Amsterdam.

203. Seezink, A. (18-11-2009). *Continuing teacher development for competence-based teaching*. Tilburg: Tilburg University.

204. Rohaan, E.J. (09-12-2009). *Testing teacher knowledge for technology teaching in primary schools*.

Eindhoven: Eindhoven University of Technology.

205. Kirschner, F.C. (11-12-2009). *United brains for complex learning*. Heerlen: Open University of the Netherlands.

206. Wetzels, S.A.J. (18-12-2009). *Individualized strategies for prior knowledge activation*. Heerlen: Open University of the Netherlands.

207. Zitter, I.I. (04-02-2010). *Designing for learning: Studying learning environments in higher professional education from a design perspective*. Utrecht: Utrecht University.

208. Koopman, M. (11-02-2010). *Students' goal orientations, information processing strategies and knowledge development in competence-based pre-vocational secondary education*. Eindhoven: Eindhoven University of Technology.

209. Platteel, T. (11-02-2010). *Knowledge development of secondary school L1 teachers on concept-context rich education in an action-research setting*. Leiden: Leiden University.

210. Mittendorff, K. M. (12-03-2010). *Career conversations in senior secondary vocational education*. Eindhoven: Eindhoven University of Technology.

211. Moolenaar, N.M. (01-06-2010). *Ties with potential: Nature, antecedents, and consequences of social networks in school teams*. Amsterdam: University of Amsterdam.

212. Duijnhouwer, H. (04-06-2010). *Feedback effects on students' writing motivation, process, and performance*. Utrecht: Utrecht University.

213. Kessels, C.C. (30-06-2010). *The influence of induction programs on beginning teachers' well-being and professional development*.Leiden: Leiden University.

214. Endedijk, M.D. (02-07-2010). *Student teachers' self-regulated learning*. Utrecht: Utrecht University.

215. De Bakker, G.M. (08-09-2010). *Allocated online reciprocal peer support as a candidate for decreasing the tutoring load of teachers*.Eindhoven: Eindhoven University of Technology.

216. Groenier, M. (10-09-2010). *The decisive moment: Making diagnostic decisions and designing treatments*. Enschede: University of Twente.

217. Bonestroo, W.J. (24-09-2010). *Planning with graphical overview: Effects of support tools on self- regulated learning*. Enschede: University of Twente.

218. Vos, M.A.J. (30-09-2010). *Interaction between teachers and teaching materials: On the implementation of context-based chemistry education*. Eindhoven: Eindhoven University of Technology.

219. Kostons, D.D.N.M. (05-11-2010). *On the role of self-assessment and task-selection skills in self- regulated learning*. Heerlen: Open University of the Netherlands.

220. Bruin-Muurling, G. (21-12-2010). *The development of proficiency in the fraction domain: Affordances and constraints in the curriculum*.Eindhoven: Eindhoven University of Technology.

221. Slof, B. (28-01-2011). *Representational scripting for carrying out complex learning tasks*. Utrecht: Utrecht University.

222. Fastré, G. (11-03-2011). *Improving sustainable assessment skills in vocational education*. Heerlen: Open University of the Netherlands.

223. Min-Leliveld, M.J. (18-05-2011). *Supporting medical teachers' learning: Characteristics of effective instructional development.* Leiden: Leiden University.

224. Van Blankenstein, F.M. (18-05-2011). *Elaboration during problem-based small group discussion: A new approach to study collaborative learning.* Maastricht: Maastricht University.

225. Dobber, M. (21-06-2011). *Collaboration in groups during teacher education.* Leiden: Leiden University.

226. Jossberger, H. (24-06-2011). *Towards self-regulated learning in vocational education: Difficulties and opportunities.* Heerlen: Open University of the Netherlands.

227. Schaap, H. (24-06-2011). *Students' personal professional theories in vocational education: Developing a knowledge base.* Utrecht: Utrecht University.

228. Kolovou, A. (04-07-2011). *Mathematical problem solving in primary school.* Utrecht: Utrecht University.

229. Beausaert, A.J. (19-10-2011). *The use of personal developments plans in the workplace. Effects, purposes and supporting conditions*. Maastricht: Maastricht University

230. Favier, T.T. (31-10-2011). *Geographic information systems in inquiry-based secondary geography education: Theory and practice.*Amsterdam: VU University Amsterdam.

231. Brouwer, P. (15-11-2011). *Collaboration in teacher teams.* Utrecht: Utrecht University.

232. Molenaar, I. (24-11-2011). *It's all about metacognitive activities; Computerized scaffolding of self- regulated learning.* Amsterdam: University of Amsterdam.

233. Cornelissen, L.J.F. (29-11-2011). *Knowledge processes in school-university research networks*. Eindhoven: Eindhoven University of Technology.

234. Elffers, L. (14-12-2011). *The transition to post-secondary vocational education: Students' entrance, experiences, and attainment*. Amsterdam: University of Amsterdam.

235. Van Stiphout, I.M. (14-12-2011). *The development of algebraic proficiency.* Eindhoven: Eindhoven University of Technology.

236. Gervedink Nijhuis, C.J. (03-2-2012) *Culturally Sesitive Curriculum Development in International Cooperation* Enschede: University of Twente

237. Thoonen, E.E.J. (14-02-2012) *Improving Classroom Practices: The impact of Leadership School Organizational Conditions, and Teacher Factors* Amsterdam: University of Amsterdam

238. Truijen, K.J.P (21-03-2012) *Teaming Teachers. Exploring factors that influence effictive team functioning in a vocational education context* Enschede: University of Twente

239. Maulana, R.M. (26-03-2012)*Teacher-student relationships during the first year of secondary education. Exploring of change and link with motivation outcomes in The Netherlands and Indonesia*. Groningen: University of Groningen

240. Lomos, C. (29-03-2012) *Professional community and student achievement.* Groningen: University of Groningen

241. Mulder, Y.G. (19-04-2012) *Learning science by creating models* Enschede: University of Twente

242. Van Zundert, M.J. (04-05-2012) *Optimising the effectiveness and reliability of reciprocal peer assessment in secondary education* Maastricht: Maastricht University

243. Ketelaar, E. (24-05-2012) *Teachers and innovations: on the role of ownership, sense-making, and agency*. Eindhoven: Eindhoven University of Technology

244. Logtenberg, A. (30-5-2012) *Questioning the past. Student questioning and historical reasoning* Amsterdam: University of Amsterdam

245. Jacobse, A.E. (11-06-2012) *Can we improve children's thinking?* Groningen: University of Groningen

246. Leppink, J. (20-06-2012) *Propositional manipulation for conceptual understanding of statistics* Maastricht: Maastricht University

247. Van Andel, J (22-06-2012) *Demand-driven Education. An Educational-sociological Investigation.* Amsterdam: VU University Amsterdam

248. Spanjers, I.A.E. (05-07-2012) *Segmentation of Animations: Explaining the Effects on the Learning Process and Learning Outcomes.* Maastricht: Maastricht University

249. Vrijnsen-de Corte, M.C.W. *Researching the Teacher-Researcher. Practice-based research in Dutch Professional Development Schools* Eindhoven: Eindhoven University of Technology

250. Van de Pol, J.E. (28-09-2012) *Scaffolding in teacher-student interaction. Exploring, measuring promoting and evaluating scaffolding* Amsterdam: University of Amsterdam

251. Phielix, C. (28-09-2012) *Enhancing Collaboration through Assessment & Reflection* [Samenwerking Verbeteren door middel van Beoordeling en Reflectie] Utrecht: Utrecht University

252. Peltenburg, M.C. (24-10-2012) *Mathematical potential of special education students* Utrecht: Utrecht University

253. Doppenberg, J.J. (24-10-2012) *Collaborative teacher learning: settings, foci and powerful moments* Eindhoven: Eindhoven University of Technology

254. Kenbeek, W.K. (31-10-2012) *Back to the drawing board. Creating drawing or text summaries in support of System Dynamics modeling* Enschede: University of Twente

255. De Feijter, J.M. (09-11-2012) *Learning from error to improve patient safety* Maastricht: Maastricht University

256. Timmermans, A.C. (27-11-2012) *Value added in educational accountability: Possible, fair and useful?* Groningen: University of Groningen

257. Van der Linden, P.W.J. (20-12-2012) *A design-based approach to introducing student teachers in conducting and using research.* Eindhoven: Eindhoven University of Technology

258. Noroozi, O. (11-01-2013) *Fostering Argumentation-Based Computer-Supported Collaborative Learning in Higher Education* Wageningen: Wageningen University

259. Bijker, M.M. (22-03-2013) *Understanding the gap between business school and the workplace: Overconfidence, maximizing benefits, and the curriculum* Heerlen: Open University of the Netherlands

260. Belo, N.A.H. (27-03-2013) *Engaging students in the study of physics* Leiden: Leiden University

261. Jong, R.J. de (11-04-2013) *Student teachers' practical knowledge, discipline strategies, and the teacher- class relationship* Leiden: Leiden University

262. Verberg, C.P.M. (18-04-2013) *The characteristics of a negotiated assessment procedure to promote teacher learning* Leiden: Leiden University

263. Dekker-Groen, A. (19-04-2013) *Teacher competences for supporting students' reflection. Standards, training, and practice* Utrecht: Utrecht University

264. M.H. Knol (19-04-2013). *Improving university lectures with feedback and consultation.* Amsterdam: University of Amsterdam

265. Diggelen, M.R. van (21-05-2013) *Effects of a self-assessment procedure on VET teachers' competencies in coaching students' reflection skills* Eindhoven: Eindhoven University of Technology

266. Azkiyah, S.N. (23-5-2013) *The effects of Two Interventions - on Teaching Quality and Student Outcome* Groningen: University of Groningen

267. Taminiau, E.M.C. (24-05-2013) *Advisory Models for On-Demand Learning* Heerlen: Open University of the Netherlands

268. Milliano, I.I.C.M. de (24-05-2013) *Literacy development of low-achieving adolescents. The role of engagement in academic reading and writing* Amsterdam: University of Amsterdam

269. Vandyck, I.J.J. (17-06-2013), *Fostering Community Development in School-University Partnerships.* Amsterdam: VU Universtiy Amsterdam

270. Hornstra, T.E. (17-06-2013) *Motivational developments in primary school. Group-specific differences in varying learning contexts* Amsterdam: University of Amsterdam

271. Keuvelaar-Van den Bergh, L. (26-06-2013) *Teacher Feedback during Active Learning: The Development and Evaluation of a Professional Development Programme.* Eindhoven: Eindhoven University of Technology.

272. Meeuwen, L.W. van (06-09-13) V*isual Problem Solving and Self-regulation in Training Air Traffic Control* Heerlen: Open University of the Netherlands

273. Pillen, M.T. (12-09-2013) *Professional identity tensions of beginning teachers* Eindhoven: Eindhoven University of Technology

274. Kleijn, R.A.M. de, (27-09-2013) *Master's thesis supervision. Feedback, interpersonal relationships and adaptivity* Utrecht: Utrecht University

275. Bezdan, E. (04-10-2013) Graphical *Overviews in Hypertext Learning Environments: When One Size Does Not Fit All* Heerlen: Open University of the Netherlands

276. Bronkhorst, L.H. (4-10-2013) *Research-based teacher education: Interactions between research and teaching* Utrecht: Utrecht University

277. Popov, V. (8-10-2013) *Scripting Intercultural Computer-Supported Collaborative Learning in Higher Education* Wageningen: Wageningen University

278. Dolfing, R. (23-10-2013) *Teachers' Professional Development in Context-based Chemistry Education. Strategies to Support Teachers in Developing Domain-specific Expertise.* Utrecht: Utrecht University

279. Lucero, M.L. (21-11-2013) Considering teacher cognitions in teacher professional development: Studies involving Ecuadorian primary school teachers Ghent: Ghent University

280. Kamp, R.J.A. (28-11-2013) *Peer feedback to enhance learning in problem-based tutorial groups.* Maastricht: Maastricht University

281. Cviko, A. (19-12-2013) *Teacher Roles and Pupil Outcomes. In technology-rich early literacy learning.* Enschede: University of Twente

282. Zwet, J. van der (30-1-2014). *Identity, interaction, and power. Explaining the affordances of doctor- student interaction during clerkships.* Maastricht: Maastricht University.

283. Smet, M.J.R. de (31-1-2014). *Composing the unwritten text: Effects of electronic outlining on students' argumentative writing performance.* Heerlen: Open University of the Netherlands.

284. Hagemans, M.G. (07-03-2014) *On regulation in inquiry learning*. Enschede: University of Twente

285. Kuijk, M.F. van (13-03-2014*). Raising the bar for reading comprehension. The effects of a teacher professional development program targeting goals, data use, and instruction*. Groningen: University of Groningen

286. Karimi, S (14-3-2014) *Analysing and Promoting Entrepreneurship in Iranian Higher Education: Entrepreneurial Attitudes, Intentions and Opportunity Identification*. Wageningen: Wageningen University

287. Frambach, J.M. (26-3-2014) *The Cultural Complexity of problem-based learning across the world*. Maastricht: Maastricht University.

288. Mascareno, M.N. (11-4-2014) *Learning Opportunities in Kindergarten Classrooms. Teacher-child interactions and child developmental outcomes*. Groningen: University of Groningen

289. Bakker, M. (16-04-2014) *Using mini-games for learning multiplication and division: A longitudinal effect study.* Utrecht: Utrecht University

290. Loon, Marriette van (8-5-2014) *Fostering Monitoring and Regulation of Learning.* Maastricht: Maastricht University

291. Coninx, N.S. (28-05-2014) *Measuring effectiveness of synchronous coaching using bug-in-ear device of pre-service teachers*. Eindhoven: Eindhoven University of Technology.

292. Baars, M.A. (6-6-2014) *Instructional Strategies for Improving Self-Monitoring of Learning to Solve Problems.* Rotterdam: Erasmus University Rotterdam.

293. Hu, Y. (26-6-2014) *The role of research in university teaching: A comparison of Chinese and Dutch teachers*. Leiden: Leiden university

294. Rutten, N.P.G. (5-9-2014) *Teaching with simulations*. Enschede: University of Twente

295. Rijt, J.W.H. van der, (11-9-2014) *Instilling a thirst for learning. Understanding the role of proactive feedback and help seeking in stimulating workplace learning*. Maastricht: Maastricht University

296. Engelen, J. (11-09-2014) *Comprehending Texts and Pictures: Interactions Between Linguistic and Visual Processes in Children and Adults*. Rotterdam: Erasmus University Rotterdam

297. Khaled, A.E. (7-10-2014) *Innovations in Hands-on Simulations for Competence Development. Authenticity and ownership of learning and their effects on student learning in secondary and higher vocational education.* Wageningen: Wageningen University

298. Gaikhorst, L. (29-10-2014) *Supporting beginning teachers in urban environments*. Amsterdam: University of Amsterdam

299. Wijnia, L. (14-11-2014) *Motivation and Achievement in Problem-Based Learning: The Role of Interest, Tutors, and Self-Directed Study*. Rotterdam: Erasmus University Rotterdam

300. Gabelica, C. (4-12-2014) *Moving Teams Forward. Effects of feedback and team reflexivity on team performance*. Maastricht: Maastricht University.

301. Leenaars, F.A.J. (10-12-2014) *Drawing gears and chains of reasoning*. Enschede: University of Twente

302. Huizinga, T. (12-12-2014*) Developing curriculum design expertise through teacher design teams*. Enschede: University of Twente

303. Strien, J.L.H. van (19-12-2014) *Who to Trust and What to Believe? Effects of Prior Attitudes and Epistemic Beliefs on Processing and Justification of Conflicting Information From Multiple Sources.* Heerlen: Open University of the Netherlands.

This research was financially supported by chair group Education and Competence Studies, and lectorate on Food and Health of Van Hall Larenstein University of Professional Education, the Netherlands

Cover design: Elsbeth Spelt

Printed by: GVO drukkers en vormgevers, Ede