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Development and assessment of iSTEM competencies

Leen Goovaerts

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Dissertation presented in partial fulfillment of the requirements for the degree of Doctor of Engineering Science (PhD)

February 2019

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Preface

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Abstract

Our current society demands for more STEM-professionals in order to meet the industry standards. Unfortunately, few students choose for a STEM-study and -profession. In order to provide more insight in the STEM-professions, an integrated STEM (iSTEM) teaching approach is suggested. In this PhD a framework for iSTEM education is described and illustrated by some developed iSTEM learning modules is elaborated. Within these learning modules, the focus is on developing iSTEM competencies. Transfer is one of those competencies, and, as a consequence, the transfer abilities of students to transfer a concept from one context to the other is examined. Since another teaching approach is used, the assessment strategies also need to be adapted. So, the assessment methods used in iSTEM classrooms are explored.

This research shows that a good collaboration between teachers, researchers, experts and educational umbrella organisations results in powerful and useful iSTEM learning modules in Flemish secondary schools. Though, teachers indicate they would like to have more time in order to develop, implement and assess the iSTEM teaching approach. For now, teachers still prefer previously used assessment methods, because of a lack of time, while these methods are not aligned with the new iSTEM goals and teaching approach. This lack of alignment could influence students' development of iSTEM competencies. The competency under study is transfer. Although students struggle with transferring a concept, they do succeed in transferring some parts of the concepts to a new context.

Beknopte samenvatting

De huidige kennismaatschappij vraagt meer STEM-profielen om te voldoen aan de vraag van de industrie. Jammer genoeg kiezen weinig leerlingen voor een STEM-studie en -beroep. Om leerlingen meer voeling te laten krijgen met STEM-beroepen, wordt een geïntegreerde STEM-aanpak (iSTEM) gesuggereerd. Dit doctoraat beschrijft een kader voor iSTEM-onderwijs, geïllustreerd door de ontwikkeling van enkele modules, die voldoen aan het theoretisch kader. Binnen deze modules ligt de focus op het ontwikkelen van geïntegreerde STEM-competenties. Transfer is één van deze competenties en er wordt dan ook nagegaan in welke mate leerlingen concepten kunnen transfereren van de ene naar de andere context. Aangezien een andere didactische aanpak gehanteerd wordt in iSTEM onderwijs, zal ook de evaluatie aangepast moeten worden. Dus, er wordt onderzocht hoe leerkrachten de iSTEM competenties van de leerlingen evalueren in de klas.

Uit dit onderzoek blijkt dat een goede samenwerking tussen leerkrachten, onderzoekers, vakspecialisten en de onderwijskoepels leidt tot krachtige, bruikbare leermodules voor leerlingen in het middelbaar onderwijs. Toch geven leerkrachten aan dat ze graag meer tijd zouden hebben om een geïntegreerde lesaanpak te ontwikkelen, te implementeren en te evalueren. Nu vallen leerkrachten voor de evaluatie nog vaak terug op eerder gebruikte methodes, omwille van tijdsdruk, ondanks het feit dat deze methodes niet afgestemd zijn op de nieuwe doelen en onderwijsaanpak. Het gebrek aan afstemming tussen de leerdoelen, lesaanpak en evaluatie kan een invloed hebben op de ontwikkeling van de iSTEM-competenties bij leerlingen. Transfer wordt hier nader onderzocht. Ondanks het feit dat leerlingen meestal niet in staat zijn een volledig concept te transfereren, blijkt toch dat ze deelaspecten kunnen overdragen naar een andere context.

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Chapter 1

Introduction

This PhD is conducted in the context of the STEM@school project. The goal of the project is to incorporate engineering and applied sciences in Flemish secondary education, and to examine the effect of this incorporation on students and teachers. In order to fulfill this project, a collaboration between academic researchers in Science, Engineering, Science education, and Educational sciences, of the University of Antwerp and KU Leuven, on the one hand and secondary school teachers and umbrella organizations on the other hand was organized. This multidisciplinary collaboration ensures the research is relevant for real school practice and the engagement of policy makers increases chances for long term implementation of developed ideas.

The described project team has developed a new teaching approach, with a concrete translation into learning modules. Five central ideas are considered to be essential in the development of the learning materials (Thibaut, Ceuppens, et al., 2018): integration of different STEM disciplines, problem-centered and cooperative learning, with explicit attention to research and design, as well as the application of discipline-specific educational research results. These underlying ideas are explained in detail below. Based on the central ideas, different learning modules are developed and implemented in a new course named STEM, in secondary school. In this course, students invoke content covered in their other science and mathematic courses. The introduced challenge, which represents a problem, is a stepping stone to the compulsory scientific and mathematical topics. Students encountering the STEM-course challenges, need to combine ideas and concepts discussed across different courses or they will be at a loss. By applying this approach, students are shown the substantive relevance of the different course topics and of science, technology, engineering

and mathematics (Ríordáin, Johnston, & Walshe, 2016; Mehalik, Doppelt, & Schuun, 2008; Wicklein & Schell, 1995). Furthermore, pupils develop a sophisticated understanding of STEM studies and professions. This facilitates their decision-making when choosing a study or profession (Kelley & Knowles, 2016).

STEM@school not only creates an additive course in secondary schools, moreover, a complete integrated STEM-curriculum is obtained, as explained below. In this newly developed course, namely the STEM-course, linking with the current science and mathematic courses is crucial. To create this integrated STEM-curriculum, some requirements need to be fulfilled (Heil, Pearson, & Burger, 2013). A horizontal alignment of content over the different STEM courses is crucial. This alignment is necessary because two or more disciplines need to be addressed at the same time in order to talk about integrated STEM. When this content is taught just-in-time, students will see the relevance of the content (Ross & Hogaboam-Gray, 1998). On top of that, STEM@school encourages students to transfer concepts of one specific discipline to another. Therefore, the concepts need to be abstracted into models and applied in a new context or the other way around, in other words, by forward-reaching-high road transfer or backward-reaching high road transfer (Perkins & Salomon, 1988). Perkins and Salomon (1988) describe forward-reaching-high road transfer 'as one learns something and abstracts it in preparation for applications elsewhere.' On the contrary, when 'one finds oneself in a problem situation, abstracts key characteristics from the situation, and reaches backward into one's experience for matches' is defined as backward-reaching-high road transfer. So, specific attention in the learning modules for abstracting and model thinking, facilitates transfer.

1.1 Current situation on STEM education

1.1.1 Situation on STEM students and professionals

The current industry in Flanders (Belgium), and in the rest of the Western world, has a lack of scientists, technicians and engineers (Van den Berghe & De Martelaere, 2012; *Engineering UK 2014 The state of engineering*, 2014; *Actieplan voor het stimuleren van loopbanen in wiskunde, exact wetenschappen en techniek [Plan of action for stimulating carreers in math, science and technology]*, 2012; Appianing & Van Eck, 2018; Moens, 2008; Bøe, Henriksen, Lyons, & Schreiner, 2011). The choice for these STEM (Science, Technology, Engineering and Mathematics)-professions is made early in the educational careers of students depending on their enthusiasm for and view on these professions (*Advies STEM-*

studiekeuze [Advice STEM choice of study], 2014; Weerden, Thijssen, & Verhelst, 2003; Sadler, Sonnert, Hazari, & Tai, 2012), unfortunately the attitudes of students toward STEM are rather low (Faber, Unfried, Wiebe, Corn, & Collins, 2013; van Aalderen-Smeets, Walma van der Molen, & Asma, 2012). The lack of scientists, technicians and engineers has four reasons. Firstly, current secondary school curricula do not always succeed in showing the content of these jobs, because concepts of different fields are taught in separate courses, while STEM-professions typically rely on integration of concepts from different fields (*Engineering UK 2014 The state of engineering*, 2014). Secondly, the separation of school subjects and the lack of integration between them, seems to make specific course topics less relevant for students (Mehalik et al., 2008; Stuckey, Hofstein, Mamlok-Naaman, & Eilks, 2013). Thirdly, derived from previous statement, we can state that authentic problems are neglected because they require integration of different subjects. Due to this, students are not aware of the societal relevance of their course content, which is more a problem for women than for men (*Project STEM: Book of insights*, 2014; Sjøberg & Schreiner, 2010; Stuckey et al., 2013; Struyf, Boeve-de Pauw, & Van Petegem, 2017; Sjøberg & Schreiner, 2010; Faber et al., 2013; Mahoney, 2009; Walma van der Molen, Wiegerinck, & Rohaan, 2007; *Advies STEM-studiekeuze [Advice STEM choice of study]*, 2014; J. Sanders, 2005; Jansen & Joukes, 2013; Booy, Jansen, & Joukes, 2011; Sadler et al., 2012; Verentinnicoff & Vandewalle, 2015). Fourthly, psychological barriers arise, since mathematics and science are perceived as difficult and stereotyped (Kier, Blanchard, Osborne, & Albert, 2014; van Aalderen-Smeets et al., 2012; Jansen & Joukes, 2013; Booy et al., 2011; de coopération et de développement économiques, 2015; Bøe et al., 2011). As a result, mediate students hesitate to study science and mathematics, because they are afraid to fail.

Teaching STEM in an integrated way is put forward as a possible solution to these challenges. This integrated STEM, also named iSTEM, focuses on integration between the different components of STEM. In general, recent research has shown promising results on attitude, motivation and learning outcomes of integrating courses (James, Lamb, Householder, & Bailey, 2000; Ross & Hogaboam-Gray, 1998; Lam, Doverspike, Zhao, Zhe, & Menzemer, 2008; Becker & Park, 2011). Nowadays, this iSTEM education is not only gaining interest in secondary schools (Herro, Quigley, Andrews, & Delacruz, 2017), also primary education supports STEM initiatives and lots of extracurricular events are appearing (Capraro, 2008; Klein & Sherwood, 2005; Petrosino, 2004; Lam et al., 2008; Daugherty, 2009; Apedoe, Reynolds, Ellefson, & Schunn, 2008).

1.1.2 Flemish secondary schools

Since this PhD took place in Belgium in Flemish education and education differs a lot over countries and regions, this section provides some information on the education in Flemish secondary schools. Only the relevant information to sketch the context of the PhD is provided.

Flemish secondary education is divided into four major parts. This partition is based on the knowledge and skills students need to gather during their education. The four parts are BSO (Beroeps Secundair Onderwijs), TSO (Technisch Secundair Onderwijs), KSO (Kunst Secundair Onderwijs) and ASO (Algemeen Secundair Onderwijs). The BSO trajectory is vocational education and does prepare for a specific profession, not for studies in higher education. TSO is technical oriented and prepares for a profession or higher education. KSO entails arts. Finally, ASO entails the most abstract knowledge and prepares only for higher education.

In Flanders, two types of teachers are active in secondary education: undergraduate and graduate teachers. An undergraduate teacher is a teacher with an educational bachelor degree. In this education, future teachers are trained on course content for one or two specific courses, described in the curriculum guidelines and teaching approaches. They are only allowed to teach in the first four years of secondary education (K7 until K10). A graduate teacher holds a master degree in a specific discipline and followed a teacher training program afterwards. Sometimes, these teachers first gain industrial working experience before teaching. These teachers can teach from the 3rd year (K9) until the 6th year (K12), i.e. the final year, of secondary education.

Teaching time in school is divided into hours and each hour, students participate in another course with another teacher. Each teacher is trained in his or her own course discipline. This implies the different courses are separated from each other by teachers, hours and content (Sternberg & Williams, 1998).

The educational system in Flanders aims for objectives imposed by the government. The objectives are then translated in more practical and testable format by the Flemish educational umbrella organisations. Depending on which umbrella organisation the school is connected to, those objectives need to be pursued. Although teachers are bonded to these learning objectives, they are free to choose in what manner they achieve these objectives. They can choose their classroom practice themselves. Some textbooks are provided, based on the posed objectives, but teachers are not obliged to use them, and even when they do so, the teaching approach is one of their own choice. Furthermore, teachers are responsible themselves for determining whether each student has achieved the objectives. No central exams are organised in Belgium, so the decision on

whether a student passes, is the responsibility of the teacher teams in the schools. Due to the fact that not the government, nor the umbrella organisations impose assessment strategies, teachers can choose in which manner they will assess the students during their course. This gives a lot of freedom to the teachers, but implies also a lot of responsibility.

1.1.3 Occurring problem

As mentioned before, in order to educate enough STEM professionals for our current and future society, another teaching approach is necessary (Rugarcia, Felder, Woods, & Stice, 2000; Kober, 2015; Zemira & Bracha, 2014; Wicklein & Schell, 1995; Walther, Kellam, Sochacka, & Radcliffe, 2011; Violante & Vezzetti, 2017; Roehrig, Moore, Wang, & Park, 2012; Vaessen et al., 2015). Integrated STEM (iSTEM) is a teaching strategy that serves to meet the goals of current and future society. The integration of knowledge and skills across different courses facilitates the use of real-world problems in classrooms. These real-world problems enhance the skills students will need in the future. Nowadays, physical concepts are rarely mentioned in math class and the other way around (Frykholm & Glasson, 2005). It is therefore not surprising that students fail to see the connection (F. V. Christiansen & Rump, 2008), though this is an important skill for STEM professionals. iSTEM comes forward as a possible solution (M. E. Sanders, 2008).

Not only are the concepts not transfered to other classes, the curriculum guidelines also do not facilitate this transfer. Curriculum guidelines are constructed for each course on its own, without checking cross-links between courses. As a consequence, curriculum guidelines do not support integration across multiple courses. This is not compatible with the iSTEM teaching approach.

Unfortunately, not much research is done on an iSTEM teaching approach, iSTEM curriculum development and its impact on students' learning (Berland, 2013; Kelley & Knowles, 2016; Becker & Park, 2011; Huntley, 1998). The ones who do, report positive findings, as mentioned further. So, first of all, a framework for iSTEM education needs to be set up, based on literature findings. Afterwards, the impact of this iSTEM teaching approach on student learning should be examined.

1.2 Framework of STEM@school

This section is based on and contains excerpts from:

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and supplemented with additional literature important for this PhD.

The study below aims at addressing the lack of consensus about how integrated STEM learning and teaching should be done. To do so, a systematic review of existing literature about learning theories for and instructional practices in integrated STEM was conducted. Moreover, based on the results of the systematic review, a framework for instructional practices in integrated STEM was constructed. In the absence of empirical evidence discerning which instructional elements are crucial for the successful implementation of integrated STEM, this is a valuable alternative to provide some form of evidence-based foundation. The specific research questions addressed in the systematic review are:

1. Which learning theories (behaviorism, cognitivism, social constructivism) form the basis of integrated STEM education?
2. Which instructional practices are used in integrated STEM in secondary education?

First, a literature review is presented in order to extract suitable learning theories and preliminary instructional practices for integrated STEM in secondary education. Second, the instructional practices are elaborated. Thirdly, iSTEM framework used in the STEM@school project is set up and grounded with more literature findings.

1.2.1 Methodology

A systematic review was conducted to identify, critically evaluate and summarize the findings of all relevant studies describing learning and teaching in integrated STEM (Gopalakrishnan & Ganeshkumar, 2013). Systematic reviews differ from narrative reviews, which tend to be mainly descriptive, usually focus on a subset of studies that were chosen based on availability or author selection and

therefore often include an element of selection bias. By contrast, systematic reviews typically involve a detailed and comprehensive search strategy derived a priori, with the goal of reducing bias by identifying, appraising, and synthesizing all relevant studies on a particular topic (Uman, 2011). For the current study, a systematic review was done using two databases: ERIC and Web of Science. The databases were browsed by using four different combinations of search terms: 'Integrated STEM + secondary education' (n = 184), 'Interdisciplinary STEM + secondary education' (n = 86), 'Multidisciplinary STEM + secondary education' (n = 14), and 'STEM integration + secondary education' (n = 121), leading to a total of 405 articles. Overlapping search results were excluded and the dataset was further reduced using four criteria.

Firstly, all selected articles had to be peer-reviewed journal articles or book chapters written in English, resulting in the exclusion of, for example, conference papers and dissertations. Secondly, the articles had to focus on the integration of at least three STEM disciplines. Articles studying the combination of only two disciplines, for example, interdisciplinary mathematics and science or technology integration in mathematics, were excluded. Thirdly, the articles had to provide a clear description of teaching practices for integrated STEM. Finally, all articles had to describe instructional practices for integrated STEM in secondary education. In order to select the appropriate articles, some raters were appointed. These raters were researchers in the project team. One rater checked whether the articles met the criteria and in case of doubt, papers were discussed with two other raters until consensus was reached. After applying the criteria only 15 articles remained in the sample. Given the small number of articles, the 'snowball approach' was used to retrieve additional publications (Doust, Pietrzak, Sanders, & Glasziou, 2005). Reference lists of all selected articles were inspected and eight additional relevant articles that met the inclusion criteria were added to the dataset, resulting in a total of 23 articles.

To analyse the articles in the dataset, first a within-case analysis was conducted (Miles, Huberman, Huberman, & Huberman, 1994). Each article was analysed separately and summarized in a table, consisting of two categories:

1. theoretical grounding, and
2. instructional practices.

Secondly, a cross-case analysis was done (Miles et al., 1994). The instructional practices extracted from all articles were rearranged and similar elements were grouped, leading to nine different categories. Next, the STEM@school framework was composed by focusing on the learning theory and instructional categories named most frequently in the articles of the systematic review.

1.2.2 Systematic review

Theoretical grounding

Learning theories are typically divided in three categories: behaviorism, cognitivism and social constructivism (Ertmer & Newby, 2013; Greeno, Collins, Resnick, et al., 1996). Behaviorism is centered around the idea that one behavior leads to another and does not take into consideration the functions of the mind (Dilshad, 2017; Stavredes, 2011). According to behaviorism, knowledge is an organized accumulation of associations and skills that exists outside a person and can be gained through behavior modification (Greeno et al., 1996; Stavredes, 2011) . Therefore, learning is seen as a change in behavior that can be conditioned using positive and negative reinforcements such as reward and punishment (Stavredes, 2011).

By contrast, cognitivism focuses on students' internal mental structures and addresses the issues of how information is received, organized, stored, and retrieved by the mind (Ertmer & Newby, 2013). In accordance with behaviorism, knowledge is considered to exist outside of the person. However, unlike behaviorism, cognitivism focuses on understanding how human memory works to acquire knowledge and promote learning, instead of focusing on behavior (Stavredes, 2011). Therefore, learning is seen as the discrete changes between states of knowledge, rather than changes in behavior. Moreover, learning is described as a mental activity that entails internal coding and structuring by the student and the student is viewed as an active participant in the learning process (Ertmer & Newby, 2013).

Both behaviorism and cognitivism start from the underlying assumption that learning is an individual process (Ertmer & Newby, 2013). By contrast, social constructivism states that learning is socially situated and knowledge is constructed through interaction with others (McKinley, 2015). According to social constructivism, students learn by building personal interpretations of the world based on their experiences and interactions with the environment (Ertmer & Newby, 2013; Stavredes, 2011). Therefore, in accordance with cognitivism, the student is seen as an active participant in the learning process (Ertmer & Newby, 2013).

To answer the question: 'Which learning theories form the basis of integrated STEM education?', the articles in the dataset were examined for references to learning theories. Of the 23 papers, only seven mentioned to an underlying learning theory for instructional practices in integrated STEM: A. C. Clark and Ernst (2006); El-Deghaidy, Mansour, Alzaghibi, and Alhammad (2017); Guzey, Moore, and Harwell (2016); Riskowski, Todd, Wee, Dark, and Harbor

(2009); Satchwell and Loepp (2002); Shahali, Halim, Rasul, Osman, and Zulkifeli (2017); and H. H. Wang, Moore, Roehrig, and Park (2011). Moreover, all seven articles referred to learning theories from the social constructivist category. As mentioned above, this category of learning theories states that knowledge cannot be transmitted, but rather is actively constructed by students based on their stage of knowledge and their experiences (Driver, Asoko, Leach, Scott, & Mortimer, 1994; Eastwell, 2002). Moreover, the social aspect of social constructivism dictates that learning is a shared, rather than an individual experience (Prawat & Floden, 1994).

Instructional practices

Instructional practices were extracted from all papers and similar elements were grouped. This led to nine categories of instructional practices: integration of STEM content, focus on problems, inquiry, design, teamwork, student-centered, hands-on, assessment and 21st century skills. Below, the different categories are clarified by the enumeration of examples of instructional practices, extracted from papers. These elements reflect the instructional practices in their original wording, as used by the authors of the reviewed articles. In Table 1.1, the match between the categories and papers is displayed. After the enumeration, the extracted instructional practices are elaborated.

Examples of integration of STEM content

- multidisciplinary approach,
- interdisciplinary approach,
- content integration,
- context integration,
- integrated curriculum with equal attention to two or more disciplines,
- curriculum integration with focus on content knowledge,
- explicit assimilation/ integration of concepts from more than one discipline,
- integration of technology,
- translation of representations from different STEM disciplines,
- connections among learning goals, principles, concepts and skills across discipline-specific domains, and
- infusing/merging of two or more STEM content areas.

Examples of focus on problems

- problem-based learning,
- problem-centered learning,
- project-based learning,
- defining, formulating, evaluating and solving problems,
- meaningful/motivating/engaging context,
- focusing on big ideas, concepts, themes, and
- open-ended, real-world, authentic problems.

Examples of inquiry

- posing questions,
- planning and carrying out investigations,
- collecting, analysing and interpreting data/information,
- discovery learning,
- inquiry-based instruction,
- scientific inquiry, and
- authentic scientific practices/processes.

Examples of design

- learning through design,
- design-based learning,
- developing and using models,
- designing solutions,
- engineering design,
- design justification, and
- opportunities to learn from failure and to redesign based on that learning.

Examples of teamwork

- collaborative learning,
- cooperative learning,
- communicating information,

- teamwork,
- working in small groups,
- working with others, and
- interdependence in group work.

Examples of student-centered

- student-centered pedagogies

Examples of hands-on

- hands-on learning,
- hands-on activities, and
- effective use of manipulatives.

Examples of assessment

- understanding student misconceptions and capabilities,
- use assessment as a part of instruction,
- performance and formative assessment,
- writing for reflection, and
- building on previous knowledge.

Examples of 21st century skills

- communicating information, and
- development of 21st century skills

Integration of STEM content The first category contains instructional practices that advocate making connections between the different STEM disciplines. Several approaches for achieving these connections exist and the terminology used for these approaches differs among the reviewed articles. For example, H. H. Wang et al. (2011) distinguish between multidisciplinary and interdisciplinary approaches. According to them, in a multidisciplinary approach, subject-specific concepts and skills are learned separately in each discipline and

Table 1.1: Overview of the instructional categories present in each paper

Authors	Integration	Focus on problems	Inquiry	Design	Teamwork	Student-centered	Hands-on	Assessment	21st century skills
Asghar, Ellington, Rice, Johnson, and Prime (2012)	x	x	x		x				
Roehrig, Johnson, Moore, and Bryan (2015)	x	x	x	x	x				x
Burrows, Breiner, Keiner, and Behm (2014)		x	x		x				
Bybee (2010)	x	x	x	x					
A. C. Clark and Ernst (2006)		x		x			x		
Debs and Kelley (2015)	x		x	x					
El-Deghaidy et al. (2017)	x	x	x		x				
Guzey, Moore, and Harwell (2016)	x	x	x	x	x	x	x	x	
Guzey, Moore, Harwell, and Moreno (2016)		x	x	x	x				
Hernandez et al. (2014)		x	x	x	x				
James et al. (2000)	x	x	x		x				
Mathis, Siverling, Glancy, and Moore (2017)	x	x		x	x	x			
Pearson (2017)	x	x		x					
Riskowski et al. (2009)	x			x	x		x		
Roehrig et al. (2012)	x	x		x	x				
Satchwell and Loepp (2002)	x	x	x	x	x		x	x	
Shahali et al. (2017)	x	x	x	x	x				
Stohlmann, Moore, and Roehrig (2012)	x	x	x		x	x	x	x	
Stohlmann, Moore, McClelland, and Roehrig (2011)	x	x	x	x	x	x	x		
Stump, Bryan, and McConnell (2016)	x	x	x	x	x				
Valtorta and Berland (2015)	x	x		x					
H. H. Wang et al. (2011)	x	x	x						
Wells (2016)			x	x					

students are expected to connect the content, taught in different classrooms, on their own. An interdisciplinary approach, on the other hand, starts with a real-world problem or issue and focuses on interdisciplinary content and skills (e.g., critical thinking and problem solving), rather than subject-specific content and skills. By contrast, Satchwell and Loepp (2002), provide a different definition for interdisciplinarity. Moreover, they discriminate interdisciplinary approaches from integrated approaches, rather than multidisciplinary approaches. According to them, interdisciplinary curricula focus on instruction within one domain, while supporting the content with implicit connections to the other disciplines. Integrated curricula, on the other hand, explicitly assimilate concepts from more than one discipline and apply equal attention to two or more disciplines. A similar distinction is made by Roehrig et al. (2012) who differentiate between content and context integration. According to them, content integration focuses on the merging of the disciplines into a single curricular activity or unit to highlight 'big ideas' from multiple content areas, while context integration

focuses on the content of one discipline and uses contexts from others to make the content more relevant.

Although there is no consensus about the terminology, most of the reviewed articles do agree that making strong connections between the different STEM-disciplines is necessary for integrated STEM to work. Many papers (Satchwell & Loepp, 2002; Shahali et al., 2017; Stump et al., 2016) emphasize the importance of applying equal attention to two or more STEM disciplines and/or explicitly assimilating concepts from different STEM-disciplines. Making integration explicit is critical, because students not spontaneously integrate concepts across different representations and materials on their own (Pearson, 2017). Therefore, intentional and explicit support to help students build knowledge and skills across disciplines should be provided (Pearson, 2017). Nonetheless, although the importance of explicitly integrating large amounts of STEM content has been stressed, several papers (Guzey, Moore, & Harwell, 2016; Pearson, 2017) warn that integration should remain meaningful and purposeful and that more integration is not necessarily better. Moreover, students' knowledge in individual disciplines should be supported. Students require sufficient understanding of the relevant concepts in the individual subjects to connect ideas across disciplines (Pearson, 2017). Therefore, integrated STEM education should also focus on learning goals and standards in the individual STEM subjects, so as not to inadvertently undermine student learning in those subjects (Pearson, 2017).

Focus on problems The second category entails the use of real-world problems tied to an engaging and motivating context. In the reviewed papers, different terms are used to designate this: problem-centered learning, problem-based learning and project-based learning. Although all of these approaches are student-centered, promote active learning and advocate the use of authentic real-world problems, specific differences between these instructional approaches exist (Asghar et al., 2012). In project-based learning, students are provided with the desired specifications for the end product and teachers serve as expert coaches that provide guidelines and suggestions for more effective ways to achieve this predetermined final product (Asghar et al., 2012). By contrast, in problem-based learning, there is no predetermined end product and students are required to identify and define the problem on their own. The goal of problem-based learning is for students to develop problem-solving skills by going through a realistic self-directed problem-solving process. Therefore, the teacher does not provide specific learning guidance, but rather serves as one possible resource that students can use to achieve their goal (Asghar et al., 2012). This is a difference with project-based learning, where the teacher serves as expert coach, and as such guides the students through the process towards the final product. Finally, problem-centered learning holds the middle between project-based and

problem-based learning regarding teacher guidance. Although the problem is more open-ended compared to project-based learning, problem-centered learning focuses mainly on applying and transferring knowledge to realistic contexts, while problem-solving skills are seen as an additional outcome (Merrill, 2002; Van Merriënboer & Kirschner, 2017). Therefore, in contrast to problem-based learning, a carefully sequenced progression of problems and specific types of guidance are provided (Merrill, 2002; Van Merriënboer & Kirschner, 2017).

Nonetheless, despite the different terminology, the same important aspects are emphasized in the different articles. First of all, instruction should start by presenting students with a problematic situation that serves as the organizing center and context for learning (Asghar et al., 2012; Bybee, 2010). By introducing the problem at the start of the learning unit, students can activate existing mental models early in the learning sequence and connect new information and experiences to their prior knowledge in a meaningful way (Asghar et al., 2012). Moreover, instruction should take place in a motivating and engaging context involving current events and/or contemporary issues. That way, students can link the knowledge and skills to be learned to their personal experiences and meaningful learning is encouraged (Guzey, Moore, Harwell, & Moreno, 2016). Finally, the problems presented to the students should be authentic, open-ended, ill-structured, real world problems (Burrows et al., 2014; Satchwell & Loepp, 2002; Shahali et al., 2017). These are 'messy' problems, often with an abundance of information, that resemble challenges encountered by engineers and scientists in the workplace and allow for multiple solution paths and answers (Asghar et al., 2012).

Inquiry A third category entails instructional practices referring to the use of inquiry. In inquiry-based learning, students engage in hands-on activities that allow them to discover new concepts and develop new understandings (Satchwell & Loepp, 2002). Thus, experimental learning is intentionally used to promote knowledge construction (Wells, 2016) and students are encouraged to test their existing ideas by taking things apart, making predictions, observing and recording their explanations (Satchwell & Loepp, 2002). Although inquiry-based learning originated in science education, where it usually entails that students have to engage in authentic science practices (e.g., planning and designing experiments and collecting data), it is not restricted to this domain, but also occurs in mathematical or technological contexts (Satchwell & Loepp, 2002).

In the reviewed papers, several important aspects of inquiry-based learning are mentioned. First of all, questioning is an important part of inquiry-based learning, because it initiates all knowledge building (Wells, 2016). Students are stimulated to question their current knowledge about a given topic and to

identify which additional knowledge they require to move forward (Stump et al., 2016; Wells, 2016). Secondly, students should use this prior knowledge to generate new ideas, design and conduct investigations, and discover new concepts. Moreover, they not only need to carry out the experiments, students also need to demonstrate their understanding of the concepts explored (Satchwell & Loepp, 2002). Finally, an appropriate amount of guidance should be provided to help students achieve the desired conceptual change (James et al., 2000; Satchwell & Loepp, 2002). Truly authentic inquiry experiences might be challenging for secondary school students, due to their lack of experience and knowledge, or because they have not reached the level of cognitive development required for abstract thought (Lawson, 1980; Purser & Renner, 1983). Moreover, pure discovery learning without guidance might be ineffective because students may not come into contact with the to-be-learned content (Mayer, 2004). Therefore, teachers need to provide guidance by questioning students to help them discover flaws in their reasoning and/or research design, ultimately helping them to arrive at a solution (Buck, Bretz, & Towns, 2008).

Design The fourth category refers to the use of technological or engineering design. By actively engaging students in engineering design challenges, they not only learn about engineering design processes and engineering practices, but also deepen their understanding of disciplinary core ideas (Guzey, Moore, Harwell, & Moreno, 2016; Hernandez et al., 2014; Shahali et al., 2017). Engineering design activities can strengthen students' knowledge of science, technology and mathematics, because they fill the gap between factual content knowledge, abstract knowledge and application (Riskowski et al., 2009).

In the reviewed papers, several aspects of qualitative engineering design are mentioned. First of all, effective design challenges should be open-ended, authentic, hands-on, and multidisciplinary (Shahali et al., 2017). These are challenges that represent industry problems, allow students to explore or develop technologies and require them to work with incomplete information and to consider constraints, safety, risks, and alternative solutions (Guzey, Moore, & Harwell, 2016). Moreover, the engineering design process should entail different iterative phases, such a defining the engineering problem, designing engineering solutions, implementing a solution, testing the solution and evaluating and optimizing the solution (Roehrig et al., 2015; Wells, 2016). Furthermore, throughout the design process, students must manage risk and uncertainty, consider prior experience and learn from failure (Roehrig et al., 2015; Guzey, Moore, & Harwell, 2016). In addition, a final requirement for qualitative engineering design is the incorporation of design justification (Roehrig et al., 2015; Wells, 2016). Students should be able to demonstrate what they have learned in the design process, justify their design decisions by means of this

newly acquired knowledge and make recommendations about the design, based on the results of their tests (Roehrig et al., 2015; Wells, 2016). This design justification serves as an effective mechanism for revealing student development and therefore facilitates conceptual change (Wells, 2016).

Cooperative learning The fifth category entails the promotion of teamwork and collaboration with others. In the reviewed papers, two approaches to small-group learning are distinguished: collaborative and cooperative learning. We only include small group learning, because class groups in Flemish secondary education are not larger than 25 students, and are split-up most of the time for projects. Although the papers in the review not explicitly define both approaches, other researches have appointed their difference in teacher guidance as main discriminating factor. In collaborative learning, students structure their own group, without receiving formal training in small-group social skills. The teacher does not actively monitor the groups and refers all questions back to them, because (s)he wants students to resolve group conflicts on their own (Matthews, Cooper, Davidson, & Hawkes, 1995). In cooperative learning on the other hand, the teacher moves from team to team, observes the interactions and intervenes when he feels it is appropriate. Moreover, training in small-group social skills is provided and the teacher encourages students to assess the functioning of the group in order to improve the levels of participation and performance (Matthews et al., 1995).

Although almost all papers in the systematic review refer to the use of teamwork in integrated STEM, the description of how this teamwork should be organized or what the crucial aspects are is much less elaborated compared to the previous categories. According to Guzey, Moore, and Harwell (2016), it is important for students to have sufficient time and multiple opportunities to be involved in teamwork, such that they can improve their teamwork skills. Moreover, several authors (Roehrig et al., 2015, 2012; Stohlmann et al., 2011) stress the importance of not only stimulating teamwork skills, but fostering communication skills as well, since teamwork is hard without communication. To do so, students need to be encouraged to communicate science concepts, mathematical and engineering thinking through reading, writing, listening and speaking (Stohlmann et al., 2011). Finally, positive interdependence between the group members should also be stimulated (Asghar et al., 2012). This means that students should work on tasks that they believe are only soluble if all group members contribute to the effort and can be achieved through: (1) providing rewards for successful interdependence; (2) having activities in which resources are shared; or (3) providing a task that is too difficult for students to do individually (Johnson & Johnson, 1999).

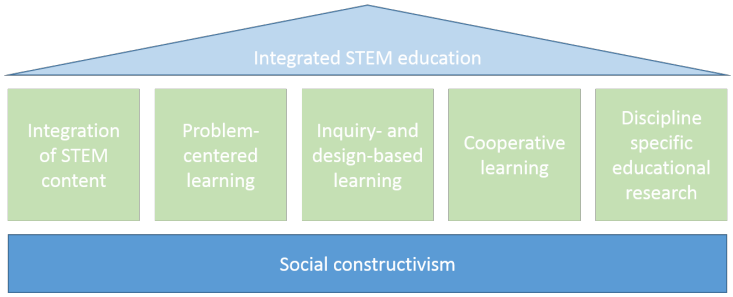
Student-centered The next category refers to the use of student-centered pedagogies and was only present in four of the reviewed articles. Guzey, Moore, and Harwell (2016) indicate that lessons and activities in an integrated STEM unit should be student-centered instead of teacher-centered, because students develop better understanding and skills through active participation in learning activities. Nonetheless, specific guidelines for implementing student-centered learning are not discussed in the reviewed articles. The difference between student- and teacher-centered education is in who is actively involved during the lesson. In a teacher-centered learning environment, the teacher is explaining a lot of concepts, while the students are listening. When the education is more student-centered, the students are processing the concepts on their own while they are actively involved.

Hands-on The instructional practices in the seventh category refer to the use of hands-on learning, hands-on activities and manipulatives. Through hands-on activities, students are less restricted and can actively experience learning. Moreover, relevance is conveyed through hands-on learning, because it allows students to observe the role of innovation in everyday life (A. C. Clark & Ernst, 2006). As with student-centered learning, no specific recommendations for implementing hands-on instruction are given in the reviewed papers.

Assessment The eighth category deals with assessment and was only mentioned in three of the reviewed articles. According to Stohlmann et al. (2012), assessment should be used as a part of instruction. Moreover, Satchwell and Loepp (2002) dictate that assessments should present students with authentic tasks that require them to connect all key concepts studied in mathematics, science, and technology and should include a scoring rubric.

21st century skills The final category comprises '21st-century skills', referring to the knowledge, skills, and character traits that are deemed necessary to effectively function as citizens, workers, and leaders in the 21st-century workplace (Roehrig et al., 2015). They were only explicitly mentioned in one of the reviewed articles, i.e. Roehrig et al. (2015). Although several lists of 21st century skills exist, the ones named by Roehrig et al. (2015) include creativity and innovation, critical thinking, problem solving, communication and collaboration.

Figure 1.1: Theoretical framework for instructional practices in integrated STEM



1.2.3 Framework of STEM@school

Based on the results of the systematic review, a theoretical framework for instructional practices in integrated STEM for secondary education was created. To do so, the five categories of instructional elements most commonly present in the papers of the systematic review were selected. These categories were deemed most essential for teaching integrated STEM. Two of these categories, inquiry and design are inseparable, and as such taken together in the further discussion. Moreover, when different instructional practices were named within the same category (e.g., cooperative learning versus collaborative learning), the strategy with the most emphasis on teachers' guidance was chosen. This approach was used, because the theoretical framework targets secondary students. Since their knowledge and experience is limited, they might need sufficient teacher assistance to achieve conceptual change (De Groof, Donche, & Van Petegem, 2012). The final framework consists of four distinctive but related key principles extracted from the systematic literature review, extended with a supplementary principle of great value to education in classroom practice. The principles extracted from literature are integration of STEM content, problem-centered learning, inquiry- and design-based learning and cooperative learning. The additional principle is the use of results of discipline-specific educational research in the teaching approach. This principle entails the teaching strategies and guidelines to teach specific concepts in order to gain deep understanding and avoid misconceptions (Christie & de Graaff, 2017; Lombardi, 2007; Ceuppens, Deprez, Dehaene, & De Cock, 2018). It is a big branch of educational research, with a lot of interesting results, but unfortunately, it is seldom implemented in classroom practices. All these principles are rooted in a social constructivist view on learning. An overview of the framework is given in Figure 1.1.

The first principle, **integration of STEM content**, refers to the explicit

assimilation of learning goals, content and practices from different STEM disciplines (S. A. Barab & Landa, 1997; Dawes & Rasmussen, 2007). Engineering design can serve as a catalyst to integrate those disciplines (Kelley & Knowles, 2016; T. J. Moore & Smith, 2014). Although integration of the STEM content is absolutely necessary, enough attention should be given to the discipline-specific aspects in the separate courses (Verentinnicoff & Vandewalle, 2015). Basic understanding should be incorporated in the separated courses, whilst the integration course has the potential for building higher-order thinking skills and helping students form meaningful connections between subject areas (Capraro, 2008; Anderson, 2013; Nogay, 1994; Shahali et al., 2017; Shernoff, Sinha, Bressler, & Ginsburg, 2017; Czerniak, Weber Jr, Sandmann, & Ahern, 1999). Although not much studies discuss integration of STEM content, those who do, report an increased content knowledge, engagement, motivation, interest, problem-solving, criticality and real-life application by the students (Barrett, Moran, & Woods, 2014; Ríordáin et al., 2016; Kelley & Knowles, 2016; Becker & Park, 2011; Lam et al., 2008; Ross & Hogaboam-Gray, 1998; Gresnigt, Taconis, van Keulen, Gravemeijer, & Baartman, 2014; Anderson, 2013; M. E. Sanders, 2008; Sternberg & Williams, 1998; Terrón-López et al., 2016; Mustafa, Ismail, Tasir, Said, & Haruzuan, 2016; Hinde, 2005; Guzey, Moore, Harwell, & Moreno, 2016; Beane, 1995). Due to the lack of consensus about terminology, no specific strategy (e.g., multidisciplinary, interdisciplinary or integrated learning (Huntley, 1998; Anderson, 2013)) is proposed.

Problem-centered learning, the second principle, contains the most effective learning products (Merrill, 2002; Burgess, 2004; Tandogan & Orhan, 2007; Mustafa et al., 2016) and shows a great learning gain by the students over time (Schmidt et al., 1996). Problem-centered learning environments should involve students in authentic, open-ended, ill-structured, real world problems to increase the meaningfulness of the content to be learned and increase motivation (Capraro, 2008; Burgess, 2004; Christie & de Graaff, 2017; Hmelo-Silver, 2004; Violante & Vezzetti, 2017; Lombardi, 2007; Rule, 2006; Van Merriënboer, Clark, & De Croock, 2002; Terrón-López et al., 2016; Shepard, 2000) and provide an ideal fit with engineering education (D. J. Harrison, Saito, Markee, & Herzog, 2016; Perrenet, Bouhuijs, & Smits, 2000; Bubou, Offor, & Bappa, 2017). This context-based approach fosters more positive attitudes to school science than conventional courses (J. Bennett, Lubben, & Hogarth, 2007; Tandogan & Orhan, 2007; Vernon & Blake, 1993; Terrón-López, Velasco-Quintana, García-García, & Ocampo, 2017). Another consequence of using real world problems, is that such problems have multiple solutions or multiple paths to a solution (Capraro, 2008; Hmelo-Silver, 2004; Koehler & Mishra, 2005; Nadelson & Seifert, 2017), so students have no predefined outcome and experience a lot of freedom. This freedom stimulates students' critical thinking and learning to iterate in the design or research process (S. G. Puente & Jansen, 2017; Kolodner et al., 2003;

McCrory Wallace, Kupperman, Krajcik, & Soloway, 2000; Stepien & Gallagher, 1993). The problem-solving paths are formed by applying skills in a certain sequence and forming a strategy as such (Schwieger, 2003). In literature, this is defined as an authentic context (van Eijck, 2009; Mehalik et al., 2008; Dochy, Segers, Van den Bossche, & Gijbels, 2003; Dunlap, 2006; Herrington & Oliver, 2000; Rule, 2006; Meyers & Nulty, 2009).

The third principle is twofold, namely, **inquiry- and design-based learning**. Although a distinction between these two can be made, they are often perceived as interrelated (Thys, Verschaffel, Van Dooren, & Laevers, 2016). On top of that, combining inquiry and design results in higher achievement of science concept learning (Mehalik et al., 2008). Inquiry-based learning, refers to learning environments that engage students in questioning, experiential learning and hands-on activities that allow them to discover new concepts, develop new understandings and gain practical skills (Cuevas, Lee, Hart, & Deaktor, 2005; Bubou et al., 2017; Dawes & Rasmussen, 2007; Han, Capraro, & Capraro, 2014). These investigations by students result in significant improvements in students conceptual learning (Minner, Levy, & Century, 2010), enhance student performance (Haury, 1993; Furtak, Seidel, Iverson, & Briggs, 2012; McNeill, Pimentel, & Strauss, 2013) and serve to make links between the real world and the abstract concepts taught in classes (Abrahams & Millar, 2008). Moreover, the learning gains are not only for students, but also for teachers involved in the design process (Koehler & Mishra, 2005; Koehler, Mishra, & Yahya, 2007). It is important to engage students in authentic inquiry, in which they need to explore their own research questions, otherwise the learning gains and development of scientific literacy are limited (Bielik & Yarden, 2016; Chinn & Hmelo-Silver, 2002; Chinn & Malhotra, 2002; Zion & Mendelovici, 2012). Unfortunately, this authentic inquiry also brings along more failure to obtain a solution, which decreases student confidence (Gormally, Brickman, Hallar, & Armstrong, 2009; Sternberg & Williams, 1998). Design-based learning entails the use of open-ended, hands-on design challenges that provide students with the opportunity to not only learn about engineering design processes and engineering practices, but also deepen their understanding of disciplinary core ideas and learn from previous designs (Schnittka & Bell, 2011; Ke, 2014; de Vries, 2006; Holland, Walsh, & Bennett, 2018; S. G. Puente & Jansen, 2017; S. M. G. Puente, van Eijck, & Jochems, 2013). Moreover, design project are able to fill the gap between factual content knowledge, abstract knowledge and application (Riskowski et al., 2009). This design challenge can be an artifact or program or anything that encloses design (Kafai, 2006; Kolodner et al., 2003; Fortus, Dershimer, Krajcik, Marx, & Mamlok-Naaman, 2004; Singer, Marx, Krajcik, & Clay Chambers, 2000; R. Clark & Harrelson, 2002).

Fourthly, the principle of **cooperative learning** indicates that students should

get the opportunity to communicate and collaborate with each other to deepen their knowledge. This is important, since research has shown that students in collaborative groups are better in formulating concrete ideas and posing high-level questions than students working individually (Dessouky, Verma, Bailey, & Rickel, 2001; Zemira & Bracha, 2014; Işık & Tarım, 2009; Leikin & Zaslavsky, 1997; Merrill & Gilbert, 2008; Herro et al., 2017) and had greater student learning (Roedel et al., 1995; Brush, 1997; Nichols & Miller, 1994; Sharan, 1980; Slavin, Leavey, & Madden, 1984; Tarim, 2009; Zakaria, Chin, & Daud, 2010; McNeill et al., 2013), since they construct knowledge within a social context (Kober, 2015; Davis, 2000; Johnson, Johnson, & Smith, 1998; Leikin & Zaslavsky, 1997; Tandogan & Orhan, 2007; Donnelly, Linn, & Ludvigsen, 2014; M. E. Sanders, 2008; Herrington & Oliver, 2000; Slavin, 1987; Sawyer, 2006). On top of that, misconceptions are less present in collaborative groups (Dessouky et al., 2001; Baillie, Goodhew, & Skryabina, 2006) and students' interest, attitude and motivation increases (Bell, Urhahne, Schanze, & Ploetzner, 2010; Brush, 1997; Tarim & Akdeniz, 2008; Ifamuyiwa & Akinsola, 2008).

Finally, **the use of results of discipline-specific educational research** is added to the framework. This key principle entails the teaching strategies and guidelines to teach specific concepts in order to gain deep understanding and avoid misconceptions. It is important to incorporate this knowledge and bring it into classroom practice (Cuevas et al., 2005; Duit & Treagust, 2003; Bybee et al., 2006). Nowadays, a lot of discipline-specific educational research is done, but few results make it to a practical implementation (Bubou et al., 2017). This is a missed opportunity, because teachers are mostly not aware of misconceptions students hold (Kearney, 2006; Cox, Steegen, & De Cock, 2016) and designing interventions using discipline-specific educational research shows large and sustainable improvements in skill and self-confidence (Sanci et al., 2000). On top of that, misconceptions seem not to be isolated but part of a complex structure in students' thinking and, as a consequence, impede proportional reasoning (Watts, 1983; Akatugba & Wallace, 1998; Perrenet et al., 2000; Vosniadou, 1994; Duit & Treagust, 2003). This robust structure in which the misconception is embedded seems very hard to change (Eryilmaz, 2002). Not only misconceptions can be overcome or avoided by the use of discipline-specific educational research, also teaching strategies to enhance conceptual learning are part of this research. As a consequence, the results can assist teachers in choosing appropriate and encouraging teaching strategies. Moreover, research suggests that the quality of student learning increases when teachers take into account pedagogical and pedagogical content knowledge (Zeidler, 2002).

All key principles are supported by a social constructivist view on learning, which dictates that knowledge is actively constructed by the students (Loyens & Gijbels, 2008; D. J. Harrison et al., 2016; Işık & Tarım, 2009; Haury, 1993; Ke, 2014;

Zion & Mendelovici, 2012; X. Wang, Su, Cheung, Wong, & Kwong, 2013; Cain, Grundy, & Woodward, 2018; Birenbaum, 1996) and that learning is a shared, rather than an individual experience (Riskowski et al., 2009; Wilson, 1995). The constructivist teaching approach, for example consisting of activities, practical sessions, book work, video watching, library research sessions and classroom discussion (Freeman et al., 2014; Fetherston, 1999; Waldrop, 2015; Terrón-López et al., 2017), has many advantages. For example, this active learning has a positive influence on concept inventories, higher-order thinking skills and student performances (Freeman et al., 2014; Laws, Sokoloff, & Thornton, 1999; S. G. Puente & Jansen, 2017; Lima, Andersson, & Saalman, 2017; Wallin, Adawi, & Gold, 2016; Singer et al., 2000). Although the advantages of active learning are clear, some barriers hinder the use of active learning strategies (Tharayil et al., 2018). These barriers include concern about the effectiveness of the teaching approach, the preparation time for the teacher, the teaching time and the teacher's ability to cover the syllabus, and student resistance (Tharayil et al., 2018; Gratchev & Jeng, 2018). As a consequence, it is difficult to bridge between constructivist theory and classroom practices (Loyens & Gijbels, 2008). Therefore, it is important to provide appropriate learning materials and guiding for teachers, as described in Chapter 2.

Although the other instructional categories distinguished in the systematic review were not explicitly included in the framework, this does not mean they are considered to be unimportant. Rather, we believe that many of these categories are overarching aspects that are inextricably linked with one or more of the discerned key principles. For example, both problem-centered learning and inquiry-based learning are student-centered pedagogies and both inquiry-based and design-based learning advocate the use of hands-on learning. Moreover, the 21st century skills named by Roehrig et al. (2015) include creativity and innovation, critical thinking, problem solving, communication and collaboration. Hence, the importance of developing these skills is not denied. They are already largely present in the other key principles, defying the need for a separate category. In addition, assessment is not explicitly incorporated in the framework, because it is an indispensable aspect of any instructional approach (Black & Wiliam, 1998) and not specifically linked to integrated STEM education.

1.3 Outline of this PhD

The framework elaborated above served as a base for implementing and examining iSTEM in Flanders secondary education.

In Flanders, two universities, the University of Antwerp and the KU Leuven, have joined hands to conduct a research project about iSTEM, called STEM@school. In this project, a problem solving teaching approach is developed, implemented and tested in Flemish secondary schools. This approach is grounded in five key principles (Thibaut, Ceuppens, et al., 2018), namely integration of different STEM disciplines, problem-centred and cooperative learning, with explicit attention to research and design, as well as the application of discipline-specific educational research results, as explained above.

As part of their particpation to STEM@school, schools created a new course, named iSTEM. In this course, students need to solve a real world problem through research and design. Since participating in research and design requires scientific, mathematical and technological knowledge, the content of these courses is rearranged in order to obtain alignment between the separate courses and the iSTEM course. Furthermore, teachers in the iSTEM course adopt the role as a coach instead of an omniscient teacher (Işık & Tarım, 2009; Hmelo-Silver, 2004; Dochy et al., 2003; Kolodner et al., 2003; Zeidler, 2002; Wu & Hsieh, 2006; Birenbaum, 1996). As a coach, teachers guide students in a team through the development process and provide appropriate scaffolding (Merrill, 2002; Van Merriënboer et al., 2002). This teaching approach focuses on other aspects of learning and provides more attention to competencies and attitudes. For instance, students are confronted with a STEM-design challenge or problem (Berland, 2013; Thys et al., 2016) in which they need to address their knowledge of all STEM-disciplines, in order to complete the challenge.

Multiple research questions arose at the start of this project, but the focus of this work was on assessment of iSTEM competencies. First of all, the transfer skills of students participating in the iSTEM course is studied, because research indicates this problem-based learning facilitates transfer (Ke, 2014; Hmelo-Silver, 2004). Secondly, it was investigated how students are assessed during the iSTEM course. But before it was possible to focus on assessment, iSTEM learning modules needed to be developed. This development was important for the whole project, especially for the participating teachers and schools.

So, after this introduction, the focus is on the developed learning modules in Chapter 2. To start, the development strategy is briefly described. After that, the learning modules created by the author are elaborated. Since we designed the theoretical framework for iSTEM ourselves and developed modules to fit this framework, this part is as design-based research (S. Barab & Squire, 2004). So, the research questions in this chapter are:

1. Is it possible to design learning modules based on the iSTEM framework of STEM@school?

2. How do teachers implement the learning modules in their classroom practices?

3. What barriers do teachers face while implementing the modules in todays secondary education?

Chapter 3 follows and will describe the study of the transfer abilities of students, with iSTEM as well as without iSTEM. This chapter will address the following research questions:

1. To what extent are students able to transfer the concepts of slope, programming loop, area under the curve, and series and parallel circuits from one familiar context, encountered in class, to another familiar context, not encountered in class?

2. To what extent do students refer to one context in order to solve a problem in another context?

3. Which difficulties arise during solving problems concerning the concepts of slope, programming loop, area under the curve and which of these are persistent in an attempt to transfer them? And what hints can help to overcome those difficulties?

4. Do students who are involved in an integrated STEM curriculum transfer the use of concepts to another context more easily than students who are involved in a regular science curriculum? Do the former students connect concepts more flexibly across contexts than the latter?

The assessment strategies used by the teachers are the subjects of Chapter 4. An assessment strategy matching to the iSTEM goals is designed. Furthermore, the assessment strategies of the teachers in iSTEM classes are examined, compared to each other and the proposed assessment strategy, and linked to the impressions of the students. With this study, we want to examine how students, enrolled in the iSTEM course, are assessed. Whereby we take into account the perceptions of students and teachers. The overall question is: How do teacher teams align goals, instruction and assessment, and make sure this triangle is constructive for the students? More precisely, the following research questions are posed:

1. Which assessment method do teachers chose in the iSTEM course?
2. Which theoretical grounding do they use to justify their choice for the assessment method?
3. What are the catalysts and barriers that teacher teams experience to implement an unfamiliar assessment method?
4. How do students experience the assessment method related to the iSTEM classes?

Chapter 2

Design of a STEM curriculum

This chapter describes the developed iSTEM modules within the STEM@school project. Since not much iSTEM curriculum materials are developed yet (Dare, Ellis, & Roehrig, 2018), the development of these modules is necessary in order to test students transfer ability and investigate the assessment of iSTEM classes. This development is design-based research and focuses on the following research questions:

1. Is it possible to design learning modules based on the iSTEM framework of STEM@school?
2. How do teachers implement the learning modules in their classroom practices?
3. What barriers do teachers face while implementing the modules in todays secondary education?

The chapter first describes the used approach to develop the modules. Second, the three modules the author of this work collaborated on with the teachers are described in more detail. The modules are described in a chronological order, to make the development process more clear and to show how the development team has learned from previous experience.

2.1 Approach

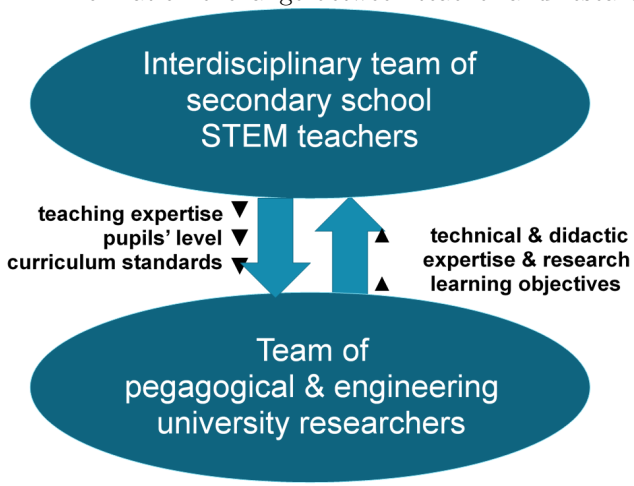
This section describes the used approach to develop the iSTEM learning modules. First, the collaboration with the teachers in teacher design teams is explained. Second, the aligment of the course topics is elaborated, followed by the development process itself. At last, the use of the modules and feedback gathering is explained.

2.1.1 Collaboration with secondary school teachers

Together with teachers, the development team of STEM@school began a brainstorm for developing new integrated STEM modules, in order to establish the team and set a common focus (Capraro, 2008). This collaboration is a conscious choice of the project team. First of all, teachers have everyday classroom experience with students. As a result, they are in the best position to estimate the level of competence of the students (J. Bennett & Lubben, 2006). In addition, secondary school teachers are familiar with the course content of the curriculum. The development team of the project, on the other hand, has innovative ideas about the teaching approach and course content, and are aware of results from discipline specific education research. Supported by Flanders' educational umbrella organizations, this collaboration provides a broad support base for the newly developed teaching approach. The information exchange in this development team is visualised in Figure 2.1. A third reason to involve teachers in the development of the modules is because teachers perform better when they experience ownership over the learning materials (McFadden & Roehrig, 2017). On top of that, developing learning materials serves as professional development for participating teachers (Dawes & Rasmussen, 2007; Mathis et al., 2017; Guzey, Moore, & Harwell, 2016; El-Deghaidy & Mansour, 2015). This ownership is not only given to the developing teachers, but also to the teachers who implement the modules, by handing them the modules in an adaptable format. This opportunity to adapt the curriculum materials is important, because of how teachers enact the curriculum has a lot of influence on student learning (McNeill et al., 2013; Shulman, 1987).

Ten schools in Flanders volunteered for developing learning modules. Each of those schools composed a team of several teachers, to develop a module in collaboration with the researchers of STEM@school. This team is mostly a mixture of undergraduate and graduate teachers, specialized in different courses (Ríordáin et al., 2016), and combines teachers with long-term experience together with novice teachers. This mixture of specialization is necessary because teachers are not aware of the concepts of neighboring courses (Yeatts & Hundhausen,

Figure 2.1: Information exchange between teacher and research teams



1992; El-Deghaidy & Mansour, 2015). This awareness is necessary to make explicit connections or differences in meanings of concepts between scientific specialties (F. V. Christiansen & Rump, 2008; Ríordáin et al., 2016; Shernoff et al., 2017). The mixture of undergraduate and graduate teachers brings other advantages. Undergraduate teachers are trained on course content described in the curriculum guidelines and teaching approaches. A graduate teacher holds a master degree in a specific discipline and followed a teacher training program afterwards. Sometimes, these teachers first gain industrial working experience before teaching. As a consequence, they have a broad knowledge, but less educational knowledge than the undergraduate teachers. The mixture of novel and long-term teachers provides a lot of classroom experience (Frykholm & Glasson, 2005) together with fresh ideas and up-to-date teaching practices (Kober, 2015; Christou, Eliophotou-Menon, & Philippou, 2004). A mixture of these types of teachers covers the course content of the whole secondary school and combines different views on teaching. On top of that, collaboration among teachers increases teachers' self-confidence (Schleicher, 2015).

Not only the teacher teams are a mixture, also the development team of the project consists of researchers in different disciplines. These disciplines are science, engineering, science education and educational science. Thus, the project team can also act with a multidisciplinary view.

This multidisciplinary and multidimensional collaboration ensures the research is relevant for real school practice and the engagement of policy makers, such as employees of Flanders' educational umbrella organizations, increases chances

for long term implementation of developed ideas (Ayas & Demirbas, 1997; Mehalik et al., 2008; J. Bennett & Lubben, 2006; Roach, Kratochwill, & Frank, 2009; Verentinnicoff & Vandewalle, 2015). So, the collaboration results in a professional learning community, which is a great support for developing teachers (McFadden & Roehrig, 2017; National Academies of Sciences, Engineering, and Medicine, 2017; Frykholm & Glasson, 2005; Zemira & Bracha, 2014; Cox et al., 2016; H. H. Wang et al., 2011; Eckman, Williams, & Silver-Thorn, 2016).

2.1.2 Aligning topics

In Flemish secondary education, detailed curriculum guidelines apply, and teachers are expected to implement them (Gielen et al., 2010). This rigid structure makes it almost impossible to change the content of the courses, neither by the teacher, nor by the developers, and as such curtail their freedom (VLOR-Vlaamse onderwijsraad-Raad secundair onderwijs, 2004; Gresnigt et al., 2014; Sawyer, 2006). Though it is important to use the curriculum guidelines while designing learning modules, in order to make sure the learning modules are relevant to students obliged knowledge (Stohlmann et al., 2011; Valtorta & Berland, 2015; Hinde, 2005; Debs & Kelley, 2015; Burrows et al., 2014). When curriculum guidelines are not part of the learning modules, teachers give less attention to the learning modules, because students only have to gain the knowledge described in the curriculum guidelines. Though, students will not be able to accomplish the learning modules without thorough understanding of the concepts. So, it is recommended to match the learning modules with the curriculum guidelines. Given the Flemish curricula for the 3rd and 4th year, an engineering or research project, integrating physics and mathematics, is the most obvious. This integration is limited to these courses due to several reasons. First of all, the link between mathematics and physics is more obvious than the link to other sciences during the 3rd and 4th year of Flemish secondary school (Frykholm & Glasson, 2005). Secondly, the content of the other sciences in the 3rd and 4th year of Flemish secondary education is less suited to apply in a project.

In order to align the topics of the obligated curriculum (Ross & Hogaboam-Gray, 1998; S. A. Barab & Landa, 1997), first, the overarching topics of the different courses are extracted by the researchers of STEM@school. The result of this action for the 3rd year can be found in Figure 2.2. In a second step, the overarching topics of mathematics and physics are matched, based on the underlying concepts, as showed in Figure 2.3. This horizontal alignment and collaboration between courses can detect similar concepts in different classes and as such serve a more efficient teaching of those concepts (VLOR-Vlaamse onderwijsraad-Raad secundair onderwijs, 2004; Sjøberg & Schreiner, 2010).

After matching the topics, a suitable challenge and engineering content were added. Also rehearsal of some concepts was added in order to make sure students understand these concepts. These aligning steps, result in the following overview for the 3rd year of Flemish secondary education (Table 2.1).

Figure 2.2: Extraction of the obligated curriculum topics for the 3rd year of Flemish secondary education

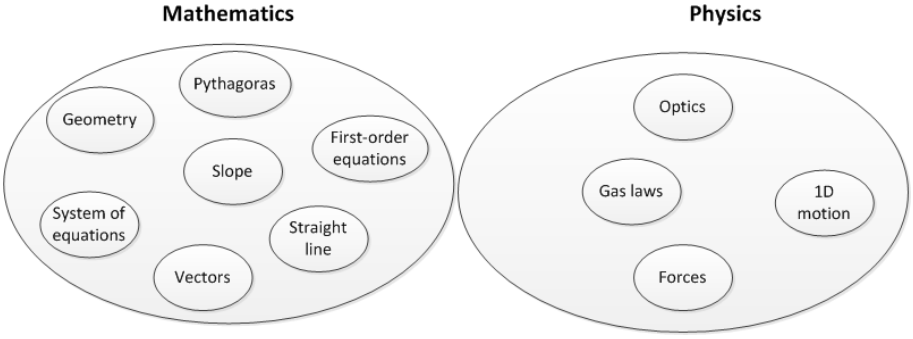
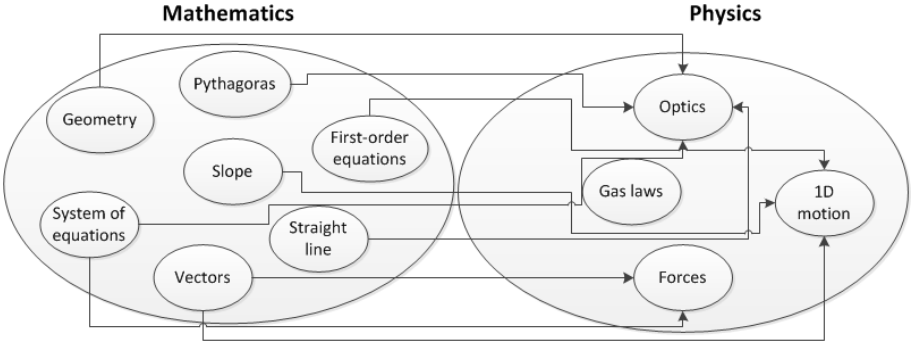


Figure 2.3: Connection between mathematics and physics, for the 3rd year of Flemish secondary education



2.1.3 Development process

The iSTEM learning modules should contain content knowledge from multiple STEM courses in order to be integrative. Besides the typical school's content knowledge, the procedural problem solving knowledge is very important for students to learn, because the engineering part mostly consists of procedural knowledge in order to solve a problem. Students should use an iterative design

Table 2.1: Aligned content with challenge

Challenge	**Mathematics**	**Technique/ Engineering**	**Science**
Autonomous car	Functions First-order equations Graphs Slope	Design Electronics	Kinematics 1D
Museum security	Geometry Pythagoras	Design Optimization	Optics
Rehabilitation medium	Vectors System of equations	Design Hinges	Forces

or research cycle (T. J. Moore, Guzey, & Brown, 2014; Wells, 2016; Pellegrino, Wilson, Koenig, & Beatty, 2014). In the STEM@school project, we chose to use the Legacy Cycle (Klein & Sherwood, 2005), presented in Figure 2.4, because of the clear and well described steps in the cycle and its applicability to science and engineering. On top of that, research has indicated that students involved in the Legacy Cycle gain a greater grow in conceptual understanding than their peers in traditional curriculum (Klein & Sherwood, 2005). The developers designed the modules to force students in an implicit way to use the legacy cycle and as such gain procedural knowledge implicitly. Students should use it in order to solve the engineering or research challenge.

The development process of the learning material can be seen as a compact design cycle, since it only uses two steps of the legacy cycle, as presented in Figure 2.5. An iterative process needs to be done between the challenge and the learning topics (Mathis et al., 2017). The challenge is the problem students need to solve with the learning module. This iteration needs to assure that the selected content is relevant in completing the challenge (Berland, 2013). The concerned teachers attach great importance to this iteration, because they think students will lose their interest in the STEM-course from the moment that the provided content is not relevant anymore to the challenge. However, the same teachers are willing to change the challenge in order to integrate some more course content, which is recommended by literature (Ross & Hogaboam-Gray, 1998). Not only the course content of a certain class can change, sometimes, also concepts normally taught in next years is expedited, when it fits to the challenge. This is not a problem because learning concepts is not a linear process and students will use every experience to refine their learned concepts (van Petegem & Vanhoof, 2002).

After defining the challenge, a script for the learning module was developed. This script is a guideline for developers, teachers and students to complete the

Figure 2.4: Legacy cycle (Klein & Sherwood, 2005)

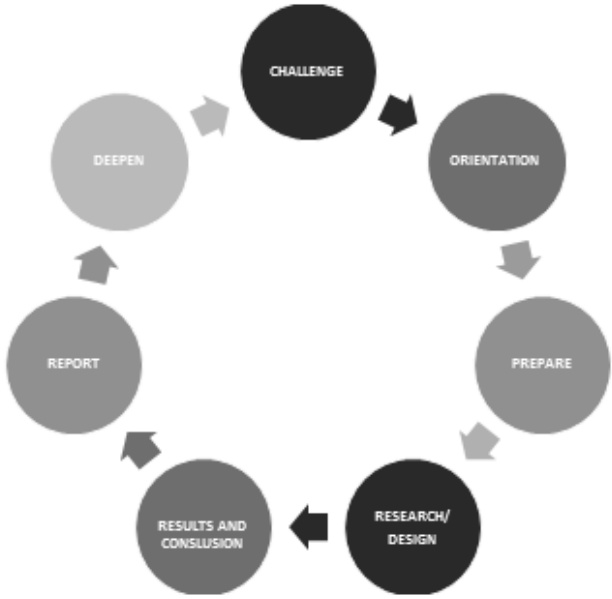
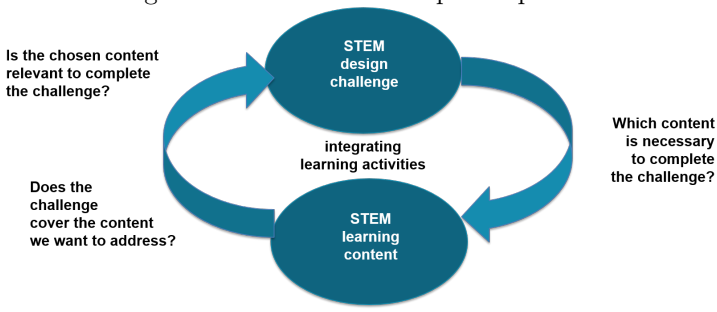


Figure 2.5: Iterative development process



challenge. It contains relevant links to other submodules, summaries and the general flow of the problem-solving process. In the beginning of the curriculum, the script is very strict, since students need a holdfast, but as the curriculum continues, the script provides more freedom for the students (Merrill, 2002). This approach results in learning materials of a Babylonian style, with more emphasis to useful models and systems instead of focusing on axioms (F. V. Christiansen & Rump, 2008). This Babylonian style focuses on the applicability of the learned knowledge, in contrast to the Euclidian style, in which the focus is on axioms and deductivity. The Babylonian style in only used in the STEM-course, where the developed learning modules are used, since the other courses retain their identity, meaning they are taught in a more classic way.

While developing, the five key principles of STEM@school, namely integration of different STEM disciplines, problem-centered and cooperative learning, with explicit attention to research and design, as well as the application of discipline specific educational research results, are taken into account. How this is done for the different learning modules, is explained below.

The whole development process is monitored and put into a roadmap by De Meester (2018). This roadmap provides a methodology and will help teachers to develop their own iSTEM learning modules in the future.

2.1.4 Use of the modules

The developed modules are implemented in 30 schools in Flemish secondary education, in curricula with a strong mathematical, scientific and technical focus. These schools implement a new course, namely iSTEM (Shernoff et al., 2017). This course takes 3 hours a week, preferably contiguous (Schalk & Bruning, 2014) during 8 to 12 weeks, and serves to complete the proposed challenges. Aside this course, the course content needed to complete the challenge, is aligned with the other relevant courses, such as mathematics, physics and programming. This alignment makes the learned content immediately relevant for the students, instead of first having some basic courses in order to apply them later (Engelbrecht, Bergsten, & Kågesten, 2012; Nadelson & Seifert, 2017). Ideally, the necessary information is given just-in-time, so it is immediately applicable (Van Merriënboer et al., 2002; Hmelo-Silver, 2004). Some schools involved one hour of the obligated physics course into the STEM course, which implies some physics goals need to be fulfilled in the STEM course. Most of the participating schools implemented these learning modules in co-teaching. Schools conscientiously incorporated co-teaching because of the learning gains for the students (Roach et al., 2009). This co-teaching also seems to be a good investment for the teachers, because it results in a high quality

STEM integration, shared responsibility, greater self-efficacy and good teachers' professional development (Roehrig et al., 2012; Nogay, 1994; Vesikivi, Lakkala, Holvikivi, & Muukkonen, 2018; Schleicher, 2015).

2.2 Revisions

As indicated before, these modules are all designed in a cooperation between teachers, researchers and employees of the Flemish educational umbrella organisations. Although the modules are designed with great care, and reviewed several times within the design team, the implementation of the modules can reveal some aspects that are not taken into account by the design. To make sure the modules are suitable for classroom use, we gathered feedback during and after the implementation in the classroom and adapted the modules based on this feedback (Ross & Hogaboam-Gray, 1998; J. Bennett & Lubben, 2006; Mathis et al., 2017; Gentile et al., 2012).

2.2.1 Intervision

In the first year of implementation, four intervision moments were planned. Intervision moments are meetings were teachers could meet each other and the researchers in person. During an intervision moment, schools are consulted one by one and are asked to tell about their experiences with the module. Teachers tell about their troubles and moments of success, about their teaching strategy and about the reaction of the students.

These intervision moments are organised in the first place to help the teachers. They can interact with each other and get some new ideas about how to approach certain concepts. Moreover, teachers and researchers can also interact with each other in order to discuss why a certain passage or concept in the module is or is not necessary. Besides helping the teachers, the intervision moments are a great tool to receive feedback about the designed modules and their implementation in the classroom. Researchers took a lot of notes and asked for clarification in order to adapt the modules. So, the researchers were mostly observing the discussions during the intervisions.

2.2.2 Questionnaires

Another way to receive feedback, was by letting the iSTEM team fill in a questionnaire after completion of the module. In this questionnaire, we

probed for which concepts and misconceptions they have taught in class, which experiments they had done with what level of freedom to the students, and which suggestions they have to adapt the module. Only the last question was an open-ended question. For the other questions we indicated the different possibilities and teacher teams could check the box matching their practice. An examples of this questionnaire for the module of the passive house can be found in Appendix A. The answers to these questions gave a good overview of what teachers had implemented in class and how they experienced it. In other words, we checked for the fidelity.

The questionnaires served as a practice-based orientation and only to refine the learning modules. No systematic analysis of these questionnaires is done.

2.3 Developed learning modules

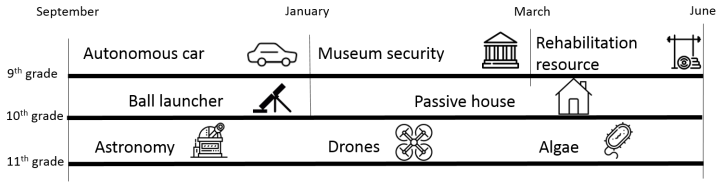
During the STEM@school project, eight learning modules are developed in a cooperation between teachers, researchers and educational umbrella organisations. The developed modules are:

- autonomous car driving through a green wave,
- museum security system,
- rehabilitation device,
- ball launcher,
- passive house with sun boiler,
- drones,
- algae cultivation, and
- binary stars

These modules were developed for a specific time frame in the curriculum of the students. This time frame is important, because the modules take into account the curriculum guidelines, the knowledge already built in the previous modules and the degree of independence students are used to. This results in the order of the modules, presented by Figure 2.6.

In the following sections, the modules developed by the author, together with a teacher team, are described in further detail.

Figure 2.6: The order to teach the developed modules



2.3.1 iSTEM module: Hovercraft

The module of the hovercraft was initially designed to be the 4th module of the 9th grade, but after well-grounded research about the feasibility, the concepts seemed too difficult for students of the 9th grade. This section explains why and how we started the hovercraft learning module, because it provided us some insight in conceptual thinking and development of learning modules.

The motivation to develop this module was threefold:

1. The 1D movement taught in the first module, with the autonomous car and the green wave, could not stand alone, without 2D movement, according to the principle of making learning whole (Perkins, 2010);
2. The hovercraft has minimal friction, so calculations would be easier; and
3. Since the hovercraft has one engine to move forward and backward, and one engine to move left and right, the 2D movement can be treated as two 1D movements, and as such serve as a transfer opportunity from 1D to 2D.

Nevertheless, while developing the module, two big problems arose:

1. The physics, mathematics and programming knowledge needed to control the hovercraft, is way too complex for students of the 9th grade. For instance, an accelerometer as only measurement device has a large error which only increases by time (Fisher, 2010). But when using multiple measurement instruments a Kalman filter in the programming code is necessary in order to work with clear data (Faragher, 2012). This is too advanced; and
2. The first three modules of the 9th grade became more elaborate and time consuming, so no time was left to solve a complex challenge such as the hovercraft.

These problems were too big to overcome in the 9th grade. So the decision was made to drop the hovercraft as a module. Though, some thinking and developing work has been done, and provided us with some insights about conceptual thinking and development of modules.

Challenge

The challenge of the hovercraft was not based on the curriculum of the 9th grade. The module is designed according to the principle of making learning whole (Perkins, 2010), because it does not make sense to only learn about 1D movement. In the regular curriculum, 2D movement is just taught in the 12th grade. Nevertheless, the module is designed and the challenge was formulated as: 'Design a hovercraft, which can flow through a mine field and locate the mines'. This is important, because deminers risk their lives everyday as they don't know where the mines are located and can step on it by accident. The challenge is described more precisely in a context of students who need to go around the mine field every day and since they have to go on foot, it would save them a lot of time when they are able to cross the mine field.

Content

New concepts in this module are 2D movement and Newton's law. Furthermore, a lot of concepts already learned in the 9th grade are rehearsed, such as position, velocity and acceleration, coordinates, vectors and forces. So this module can be seen as a syntheses of all the modules previously taught in the 9th grade and as a transfer exercise for the learned concepts.

Set up of the learning materials

Script The script for this challenge contains references to six submodules:

1. the challenge,
2. creating a hovercraft,
3. experiment with the hovercraft,
4. 2D movement in theory,
5. exercises on 2D movement, and
6. reference module.

The modules are not designed to follow presented order. Students can jump between the submodules, whenever extra information or exercises are necessary. Each submodule is briefly described below, with special attention to the central ideas of STEM@school, namely integration, problem-centered and cooperative learning, research and design learning, and discipline specific educational research input.

Creating a hovercraft In this submodule, the design cycle (Klein & Sherwood, 2005) needs to be fulfilled. It starts with aligning the constraints of the hovercraft. Followed by the explanation of the working principle of a hovercraft. Different physic concepts need to be taught, such as Newton's law, friction, pressure and momentum curtain. When the theoretical knowledge about the operation of the hovercraft is gained, the actual design can begin. Students need to search for the matching electronic components and make a design in which the components fit. To finish this submodule, students need to build the hovercraft. Not all students have the necessary background to select the right components, design and build a hovercraft. Teachers can coach students through this process, or the teacher can opt to provide the components for the students. Students in more technical oriented curricula have more experience with the design and building process, so can be given more freedom. Students in more general oriented curricula have already gained design experience during the previous iSTEM modules, but had no separate design courses.

While writing this submodule, the teachers were building a hovercraft themselves. The building work itself did not seem a problem for the teachers, but controlling the movement of the hovercraft was. This control was hard because of anomalies on the surface destabilised the hovercraft. They consulted several experts, but they did not manage to simplify the control system is such a way that was manageable for the students. Teachers realized the concept of the hovercraft was good, but it was unfeasible for students. Teachers concluded and told other development teams they should build the projects under development themselves in order to check the feasibility.

Experiments with the hovercraft In the submodule of the experiments, students are receiving small tasks, in order to program the hovercraft completely. When students have finished all the experiments, the programming code of the hovercraft is completed. The submodule starts with calibrating the engines, based on graphs students make out of the experiments. The experiments following the calibration slowly construct 2D movement of the hovercraft. The first experiment is about letting the hovercraft move in each direction separately.

When students succeed in this experiment, 2D experiments are the next step in the submodule.

2D movement in theory This submodule sets as goal to let students draft the equation of the 2D motion. To reach this goal, students first need to rehearse 1D movement and then grasp the concept of 2D is twice 1D movement, this seen as a coordinate, representing the position and a vector, representing the orientation. In this way, the thoughts of the students are carefully scaffolded toward what we want them to know.

Exercises on 2D movement The submodule 'Exercises on 2D movement' contains exercises to convert the theoretical knowledge of the students about 2D movement into practice.

Reference module The reference submodule serves as a guide through all electronic components necessary to create the hovercraft. Not only the components are presented, also the scientific background and working principle of the component are explained.

Conclusion

The idea of designing a hovercraft was definitely worth investigating, but seemed unfeasible for students of the 9th grade. As described above, some development of the module is done, but is definitely not finished. To finish the module, attention needs to be given to the feasibility of the challenge, the misconceptions students have about the learned concepts and to the integration of the different submodules.

The learning objectives of this iSTEM learning module were to synthesize and transfer the gained knowledge from the previous iSTEM learning modules. More specifically, we wanted to teach the 2D-movement as two times a 1D movement and apply the concepts of position, velocity and acceleration on this movement. Although the module is not finished, these learning objectives are integrated in the module. Also the central ideas of iSTEM, such as integration, inquiry and design based learning, and problem-centered learning are embedded in the module. Cooperative learning and suggestion from discipline-specific educational research are missing.

Despite the cancellation of this learning module, teachers reported it was enriching to work on it. They realized conceptual thinking about projects is

important, but the practicalities should always be taken into account. They made a commitment to always try out a new project in advance, because building an artifact yourself confronts you with the difficulties students will encounter.

2.3.2 iSTEM module: Passive house with sun boiler

This section is based on:

Goovaerts, L., De Cock, M., Struyven, K., Dehaene, W. (2018). Developing a module to teach thermodynamics in an integrated way to 16 year old pupils. textitEuropean Journal of STEM Education. `https://doi.org/10.20897/ejsteme/3964`

and

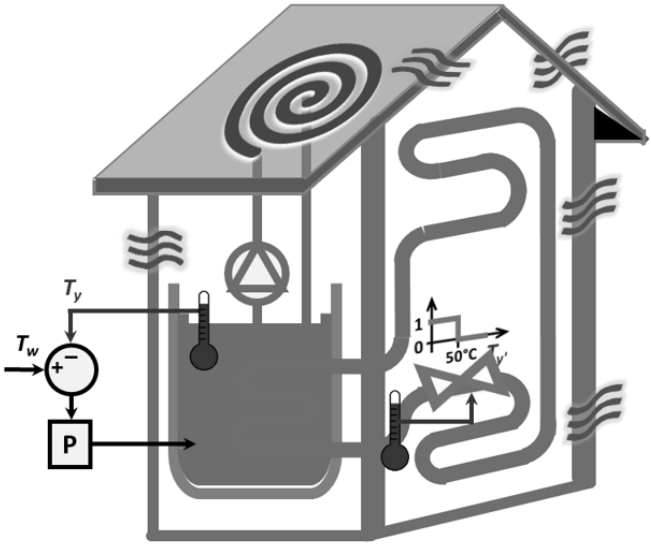
Goovaerts, L., De Cock, M., Struyven, K., Dehaene, W. (2018). *A concrete proposal to introduce control theory to 16 year old pupils.* Manuscript submitted for publication.

Although we did not succeed to make a learning module for the hovercraft, the development team learned a lot from the development of their first iSTEM module and started with good courage at the second one. The module of the passive house with sun boiler is the second module in the 10th grade. Students already experienced one and a half year of iSTEM modules, and this module builds on the knowledge they already gained in the previous modules, and offers more independence for the students.

Challenge

The physics curriculum for the 4th year of secondary education focuses on three main themes: work, energy and power; pressure and gas laws; and heat. In mathematics, topics related to both geometric and analytic description of the circle, quadratic equations and geometric sequences are dealt with. Taking these curriculum guidelines into account, a project relevant to students and relating to the mentioned content was selected. The challenge was formulated as 'Design and develop a model of a passive house with a sun boiler that heats the house and control the temperature in the house'. This STEM-design challenge is presented in Figure 2.7. In this figure a sun boiler is placed on top of the roof. Through a tank, this boiler will provide the hot water for the floor heating of the house.

Figure 2.7: Schematic presentation of the challenge of the passive house. The waves through the walls represent the heat losses to the environment. The loop and graph in the figure illustrate the control system of the house.(Constructed by J. De Meester)



The choice to formulate a STEM-design challenge about heat, is supported by Papadouris, Constantinou, and Kyratsi (2008) and Schnittka, Bell, and Richards (2010). They claim any teaching approach for energy has to be integrative, in order to expose students to all fundamental aspects of energy as a physical quantity.

Content

A major argument for the choice of an iSTEM-design challenge on heat and thermodynamics, relates to the learning goals in the established, existing curriculum for the fourth year of physics. According to the prescribed curriculum goals, students need to learn about calorimetry. More specifically, they are trained to calculate the temperature rise or added amount of heat during an experiment with a calorimeter. Unfortunately, they do not need to study heat transport. However, every real world heat problem contains heat loss by heat

Table 2.2: Physics content

Equations	**Parameters**
The power to heat everything inside the house, can be calculated as follows: $P = \frac{Q}{\Delta t} = \frac{m \cdot c \cdot (T_{end} - T_{begin})}{\Delta t} = \frac{C \cdot (T_{end} - T_{begin})}{\Delta t}$	m = mass [kg] c = specific heat capacity $[\frac{\text{J}}{\text{kg} \cdot °\text{C}}]$ T_{end} = temperature at the end [°C] T_{begin} = temperature at the beginning[°C] t = time necessary to go from the beginning to the end temperature [s] P = power [W]
The leak power through the walls, doors and windows, can be calculated as follows: $P_{Leak} = \frac{S \cdot k}{d} \cdot (T_{inside} - T_{outside}) = \frac{(T_{inside} - T_{outside})}{R_{th}}$	S = surface [m^2] k = thermal conductivity coefficient $[\frac{\text{W}}{\text{m} \cdot °\text{C}}]$ d = thickness [m] T_{inside} = temperature inside the house [°C] $T_{outside}$ = temperature outside the house [°C] P_{Leak} = leak power [W] R_{th} = thermal resistance $[\frac{°\text{C}}{\text{m}}]$

transport, so this content is added to the STEM-course. While treating this concept, students learn how to calculate heat losses through the walls and windows of a house. The needed formulas for this calculations can be found in Table 2.2.

To relate to the mathematics curriculum, the analytic and geometric approach of the circle is used to build the roof, as described later. Students are forced to build a roof with a circular support. As a result of this decision, students need to formulate the equation of the circle and the tangent to the circle, since the roof is supported by the circle. The intersection of the tangent and the circle is the juncture of the roof. This reveals the relevance of the equations of the circle. Other mathematics concepts are necessary while controlling the temperature. Geometric sequences can be used to predict the behavior of the system, since solving numeric differentiation is not yet taught to the students. The needed formulas for this calculations can be found in Table 2.3

The necessary new course content in order to complete the challenge, is summarized in Table 2.4.

Set up of the learning materials

Script Once the challenge is formulated, it is split in several submodules. First of all, a sun boiler needs to be constructed. Secondly, the walls of the house need to be build and insulated. Thirdly, the roof with a circular support needs

Table 2.3: Mathematics content

Equations	**Parameters**
Straight line $y = m \cdot x + b$	m = slope b = intercept
Recursive formula of geometric sequence terms $u_n = u_{n-1} \cdot q$ Explicit formula of geometric sequence terms $u_n = u_1 \cdot q^{n-1}$	$u_n = n^{th}$ term of the geometric sequence q = the multiplicator of the geometric sequence u_1 = first term of the geometric sequence
Sum of the terms of a geometric sequence $s_n = u_1 \cdot \frac{q^n - 1}{q - 1}$	s_n = sum of the geometric sequence q = the multiplicator of the geometric sequence u_1 = first term of the geometric sequence
Formula of a circle $(x - x_0)^2 + (y - y_0)^2 = r^2$	(x_0, y_0) = center of the circle r = the radius of the circle

Table 2.4: Content needed to complete the challenge of the passive house

Physics content	**Mathematics content**	**Engineering content**
Heat capacity	Geometric sequence: Recursive and explicit equations	Integration of science, mathematics and technology
Thermal resistance	Transformation of functions	Mathematical model for the time-behaviour of a system

to be put upon the walls. Finally, the sun boiler needs to be connected with the floor heating of the house and the temperature should be actively controlled.

The first submodule is provided and contains the general storyline, referred to as the script. In this submodule a reference to the other submodules is made, when the content of this submodule is necessary in order to progress in the challenge. The other submodules deal with the building of the sun boiler, the house and control engineering in order to control the temperature in the house. All submodules contain references to relevant chapters in textbooks of physics and mathematics. The content of the regular courses is not redeveloped. Consequently, the changes in the regular courses are reduced to a minimum in order to minimize the necessary extra effort of the teachers (He et al., 2016). The script for this challenge contains references to six submodules:

1. the challenge,
2. energy in a house,

3. the sun boiler,
4. the passive house,
5. heating the house with the sun boiler, and
6. the result.

Each submodule is briefly described below, with special attention to the central ideas of STEM@school, namely integration, problem-centered and cooperative learning, research and design learning, and discipline-specific educational research input.

Summaries in the script Due to the use of submodules, the total knowledge is fragmented. Therefore, some summaries are embedded in the script to keep students on track and select the important issues and formulas. After such a summary, some specific questions about misconceptions are posed. These questions were validated by Yeo and Zadnik (2001) and are proven to be effective in revealing thermodynamic misconceptions by students. The teachers are advised to treat these questions in a peer instruction setting (Jasien & Oberem, 2002; Baser, 2006b; Mazur, 1999; Merrill & Gilbert, 2008), because students must actively process information and put their thoughts into words, which results in a better understanding (Mazur, 1999). The peer instruction setting provides multiple-choice questions for the students. Students vote for the answer they think is correct and discuss their answer afterwards with their peers. After this discussion, students can vote again for the right answer. This work flow provides immediate feedback on student understanding (Mazur, 1999). Together with the concepts, the solutions to these questions are provided for the teacher, with extra explanation. Teachers are also taught, when detecting a misconception, a demonstration or experiment needs to be shown to the students and cause a conflict between the student's conception and the newly observed phenomena. Afterwards, a solution needs to be searched in order to solve the misconception (Trumper, 1997; Baser, 2006b; Doménech et al., 2007).

The challenge The challenge is described for the students in the following way: 'You should build a scale model of a passive house, heated by a sun boiler and underfloor heating. Being sparingly with energy has become a socially relevant topic. We need to make sure that houses are well insulated and use alternative energy sources'. The challenge presented here resembles a lot to the challenge posed by Schnittka et al. (2010), but in another, more applicable format.

Energy in a house In the first step to complete the challenge, students need to learn about heat. To make them familiar with the ideas and concepts, students study the heat consumption in their own house. After this study, they get more information on renewable energy and the typical problems about energy. This phase is called this the exploration phase.

It is important to give students insight in the issue of 'shortage of energy'. Students should be taught that energy can't be lost, although this is what media write and people say. This results in a confusion by students (Goldring & Osborne, 1994). They should learn that energy can be transferred (converted) into other, less useful forms of energy (Kaper & Goedhart, 2002a, 2002b; Doménech et al., 2007) and as such is lost for further use. This misconception is already treated in the first two years of secondary education, so students only need to be reminded of that.

The sun boiler After the exploration phase, the challenge needs to be completed. As the challenge describes, a sun boiler needs to be built. In this submodule and in parallel with the physics course, students learn about heat capacity and thermal equilibrium, which are crucial aspects in learning thermodynamics (Arnold & Millar, 1996; Carlton, 2000). These concepts are best explained by the kinematic molecular theory (Carlton, 2000; Wiser & Amin, 2001). When using these concepts in order to explain heat capacity, the transfer to upcoming concepts as latent heat, will be much easier.

An analogy is used to make students confident with the concept of thermal equilibrium by well-known phenomena in the analogy (Aubusson, 2006; DeHaan, 2009). Arnold and Millar (1996) described an analogy with water flow. Students are demonstrated a glass of water with an inflow and an outflow. Next, they are asked how to adapt the flows in order to keep the water level constant, raise or decrease. The water level then becomes the equivalent of the thermal equilibrium, which makes clear that the net flow needs to be zero in order to be in balance. An analogy is used here, because it is a powerful tool to promote conceptual change and as such overcome misconceptions (A. G. Harrison, 2006). Moreover, using analogies is a facilitator of transfer ability (Kehne & Fechner, 2017b; Tiruneh, Gu, De Cock, & Elen, 2018)

Once the students master the concept of heat capacity, they can use this to select the best material to build a sun boiler. Therefore, students conduct some experiments. In this way, students are forced to combine inquiry- and design-based learning, since they first have to perform experiments in order to build the best sun boiler (Apedoe et al., 2008). Some experiments are suggested in the course material, but proposals of the student are also welcome. Giving enough freedom during the experiments, makes them feel more satisfied and capable of

making decisions. So more open-ended experiments are recommended (Berg, Bergendahl, Lundberg, & Tibell, 2003; Eastwell, 2002). This freedom can be practiced in different gradients (Donnelly et al., 2014; Zion & Mendelovici, 2012; Buck et al., 2008). The most freedom is given when students are asked to design a set of experiments in order to choose the best materials to build a sun boiler. An intermediate form is to discuss with them which experiments need to be set up, but let them design the experiments themselves. The minimum amount of freedom that is still acceptable is given when the experiments with the different steps are given to the students, but the students are free to choose the amount of the concerned materials. In the latter setting, students are forced to think about the constants, parameters, dependent and independent variables (Bielik & Yarden, 2016; Chinn & Malhotra, 2002). As a result, the experiments will not become a simple cooking book experiment (Waldrop, 2015). As mentioned before, the more freedom students get, the more ownership they gain of the experiment. Though, because of boundary conditions, it is not always possible to give so much freedom of choice to the students. The amount of time devoted to the STEM-course is limited and since freedom of choice asks a lot of extra time, freedom can be restricted. Another reason to limit the freedom of choice of students, is that the materials available in the school are below par. In the module, different stages of freedom of choice are presented to the teachers.

The necessary experiments provide an ideal climate to force students to interpret graphs in a physical context. Research has demonstrated students feel unconfident and unable to do this, because they have trouble in making a connection between a graphical representation and the physical process it represents (Boohan, Stylianidou, & Ogborn, 2001; Jasien & Oberem, 2002; Leinhardt, Zaslavsky, & Stein, 1990). In this module for example, students need to measure the temperature over time of three equal reservoirs, only their colors differ. The colors will have an influence on the energy transfer. The students are asked to put these data into a graph and select the most appropriate color in order to warm the fluid in the reservoirs. Consequently, they have to use their mathematical knowledge about graphs and slopes in order to make a physical conclusion (Woolnough, 2000). This requires some transfer ability of the students.

In a final stage, the efficiency of the system in transferring energy from the sun to the water in the sun boiler needs to be calculated. It is important to check how much power the sun radiation needs to provide in order to reach a certain amount of heat in the water, especially in the current debates on alternative energy. Moreover, proving and improving efficiency is a daily goal of an engineer. Since students have to solve an engineering challenge, efficiency will always be a part of it. Besides the social relevance of efficiency, it is part of the curriculum goals, imposed by the government and therefore important to

include in the project.

The passive house Apart from the sun boiler, a model of a passive house needs to be made. The first step is to build a model of a house. The second step is to make the house as passive as possible. In order to build the scale model of the house, students receive the dimensions of the rectangular house. These dimensions are important, because the scaling factor relative to a real house needs to be correct, otherwise it is impossible to heat the house with the floor heating. When students received the dimensions, they go to work to design the floor and the walls.

To design the roof, they need extra mathematical knowledge. The roof is a triangle, supported by half a circle. Hence, students have to calculate the characteristics of the circle, such as the radius and the points of tangency with the roof. This calculations can be done using an analytical or geometric approach, depending on the knowledge of the students and the curriculum guidelines. This step needs to be done before building the house itself, because the different parts of the house are laser cut, so the design has to be correct from the beginning. It is important to integrate mathematical calculations in the design process, so students are aware that the design process has a scientific ground.

Next, the house needs to be insulated to obtain a passive house. To obtain a relevant insulation and the necessary calculations, knowledge about heat transport is required. Students are first given a brief introduction about the different types of heat transport, such as conduction, convection and radiation. To make sure students can distinguish these types of heat transport, some everyday life situations are discussed. The presented examples are already researched and found useful for students of secondary school. For example, the thermos is designed in order to obstruct multiple forms of heat transport (Lewis & Linn, 2003).

The following steps in the challenge focus on heat conduction, because it is the most important form of heat transport when insulating houses. The concept of the heat conduction coefficient is explained and linked to the terms insulator and conductor. To clarify to students that a material will never be an ideal insulator or conductor, various materials are presented at a continuum (Lewis & Linn, 2003). Various conceptual questions are posed to the students, in order to eliminate misconceptions. For example, a frequently appearing misconception is that two or more objects are at a different temperature, because they do not feel as equally hot, although they are in the same room. This idea typically leads to the misconception that metals are naturally colder than non-metals (Frederik, Der Valk, Leite, & Thorén, 1999; Carlton, 2000; Lewis & Linn, 2003;

Sözbilir, 2003; Schnittka & Bell, 2011). Some examples are discussed during the course in order to clarify to students that a conductor always feels colder than an insulator although they are at the same temperature, because a conductor immediately conducts the heat of the body (Lewis & Linn, 2003). Another addressed misconception is that insulators keep cold out (Schnittka & Bell, 2011). Students should be aware of the fact that insulators obstruct the natural flow of heat, from the hot places to the cold places. This misconception is addressed by letting students think about the temperature inside the house during hot summer days in comparison with cold winter days.

In this phase, students are able to calculate the heat loss through the walls and windows of the house. The next step is to investigate whether the chosen insulation material will be good enough. The losses to the outside depend on the temperature of the inside and the outside. The temperature of the inside raises with the heating time. At a certain point, the heat losses will be equal to the power to warm the house, consequently the equilibrium temperature is reached (Arnold & Millar, 1996). This equilibrium temperature should be a lot higher than the desired temperature, because otherwise it is impossible to reach the desired temperature. The whole process of the equilibrium temperature can be explained with the same analogy used to explain thermal equilibrium (Arnold & Millar, 1996), mentioned before.

Heating the house Of course, it is important to assure that the house can be heated with the sun boiler and the temperature can be set. First students should learn how to control the temperature in the house. Therefore, some basic knowledge about control engineering is necessary, such as generic block diagrams, simulations and refinement of the model. These concepts are preferably taught by a modeling-based approach. Modeling processes are part of the engineering curriculum (Carberry & McKenna, 2014; Carstensen & Bernhard, 2018), are fundamental aspects of science (Schwarz & White, 2005; Gobert & Buckley, 2000; Van Driel & Verloop, 1999) and on top of that also shows the relevance of the underlying math and science concepts (Berland, 2013; T. J. Moore & Smith, 2014; Shahali et al., 2017; Pellegrino et al., 2014).

Engineering design is a 'thoughtful process that depends on the systematic, intelligent generation of design concepts and the specifications that make it possible to realize these concepts' (Dym, Agogino, Eris, Frey, & Leifer, 2005). On top of that, engineering serves as a bridge between science and mathematics (Dym et al., 2005). This explains why it is so important to engage students in engineering, although this is not common in today's secondary schools (Bybee, 2010).

System models as part of engineering are currently not embedded in secondary

education, though research suggests it is possible to do so, when 'using a carefully outlined learning and teaching strategy consisting of a sequence of modeling activities' (Boersma, Waarlo, & Klaassen, 2011). This carefully outlined strategy is elaborated below.

Modeling-based approach In order to make engineering topics suitable for students of secondary school, a modeling-based approach is suggested, since a sequence of modeling enhances system thinking (Boersma et al., 2011; Dym et al., 2005) and helps to make abstraction in order to reconstruct it to concrete experiences, also called transfer (Van Merriënboer et al., 2002; Yeatts & Hundhausen, 1992). 'A model is a simplified representation of a system, which concentrates attention on specific aspects of the system. Moreover, models enable aspects of the system, i.e., objects, events, or ideas which are either complex, or on a different scale to that which is normally perceived, or abstract to be rendered either visible or more readily visible' (Gobert & Buckley, 2000).

Constructing a model of the problem has tree goals: first, making a model helps to understand and analyse the problem (Roehrig et al., 2012). Second, it will guide you through the necessary steps to solve it (Kober, 2015). Third, once you found a solution, it can be tested on the model and check whether it is realistic (Engelbrecht et al., 2012; Roehrig et al., 2012). So, in order to make the problem and control engineering more comprehensible, the control system is modeled and made more complex and realistic step by step. In this way, modeling helps students to do problem-solving.

A mathematical modeling process, described by Gainsburg (Carberry & McKenna, 2014; Gainsburg, 2006), can be translated to an engineering approach. The modeling process Gainsburg explains, contains the following steps:

1. Identify the real-world phenomenon;
2. Simplify or idealize the phenomenon;
3. Express the idealized phenomenon mathematically;
4. Perform the mathematical manipulations;
5. Interpret the mathematical solution in real-world terms; and
6. Test the interpretation against reality.

The proposed mathematical modeling process of Gainsburg can be used as a model itself in order to use it for an engineering purpose. Abstraction can be made of the fact that the process serves mathematics. When this abstraction is

made, the modeling process can be used for other purposes. A disadvantage of the modeling process of Gainsburg, is the lack of iteration. Though, this iteration is crucial, as also indicated by the Legacy Cycle (Klein & Sherwood, 2005). However, since the modeling process of Gainsburg is a good hold-fast while modeling, this process is used and added with an iteration which implies the model can be adapted. During modeling the temperature of the house, these steps will be incorporated and will be presented through the following sections. The Legacy Cycle is more appropriate to complete experiments and challenges and serves as such.

As mentioned before, the end goal of the challenge is to actively control the temperature in the house. In order to reach this goal, students need to program the control system. On/off control is presented to the students as the control strategy to reduce the complexity of the problem. Before setting up the implementing this system in the house, students also have to model and simulate it. The concrete, intermediate goal is thus to let them predict the graph of the temperature, with on/off control system, in a realistic situation. This prediction should, in a next step, match the observations in the corresponding experimental setting. This is repeated for several idealized versions of the system. Each version will be less idealized than the previous version. This gradual set-up is explained in the section 'Gradual refinement of the model'.

To model and eventually build this kind of control systems, students need to acquire a deep insight in the concepts of heat conduction and heat capacity. With this content knowledge, students will be able to set up the equations that will predict the behavior of the system.

Generic block diagram When people start solving a problem, they construct a model of how they might approach the problem in their minds and sometimes in a tangible form like a drawing. These models, whether arrived at deliberately or with little forethought, will guide the steps people take to solve it (Kober, 2015). Block diagrams are typical examples of models used in control engineering and help students to thing back and forward between general systems models and concrete objects and processes (Boersma et al., 2011). Therefore, in order to help students make a correct and helpful model, the construction of block diagrams is introduced.

For students to communicate conversantly in a discipline, they need to be able to interpret and use the major types of representations of that discipline. Just as importantly, they need to understand the concept a particular representation is intended to convey and know why both the representation and the underlying concept are important (Kober, 2015). Since system models are a language used by engineers to enhance their engineering design process and their computational

understanding of a problem (Carberry & McKenna, 2014), teaching block diagrams is a crucial part of teaching control engineering. This is supported by Carberry and McKenna (2014) when they claim: 'When modeling is made explicit to students, they obtain a clearer understanding of model-based reasoning in engineering design.' Boersma et al. (2011) strengthens this claim by arguing that system-thinking is an important tool in decision-making and problem-solving.

As mentioned before in the model of Gainsburg (2006), an important step in almost all the models, that describe modeling, is the translation of the verbal problem description, first into a graphic representation and then into a mathematical representation. This step is known as representational transformation and enriches the problem-solving experience, since different representations are used (Dufresne, Gerace, & Leonard, 1997), though students experience this as difficult (Elia, Panaoura, Eracleous, & Gagatsis, 2007). Students have been found to frequently go straight to a mathematical formula without creating the visual representation of the problem (Dufresne et al., 1997; Van Someren, Barnard, & Sandberg, 1994), while making visualizations is integral to scientific thinking (Ainsworth, Prain, & Tytler, 2011). This usually results in failure or misapplication of a formula leading to a dead-end (Svinicki, 2011).

In contrast to novices, experts spend more time analysing the nature of a problem from the outset and creating a coherent solution strategy, while novices often jump immediately to the end goal of a problem and start looking for an equation that might help them solve it (Zemira & Bracha, 2014; Kober, 2015). Experts go on to enrich their model of the problem with information from what they know and remember. In this working forward approach, they start with the information given, making inferences based on that information, and continue refining their inferences until they have reached their goal (Kober, 2015). This construction, is exactly what teachers should teach their students.

In the case of control engineering, first a general block diagram is constructed. The next step is to incorporate specific signals to make the problem more concrete. In the last step, mathematical equations that express the physical phenomena are added.

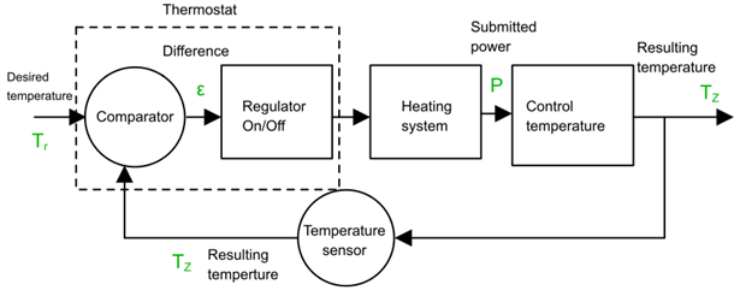
Almost any on/off control system can be presented in a general block diagram, as shown in Figure 2.8. A block diagram gives a good overview of which parts need to be connected with each other and what needs to be compared. Drawing a block diagram is a necessary skill in engineering, therefore students should be able to use and interpret this representation. Just as importantly, they need to understand the concept a particular representation is intended to convey and know why both the representation and the underlying concept are important

(Kober, 2015).

As can be seen in Figure 2.8, an on/off control system is chosen. This has a triple motivation. First of all, this is also how a realistic heating system in a normal house works. Secondly, it is important to teach the basics of control engineering to the students and the basics of control engineering is an on/off system. By discussing the basics in depth, students can build solid fundamentals. A continuous time PID (proportional, integrating, differentiating) control system is the logical next step, but only after a great insight in the basic control system is acquired. And thirdly, an on/off control system is more easily to model mathematically. PID includes integrals and derivates, what makes it too hard for the fourth year in secondary school.

The block diagram presented in Figure 2.8, can be interpreted as follows. The comparator constantly compares the desired temperature (T_r) with the resulting temperature (T_z). When those are not equal, a difference (ϵ) occurs. When the difference differs from zero, the regulator puts the heating system on. This means the maximal power (P) is submitted in order to raise the resulting temperature (T_z). When the difference has reached zero, the regulator stops working.

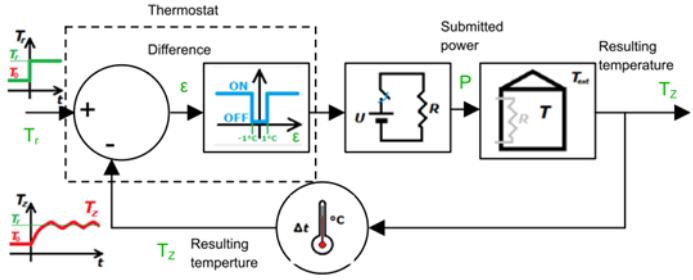
Figure 2.8: Block diagram of the temperature control system



Once the general problem and corresponding block diagram is understood, the next step is to build a more detailed version, in order to show the model building of an expert, presented in Figure 2.9. This version of the block diagram introduces the step function and step response of the system. These are key concepts in control theory. In this challenge, the step function is raising the desired temperature and the step response is the evolution of the temperature in the house. Also the different signals between the processes are made clear in this version of the block diagram.

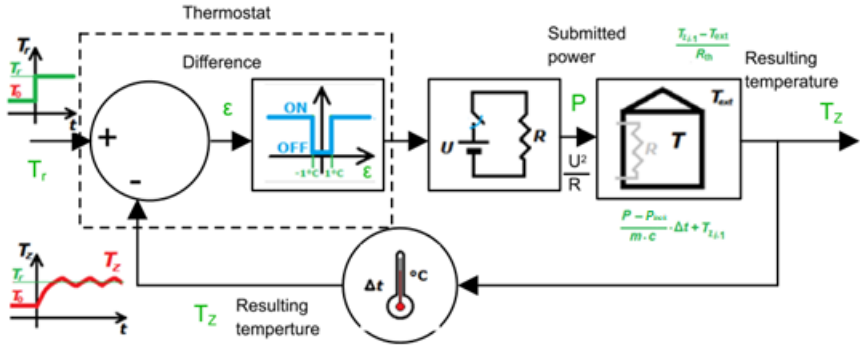
When this block diagram is made more scientific and mathematical, by adding

Figure 2.9: Detailed block diagram



the physical formulas, the block scheme will facilitate students' analyses of the situation, see Figure 2.10. At this stage, the block diagram has become a summary of the knowledge needed to solve the control problem.

Figure 2.10: Detailed block diagram with formulas



With the problem described here, it would be possible to introduce the block diagram presented in Figure 2.10 from the beginning and then strip and simplify this diagram in order to model and solve the control problem mathematically. This approach implies that the teacher immediately gives and discusses this block diagram with the students. This is however only possible when the complexity of the problem at hand is limited. Therefore we adopt another, more general, option. The starting point is a block diagram with all losses neglected, this means P_{leak} will be zero. The next step is to assume the loss is a constant factor. In the final step, students receive the block diagram as presented in Figure 2.10. This last approach is described in the paragraph of 'Gradual refinement of the model' in more detail.

The block diagram indicates that good knowledge of physics is required to

solve the challenge. When interpreting this block diagram in a correct manner, students can make the correct predictions and simulation of the behavior of the system under study. Students learn that a good block diagram provide support in finding a solution, because it captures the essentials of the system's functioning. When they follow the arrows on the block diagram, they know how they need to program the control system.

Simulations Modeling with students and discussing the shortcomings of the model afterwards provides great insights for the students about the matter (Carberry & McKenna, 2014). In this paragraph, the modeling and simulations handle the constraints and simplifications of the real-world phenomenon, which is a necessary step, according to Gainsburg (2006).

Students will model the heating of a house as a first order system, taking into account the heating itself. This means that the reaction delay, also called thermal inertia, of the heating element is neglected. It's impossible to heat the house in one second, therefore a delay occurs.

According to the model of Gainsburg (2006), the designed model needs to be tested against reality. In the case of this challenge, students need to perform experiments, for each model they research. While doing the experiments, students will notice that the house keeps on heating when the heating is switched off. This can be explained by the inertia of the heating element. We chose to model the system as a first order because a second order is not manageable for students to solve the calculations with their current knowledge. Another argument to model the situation as a first order is that in reality, every process is from infinite order. Students need to learn to handle with simplifications as a finite order.

Gradual refinement of the model We guide students to a realistic situation by first handling two cases with simplified, idealized assumptions, as mentioned in the engineering thinking process. Table 2.5 gives an overview of the different assumptions while refining the model.

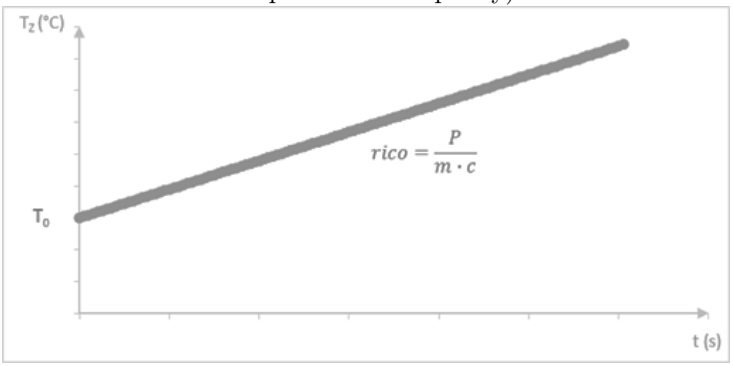
In a first, completely simplified case, we assume that there are no losses through the walls of the house. So, we assume ideal insulation. Students should think about the open loop and closed loop step response of this system. While students predict the step responses, it is important to point them to the right concepts. In this first case, the open loop step response will be a slope, as presented in Figure 2.11.

Students should think about the slope angle. They are already familiar with the mathematical concept, so they should be able to use it in the context of physics

Table 2.5: Gradual refinement of the model

Case	**Assumptions**
First case	No heat losses through the walls of the house $P_{Leak} = 0$
Second case	Constant heat loss through the walls of the house $P_{Leak} = aconstant$
Realistic case	Heat losses through the walls of the house depend on the temperature difference between in- and outside the house $P_{Leak} = \frac{S \cdot k}{d} (T_{inside} - T_{outside})$

Figure 2.11: Open loop step response for a situation with no losses (with T_0 the starting temperature, t the time, T_z the resulting temperature, P the maximal power, m the mass and c the specific heat capacity)



and control engineering. When students have predicted the correct open loop step response, the closed loop step response is discussed. The result can be seen in Figure 2.12

A next step in the build-up to a more realistic situation is the introduction of constant heat loss through the walls. Here, the open loop step response is also a straight line. Students need to compare it to the previous slope, as in Figure 2.13.

Since this case incorporates heat losses, in contrast to the previous case, the closed loop step response looks completely different, as can be seen in Figure 2.14. The temperature rises to the maximum desired temperature. When that temperature is reached, the heat supply stops and the temperature will decrease to the minimum desired temperature. In Figure 2.14, it is shown that the slope of the increase and decrease in temperature is different.

Figure 2.12: Closed loop step response for a situation with no losses (with T_0 the starting temperature, t the time, T_z the resulting temperature and T_r the desired temperature)

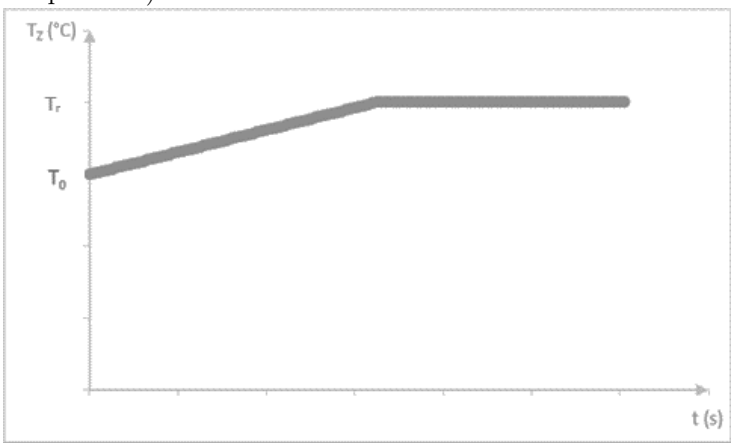
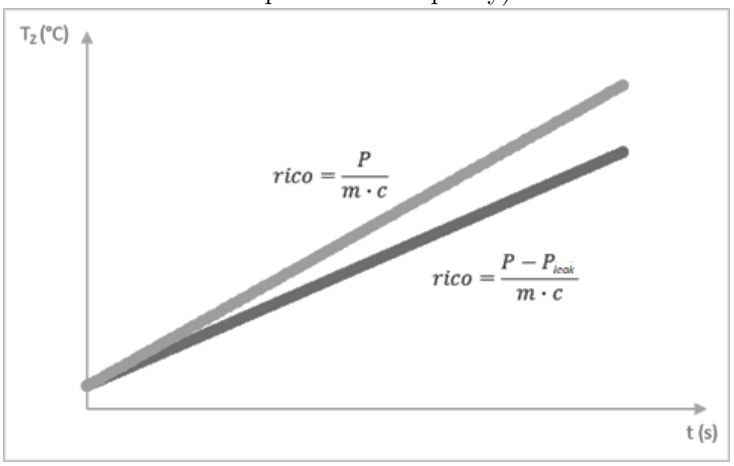
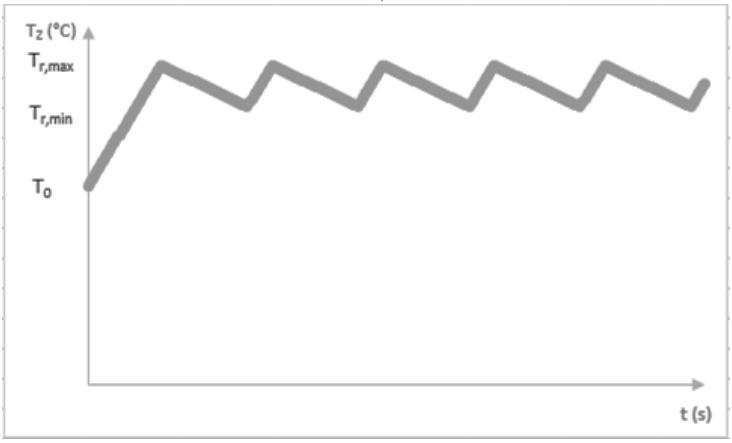


Figure 2.13: Comparison of the slope of the open loop step response in the case of ideal isolation (light gray) and constant loss (with T_0 the starting temperature, t the time, T_z the resulting temperature, P the maximal power, P_{leak} the heat losses, m the mass and c the specific heat capacity)



The final step is a realistic situation with the loss through the walls depending on the temperature difference in- and outside the house. To simulate the situation, students have to use recursive formulas. These formulas can be used for a

Figure 2.14: Closed loop step response for a situation with a constant loss (with T_0 the starting temperature, t the time, T_z the resulting temperature, $T_{r,max}$ the maximal desired temperature and $T_{r,min}$ the minimal desired temperature)



simulation in Excel. The students are also able to make the recursive formula explicit with their own knowledge of geometric sequence and transformations.

The obtained function for the open loop step response, see Figure 2.15, is an exponential function. In Flanders, this content is only treated in the fifth year of secondary education (K11), so to students of 17 year old, but knowledge of this grade goes beyond the scope of this learning module. On top of that, this function comes from the solution of a differential equation. Since the students are not able to solve this differential equitation, the exponential function would be a model without meaning, according to the educational supervisors of mathematics. In order to avoid this concept, another way was developed to come to an explicit function as the solution of the control problem.

To calculate this explicit function, geometric sequences are used. The starting point is the slope at certain moments in the time.

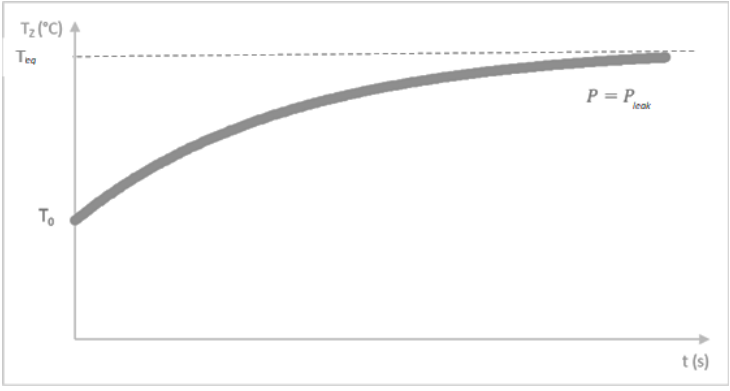
$$slope_1 = \frac{T_{Z,1} - T_0}{\Delta t} \Leftrightarrow T_{Z,1} - T_0 = \frac{(P - P_{Leak,0}) \cdot \Delta t}{m \cdot c}$$

$$\Leftrightarrow T_{Z,1} = \frac{(P - P_{Leak,0}) \cdot \Delta t}{m \cdot c} + T_0$$

$$slope_2 = \frac{T_{Z,2} - T_{Z,1}}{\Delta t} \Leftrightarrow T_{Z,2} - T_{Z,1} = \frac{(P - P_{Leak,1}) \cdot \Delta t}{m \cdot c}$$

$$\Leftrightarrow T_{Z,2} = \frac{(P - P_{Leak,1}) \cdot \Delta t}{m \cdot c} + T_{Z,1}$$

Figure 2.15: Open loop step response of the realistic situation (with T_0 the starting temperature, t the time, T_z the resulting temperature, P the maximal power, P_{leak} the heat losses and T_{eq} the equilibrium temperature)



$$slope_3 = \frac{T_{Z,3} - T_{Z,2}}{\Delta t} \Leftrightarrow T_{Z,3} - T_{Z,2} = \frac{(P - P_{Leak,2}) \cdot \Delta t}{m \cdot c}$$
$$\Leftrightarrow T_{Z,3} = \frac{(P - P_{Leak,2}) \cdot \Delta t}{m \cdot c} + T_{Z,2}$$

Since the thermal leak power always becomes bigger, the slope becomes smaller, until it approximately reaches zero. This gives the recursively defined function

$$T_{Z,n} = \frac{(P - P_{Leak,n-1}) \cdot \Delta t}{m \cdot c} + T_{n-1}$$

with $P_{Leak,n-1} = \frac{T_{Z,n-1} - T_{ext}}{R_{th}}$ and $T_{Z,0} = T_0$

This function needs to be transformed in a way that the equilibrium temperature is the origin of the graph and the function is descending, as can be seen in Figure 2.16.

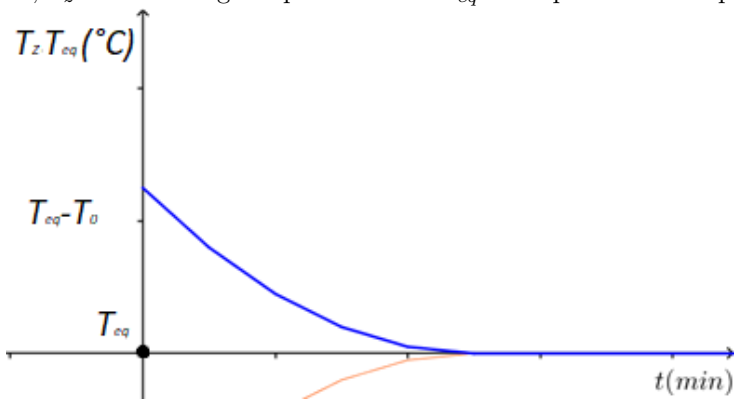
Now a geometric sequence from the form $u_n = u_1 \cdot q^{n-1}$ can be calculated.

$$q = \frac{T_{eq} - T_1}{T_{eq} - T_0} = \frac{T_{eq} - \left(\frac{(P - P_{Leak}) \cdot \Delta t}{m \cdot c} + T_0\right)}{T_{eq} - T_0} = \frac{-\frac{(P - P_{Leak_0}) \cdot \Delta t}{m \cdot c} - T_0 + T_{eq}}{T_{eq} - T_0}$$

$$q = \frac{\frac{(P - P_{Leak_0}) \cdot \Delta t}{m \cdot c} + T_0 - T_{eq}}{-T_{eq} + T_0} = \frac{(P - P_{Leak_0}) \cdot \Delta t}{m \cdot c \cdot (-T_{eq} + T_0)} + 1$$

$$q = \frac{\left(P - \frac{T_0 - T_{outside}}{R_{th}}\right) \cdot \Delta t}{m \cdot c \cdot (-T_{eq} + T_0)} + 1 = \frac{(P \cdot R_{th} - (T_0 - T_{outside})) \cdot \Delta t}{m \cdot c \cdot R_{th} \cdot (-T_{eq} + T_0)} + 1$$

Figure 2.16: Geometric transformed function (with T_0 the starting temperature, t the time, T_z the resulting temperature and T_{eq} the equilibrium temperature)



$$q = \frac{(P \cdot R_{th} - T_0 + T_{outside}) \cdot \Delta t}{m \cdot c \cdot R_{th} \cdot (-T_{eq} + T_0)} + 1 = \frac{(-T_0 + T_{eq}) \cdot \Delta t}{m \cdot c \cdot R_{th} \cdot (-T_{eq} + T_0)} + 1 = \frac{-1 \cdot \Delta t}{m \cdot c \cdot R_{th}} + 1$$

$$T_n = (T_{eq} - T_0) \cdot \left(\frac{-1 \cdot \Delta t}{m \cdot c \cdot R_{th}} + 1 \right)^{n-1}$$

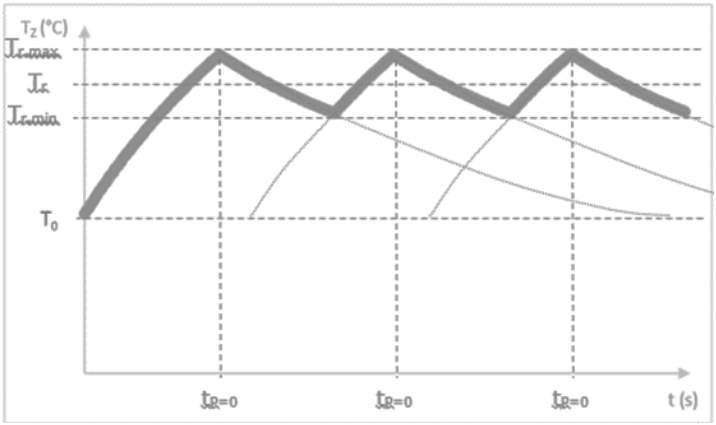
This explicit function needs to be back-transformed geometrically and results in the following function:

$$T_n = (T_0 - T_{eq}) \cdot \left(\frac{-1 \cdot \Delta t}{m \cdot c \cdot R_{th}} + 1 \right)^{n-1} + T_{eq}$$

When students have correctly predicted the behavior of the open loop system, they can model the closed loop step response, as seen in Figure 2.17. This is the ultimate goal of the challenge. By comparing their prediction with the results of the experiments, students can adjust the parameters in the model where necessary, to become a model that better represents their own heating system.

After finishing the simulations, the experiment with the house can be set up. To make the control process easier, students can start by using a power resistor. In this case, the power put in the house is invariable, which is easier to calculate. When this works out, students can switch to the floor heating they built themselves. With the length of the floor heating and the dimensions of the sun boiler, students can calculate whether it is possible to reach the desired temperature and how long it takes for the house to heat up. Though, a few simplifications are necessary in order to facilitate students to make these calculations. The first assumption clarifies that the temperature of the water in

Figure 2.17: Closed loop step response of the realistic situation (with T_0 the starting temperature, t the time, T_z the resulting temperature, $T_{r,max}$ the maximal desired temperature and $T_{r,min}$ the minimal desired temperature)



the floor system is the same at all places in the system. The conducted heat only lowers the temperature when the used fluid leaves the tubes in the floor. Since the temperature in a realistic situation would vary over time and place, a tough integral and differential equation would need to be solved. Because this is far above the heads of 16-year old students, the mentioned simplification is necessary. Another assumption is that the temperature in the house stays at the begin temperature until enough heat is provided to reach the desired temperature. The transient response of the heating system itself is ignored.

The result When all previous steps are completed, the sun boiler can be connected and the house should be heated with the sun boiler. Now, students need to reflect on the task. It is time to catalogue what went good, what went wrong, how the design can be adapted in order to improve,... Students now finally see the whole solution of their initial challenge. According to the teachers, students feel proud to have completed the challenge.

Also a check with governmental rules about heat energy and heat losses in houses is done by the researchers and teachers. As a conclusion, this learning module has covered all curriculum guidelines concerning heat. The experimental approach requires more time investment, but involves a leads to a deeper learning of the concepts, with fewer misconceptions, according to the teachers.

Implementation of the learning module in the classroom

The learning module of the passive house was tested in 30 schools in Flanders. Through meetings with the teachers at intervision moments and questionnaires, feedback is collected.

Teachers mentioned an increase in motivation for learning the concepts of heat and doing the experiments. Due to the teachers, this is caused by the context in which students need to complete the experiments in order to complete the proposed challenge. Moreover, teachers claimed students have a better view on the concept of heat because of the conducted study in their own house.

Although most teachers do not study results of discipline-specific educational research themselves, they reported they have worked explicitly on the presented misconceptions in the module.

Unfortunately, building the passive house as well as the sun boiler seemed to be too time consuming, so teachers needed to make choices. Some teachers decided to build the house this year and the sun boiler next year, or the other way around. Others opted to split the class and let half the class make the house and the other half the sun boiler, in order to create a community of practice and allowing students to learn from each other (Holland et al., 2018).

Despite some professional development courses on control engineering and the positive reactions on it, only a few teachers implemented the submodule of control engineering. Teachers mentioned time and regulation issues in Flemish secondary education to justify the drop of this submodule. For instance, control engineering is not part of the curriculum guidelines. As a consequence, teachers do not give priority to in their course, thus they skip this submodule. Therefore, we only present qualitative data of an interview with one of the implementing teachers, who has implemented most of the control engineering module. This teacher tackled the module by first adapting the language from the module, into a more appropriate level for students. The module is developed for K10 students, but the teacher wanted to use the module in K9. Therefore, she decided it was necessary to adapt the level of language. Then she taught the theoretical part of the module. Thirdly, she challenged the students to do some reverse engineering, by disassembling a flatiron, in which they had to search for the control loops. Finally, the teacher did a demo-experiment using the different models and predictions of the temperature. The teacher had the impression that the students found these concepts interesting, especially when links to reality and other courses were made in the exercises or experiments. In the future, she wants to integrate more mathematics, for example predicting the temperature evolution, which was now only demonstrated and not calculated by the students. The teacher indicated she was not familiar enough with the

concept matter and, as a consequence, preferred a demo-experiment. This is in line with the findings of Abrahams and Millar (2008), who found that teachers involved in classes outside their specialism, tend to rely more on controllable activities in order to reduce unexpected questions or events.

Conclusion

A new approach to teach concepts related to heat and heat transport in secondary school is described, which integrates physics and mathematics in an engineering design problem, taking into account results from discipline-specific educational research. While solving this engineering design challenge, students gain the opportunity to integrate science, mathematics and technology. Furthermore, every design team will follow its own path in solving the challenge, yet led by a research or design cycle. Thus, they feel free and in charge. Being a real world problem to solve, students are able to contact experts, link it to the news and compare their solution to the existing ones.

An advantage of this approach is that students immediately grasp the relevance of the subject matter provided in separate STEM courses, which can lead to increased motivation. Moreover, we expect students to gain a deeper level of understanding the content knowledge because of the relevance and specific attention to certain parts. This increased motivation, knowledge and awareness makes sure students can make a more considered choice regarding their future studies and profession.

In the submodule of control engineering, 16 year old students are introduced to a high level of engineering design. In their engineering design, the students use the physics and mathematical knowledge that is introduced in parallel and integrate it. On top of that, model thinking, abstracting processes, simulating and manipulating behavior of a system is introduced to solve the engineering problem. When involving science and mathematics in engineering modeling, students are shown that control theory is part of engineering science which is employed to solve engineering problems in a logical manner. To build this model systematically, a gradual refinement was necessary. In the first step of the refinement, the different elements will be seen as ideal, in this concrete case, e.g. heat loss is neglected. This facilitates modeling and simulating the process and can lead to progressing insight. The gradual refinement itself makes the model step by step more realistic. In this concrete case the heat loss go from zero over constant to temperature dependent. The course content integrated in this control problem is: geometric sequences, geometric transformations of functions, functions, heat capacity and heat conductivity. The latter topic is a retake from the previous school year. The other topics are all topics that need

to be taught in the 4th year of secondary schools in Flanders (K10). When more teachers implement this module in the future, it will make clear which adaptations are necessary in order to reach full understanding by 16 year old students about the concept of on/off control theory and to let them optimally set their first steps in the world of high level engineering design.

To summarize, the goal of the development of this iSTEM learning module was to develop an engineering design project to teach the concept of heat. Meanwhile, the module also needs to contain an extensive amount of engineering science in the format of control engineering. The design project and control engineering both serve as a facilitator to grasp the physical and mathematical meaning of the learned concepts, and are important for students' engineering skills. The learning modules themselves incorporate all these goals, but something went wrong with the translation to the classroom practice. Unfortunately, the control engineering unit did not make it to most of the classrooms. So this learning objective is not achieved. On the contrary, the learning objectives considering heat all found their way to the classroom and teachers reported an improvement in content knowledge. This could be due to the fact that this iSTEM learning module has given explicit attention to all key characteristics of iSTEM and, as a consequence, is successful.

2.3.3 iSTEM module: Algae cultivation

When starting the brainstorming about the iSTEM modules of the 5th year of Flemish secondary education (K11), it was clear that incorporation of other sciences, besides physics, was necessary. Furthermore, the iSTEM course in the 5th year would be apart from the obligated curriculum, so in the two hours of free choice, which provides more freedom to the teachers in order to choose the challenge. Different challenges were examined, as there were water purification, ecosystems (Pedaste et al., 2013), algae cultivation (Borowitzka, 1999), indoor farms (Dessouky et al., 2001; Morimoto, Torii, & Hashimoto, 1995), geothermics, composting with heat regeneration (Schmaltz, 2008), making diesel fuel from different ground sources (Chisti, 2008; Demirbas, 2010; He et al., 2016; Whipple & Seay, 2011; Burrows et al., 2014). Composting with heat regeneration and making diesel fuel from different ground sources were eliminated quite early in the brainstorming process, since these challenges are coupled to the concept of heat, which is already taught in the module of the passive house. Analysing water from geothermics is eliminated because of the presence of heavy metals. So three challenges left. These challenges all encounter the same concepts of mathematics, physics, biology and chemistry. The covered concepts are part of the regular curriculum of these courses, so students have to learn them anyway. Based on the necessary concepts, it does not matter what challenge will be

chosen and all projects have their own advantages. For instance, the challenge of water purification would be interesting for students, since a lot of students are not aware of the fact that domestic water is treated before it enters our house (Covitt, Gunckel, & Anderson, 2009). Moreover, a lot of students are not aware of the microscopic scale of water(Covitt et al., 2009). This can be explained by the fact that water is described and handled differently in different courses, but never as a whole (Covitt et al., 2009). Since every project covers the same concepts and has its own advantages, other factors will have an influence. For instance, in order to build a biological water purification system, bacteria and conversion will be necessary, which implies odor nuisance and the indoor farm is hard for schools with little opportunities to build a conservatory. So, algae cultivation is chosen as a challenge.

Challenge

The challenge of this module in the 5th year of Flemish secondary education (K11) is set up more broadly then the previous challenges. This extra complexity in comparison with the previous learning modules is appropriate since students have gained a lot of problem solving skills already and so are ready for more complex problems and freedom (Merrill, 2002). Since algae cultivation has various applications, students are free to choose one of these applications. So the challenge for them is to set up the algae growth, use the algae for the application of their choice and investigate whether this is a useful application of the algae through a Life Cycle Analysis.

Content

The concepts coupled to this challenge are exponential functions, growth of species, separation techniques, classification of species, nutrients, spectroscopy, pH and monitoring growth. These concepts all fit into an accompanied science, mathematics or engineering curriculum. Some of them are new, some of them are taught already, but did not get their application in the classroom until now.

Set up of the learning materials

Script Just as the other modules, also this module contains a script which guides students through the challenge. The script contains five parts, which are also submodules:

1. challenge,
2. growth,
3. harvest,
4. applications, and
5. life Cycle Analysis.

Besides these submodules, two extra submodules are added to provide extra information for the students. These submodules are separated to the other because they have no influence on the growth of the algae and just contain extra information that can be applicable during all stages of the challenge. These submodules are:

1. engineering, and
2. reference.

Each of these submodules will be described in detail below.

Challenge The challenge is formulated as follows: 'Start an algae cultivation, monitor the growth of the algae, harvest them and use them for a specific application of your choice, which can be useful for a company'. Besides the formulation of the challenge, students are also made aware that the growth conditions and the type of algae could vary along with the chosen application.

Growth In the submodule 'Growth', students are introduced in the world of eukaryotic and prokaryotic organisms, mitosis and meiosis, and photosynthesis and respiration. All this information is necessary in order to decide about the best growth conditions for the algae of their choice. Once the necessary knowledge is gained, the algae cultivation can be set up by making an appropriate recipient (Travieso et al., 2006). When the growth has started, students should monitor the growth of the algae population. This can be done by microscopy, turbidity measurement or spectrophotometry (Travieso et al., 2006). These techniques and the making-off of the equipment, are described in the submodule 'Engineering'. The monitoring shows a logistic growth model (Travieso et al., 2006), which is mathematically analysed. When the algae have reached their optimal size, some experiments photosynthesis and nutrient stress are proposed (Kim et al., 2012).

In this module, some specific teaching strategies are embedded, based on discipline-specific educational research:

- The recipient consists of a mixture of salts, of which the ions are the crucial parts for the algae. Since students have trouble with dissolving, ions and ionic compounds (Barker & Millar, 1999), some extra questions are added to the module in order to help students gain the required knowledge.
- When teaching the necessity of carbon dioxide in the recipient, the suggestion is made to let students discuss about the chemical equilibrium in a reaction. Students have a hard time with this concept (Ayas & Demirbas, 1997), but are able to overcome the difficulties when discussing them in a group (Bilgin, 2006; Boz & Uzuntiryaki, 2006).
- pH is an influencing factor on the algae cultivation, but is a new concept for students. Every time pH is discussed, the teacher should link this to the concentration of hydrogen ions. This enables students to grasp the meaning of pH in a chemical reaction (Baddock & Bucat, 2008). In the learning modules, this is done by writing down each reaction of which the pH needs to be measured.
- When teaching photosynthesis to students, specific attention should be given to photosynthesis as a process. Many students see photosynthesis as a chemical reaction of matter instead of a process. So, according to Barak, Sheva, Gorodetsky, and Gurion (1999), it should be explained by Figure 2.18 instead of Figure 2.19 and students should alternate between the matter and the process (Chi, Slotta, & De Leeuw, 1994).
- Monitoring the growth on microscopical level as well macroscopic level is important for students. They tend to struggle with meiosis and mitosis (Bahar, Johnstone, & Hansell, 1999). According to Bahar et al. (1999), placing different thought levels, macro, micro and representational, next to each other, helps students to overcome their difficulties with these concepts.
- After students have worked their way through the submodule of growth, it is suggested they make a concept map of it. The submodule is quite large and contains a lot of new terms and concepts, so structuring this new knowledge into a concept map, will help students to process (Barenholz & Tamir, 1987).

Harvest After growing the algae, they should be harvested. This implies they have to be separated from the water they are in. This can be done by different separation techniques. In this submodule, these different separation techniques are described and students are encouraged to analyse every technique critically so they are able to chose the most appropriate technique for harvesting.

Figure 2.18: Photosynthesis as a process

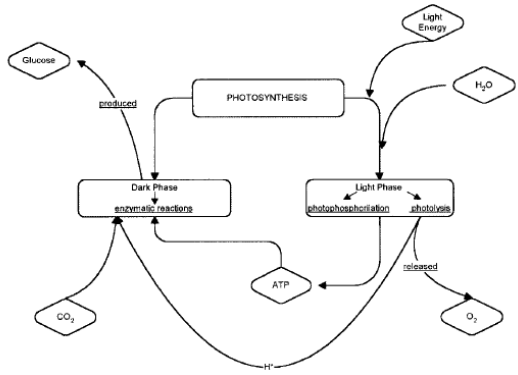
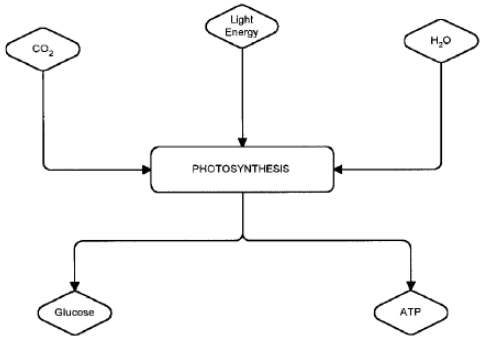


Figure 2.19: Photosynthesis as a reaction



Applications Once the algae are harvested and dried, they or some of their components, should be used in an application. Students are free to chose an application themselves. Popular applications of algae are coloring gummy bears, making biodiesel (Chisti, 2008; Sathish & Sims, 2012) and water purification (Park, Craggs, & Shilton, 2011). The necessary techniques for these applications are described in this submodule, but of course, other applications are also possible.

Life Cycle Analysis When students have used the algae for their application, an analysis of the production process should be done. In this module, a Life Cycle Analysis is suggested, in which students should examine whether the application of their choice is energy efficient and compare it to other processes which result in the same product. This investigation compares the energy put

into the process and the energy that comes out of the process. In this way, students are made aware of energy efficiency.

Engineering The 'Engineering' submodule is a stand-alone module in which building the algae growth environment and measurement techniques are explained in detail. For example, the physical and chemical operation of LEDs is explained. This is helpful, because algae need controlled lightning to grow (Travieso et al., 2006), otherwise it is hard to predict the production (Borowitzka, 1999), and this light is provided by LED-lights. The physical background includes diodes, intensity and energy of light and semiconductors. The chemical background incorporates semiconductors. The physics and chemistry are not split for the application of LEDs, since they cannot be explained without one of these courses, and linking these courses has a positive impact on students knowledge in both courses (Barker & Millar, 1999; Cervellati & Monluschi, 1982). While introducing semiconductors, special attention is given to the structural imaginations correlated to the molecules. This helps students to explain correlated phenomena (Barke & Engida, 2001; Barke & Wirbs, 2002; Chamizo, 2007). The measurement of light and heat through electronics and mathematical transformations is also explained.

Once the students have gained the necessary knowledge, they are guided to build a turbidity and spectrophotometer themselves. The needed electronics, physics, chemistry and mathematics knowledge is presented to them.

Reference module The reference submodule contains a guideline for students in STEM research and design. Different steps in research are explained in more detail so students can use it as a guideline when doing inquiry. Also some tips and tricks are added to easy the research. For example, students are given the advise to label all their samples with a code and to write down the meaning of the codes. This all to facilitate the students' research.

Implementation of the learning module in the classroom

The learning module of algae cultivation was tried out in approximately 10 schools. Schools were free to choose two of the three modules for the 5th year (K11), so not all schools implemented this module. The schools reported, through intervision moments and questionnaires, that the module enhances a lot of relevant science concepts, which are also obligated in the curriculum. Furthermore, students get to see and experience the applications of these concepts, what makes it easier for the students to grasp them. Teachers also

indicate students are more enthusiastic than in the regular science curriculum. Furthermore, teachers and students are thrilled that a variety of solutions is possible and extra information can still be enclosed. This makes the learning module really open-ended and informative.

Conclusion

The algae cultivation learning module is an appropriate way to introduce and rehearse some scientific concepts like separation techniques, exponential functions, growth of species, classification of species, nutrients, spectroscopy, pH and monitoring growth. Students get the chance to apply their knowledge, in order to complete the challenge.

The big goal of this iSTEM learning module was to involve other sciences besides physics. With the topic of algae cultivation, biology and chemistry are automatically involved. More specific learning objectives were about scientific laboratory skills and knowledge students never had the chance to practice. In this set-up, students did not only had to do research, but also design an environment for the algae to grow. This interaction of inquiry- and design-based learning is also one of the key characteristics of iSTEM. Furthermore, also results of discipline-specific educational research are embedded in the module, such as treating photosynthesis as a process and combining microscopic and macroscopic levels. Cooperative, problem-centered and integrative learning are also embedded.

2.4 Conclusion

This chapter described the developed modules of the author together with teacher teams, within the framework of STEM@school, including feedback and revisions of the teachers. It makes clear it is possible to design iSTEM learning modules with inclusion of the five key characteristics, namely integration of different STEM disciplines, problem-centered and cooperative learning, with explicit attention to research and design, as well as the application of discipline-specific educational research results are taken into account.

The structure of the learning modules is described and explained in detail. It is clear that the learning modules evolve together with the students. Learning modules for K9 education are more restricted en more guided than the ones for K11 education. This gradual construction is necessary in order to engage students in problem-based learning, make them familiar with the teaching approach and train them for solving more complex problems (Dooley, 1997;

Merrill, 2002; Gulikers, 2006). Still, some guidance is provided in every learning module, otherwise, students do not succeed in linking the to-be-learned material to their previous gained knowledge (Mayer, 2004). Moreover, this guidance and complexity also facilitates transfer of the learned concepts (Mayer, 2004; D. J. Harrison et al., 2016).

After implementation of the learning modules in the classroom, it seemed impossible to obtain all learning objectives pointed out in advance. Teachers mostly see the time restriction and curriculum goals as a barrier in order to integrate all learning objectives and engineering design (Gresnigt et al., 2014; McCrum, 2016; Roehrig et al., 2012; Hinde, 2005; Asghar et al., 2012). This can only be changed by a serious curriculum reform and reviewing school organizational structures (Singer et al., 2000; Roehrig et al., 2012).

Not only time restriction and curriculum goals were a limit for implementation, teachers also reported their confidence in teaching the learning material, unfamiliarity with the teaching approach, and resistance to change were challenging (Gresnigt et al., 2014; Tandogan & Orhan, 2007; Gero, 2017; Christou et al., 2004; Shernoff et al., 2017; El-Deghaidy & Mansour, 2015). As a result, not all curriculum materials are used as they were intended by the developers (J. Bennett & Lubben, 2006). In order to overcome this, teacher teams should be given more time to familiarize the innovative teaching approach and master the learning materials and as such take a greater ownership (Ríordáin et al., 2016).

It is difficult to make general conclusions about the implementation of these modules, since every classroom context is nested in its constraints and as such forms an unique environment (S. Barab & Squire, 2004). However, reactions of teachers changed from skeptic to enthusiast, once they saw the effect on students motivation and conceptual knowledge. So, we believe these learning modules have a positive influence on implementing iSTEM in secondary schools.

By having these learning modules set up, the learning environment is built and ready to investigate students' transfer ability and assessment in classrooms. So, in the next chapter the research about the transfer abilities of the students is elaborated.

Chapter 3

Transfer of concepts

This chapter is based on:

Goovaerts, L., De Meester, J., Buyse, M.-P., De Cock, M., Langie, G., Struyven, K., Dehaene, W. (2018). *Students' strategies and difficulties when transferring concepts of slope, area under the curve and programming loop within STEM education.* Manuscript submitted for publication.

And

De Meester, J., Goovaerts, L., Buyse, M.-P., De Cock, M., Langie, G., Struyven, K., Dehaene, W. (2018). *Students' strategies and difficulties when transferring the concept of resistance from electricity to thermodynamics within STEM education.* Manuscript submitted for publication.

The current focus in education and companies on 21st century and higher-order thinking skills, implies that students need to gain other knowledge and skills than 20 years ago in order to meet the challenges of a rapidly changing society (Zemira & Bracha, 2014; S. G. Puente & Jansen, 2017; Gresnigt et al., 2014; Lombardi, 2007; D. J. Harrison et al., 2016; Zakaria et al., 2010; DeHaan, 2009; Kelley & Knowles, 2016; Tiruneh et al., 2018). These 21st century and higher-order thinking skills are important because they are transferable to new technologies and processes of industrialization, what makes them important skills for all STEM-professions (Ivanjek, Susac, Planinic, Andrasevic, & Milin-Sipus, 2016; Hassan, 2011; Engelbrecht et al., 2012).

One of the important skills for the future is the ability to transfer learned

concepts into new contexts. This is illustrated by Zemira and Bracha (2014), who argue that students' mathematical skills should focus on solving and interpreting mathematical problems in a variety of situations, involving quantitative, spatial, probabilistic or other mathematical concepts, which is also important for science and engineering disciplines (Kober, 2015).

The framework of STEM@school incorporates some principles such as integration and design-based learning that should facilitate transfer (Fortus, Krajcik, Dershimer, Marx, & Mamlok-Naaman, 2005). Therefore, interest should be taken into examining the effect of the innovative teaching approach on the transfer abilities of the students.

This chapter investigates the transfer ability of students in secondary education, from the context of kinematics to the contexts of hydrodynamics and work, and from the context of electricity to the context of thermodynamics.

3.1 Theoretical background

This section first explains the used definition of transfer, followed by literature findings about the concepts students needed to transfer in this research.

3.1.1 Definition of transfer

In literature, many definitions of transfer can be found, ranging from far and near transfer (Perkins & Salomon, 1988; D. J. Harrison et al., 2016; Schwarz & White, 2005; Barnett & Ceci, 2002; National Research Council, 2001; R. Clark & Harrelson, 2002) over productive and reproductive transfer (Nelissen, 2007) to high road transfer (Perkins & Salomon, 1988), interdomain transfer (Ivanjek et al., 2016) and transfer in and out of situations (Schwartz, Bransford, Sears, et al., 2005). The common understanding in all these definitions of transfer is that transfer of learning occurs when learning in one context improves a related learning performance in another context (Tiruneh et al., 2018). Though, all authors choose their own focus. For instance, interdomain transfer (Ivanjek et al., 2016) is focused on transfer between different domains, and could be compared to the definition of far transfer of Perkins and Salomon (1988). While the focus of Nelissen (2007), who distinguishes productive from reproductive transfer, is not on the domain or context but on the exploration of gained knowledge. In other words, Nelissen (2007) describes reproductive transfer as using and applying gained knowledge, while productive transfer requires exploration of the knowledge into new knowledge. This exploration of knowledge

requires students not only to use known strategies, but to adapt those strategies so that they will be helpful for another problem. So, it is not only knowing when to use a certain strategy, but most of all, how to adapt the strategy in such a way that it fits.

The focus in this study is on transfer of concepts and so we operationalize transfer as 'the ability of students to retrieve general characteristics of learned concepts and use them in another context or domain in which they have not applied them before'. This definition resembles the definition of transfer given by Ivanjek et al. (2016) and Klein and Sherwood (2005). The latter argue that transfer of knowledge occurs when 'the knowledge can not only be accessed again in the context in which it was learned, but also in new contexts'.

Perkins and Salomon (1988) distinguish between near and far transfer. In near transfer, students perform a well-trained routine procedure to solve a problem in a new context, triggered by context and surface similarities between this context and the context in which the procedure was learned. Context similarities are resemblances between the presented contexts. For example, a car driving on a road and a biker moving forward resemble a lot, because in both cases a motion is involved. Surface similarities are, for example, use of the same symbolism, same representation or same formula. Context similarities and surface similarities facilitate transfer because students remember what strategy they have used in a similar context or representation. At the same time, these similarities can confuse students when the situation seems to be the same, but is not, or when the same elements are used with a different meaning (F. V. Christiansen & Rump, 2008). Far transfer requires the abstraction and recall of the concepts and principles underpinning a problem in both contexts in order to apply them in the new one (Perkins & Salomon, 1988). Research has shown that, when there are few surface similarities between two problem contexts, the required far transfer is usually very poor (Day & Goldstone, 2012; Holland et al., 2018). Far transfer requires the ability to fluently retrieve and make associative combinations among analogous features (Benedek, Könen, & Neubauer, 2012; Mayer, 1989; Kehne & Fechner, 2017b). Association involves looking at a problem from different perspectives (DeHaan, 2009; Goldstone & Day, 2012), and mentally modeling the concepts and structures underpinning the problem (Day & Goldstone, 2012). Obviously, a profound understanding and mental organization of these concepts in the initial learning context are necessary to be able to transfer them to another context (Day & Goldstone, 2012; Feldon, Hurst, Rates, & Elliott, 2013). The concepts learned in the initial context should be well constructed and readily accessible in the learners' minds (Perkins & Salomon, 1988, 1988; Feldon et al., 2013). However, when students do not spontaneously transfer the concepts and principles that are in fact well-established in their minds (Goldstone & Day, 2012), hints are required

in a new context, to scaffold their thinking process, to point out the analogy with the initial learning context, and to access the relevant concepts (Day & Goldstone, 2012; Chen & Daehler, 2000; Brown, 1990).

It is hard to make the distinction between near and far transfer, since different aspects of transfer need to be taken into account. Barnett and Ceci (2002) have distinguished six dimensions of far and near transfer. These dimensions are:

- Knowledge dimension: The knowledge base to which the skill is to be applied, such as science class versus math class. Near transfer in this dimension implies transfer of the skill in the same class, while far transfer is, for example, indicated by using a concept learned in math class, in a chemistry class.
- Physical dimension: This dimension contains both macroaspects and microaspects. Macroaspects are among other things in what context the training and transfer phases take place. The training phase, when students learn the concept, and transfer phase, when students need to carry over their knowledge, can take place in class, in an extracurricular activity, etc. Microaspects include the physical place where students have learned about the concept and need to transfer it, or who takes the interview. So near transfer for this dimension means the learning and transfer phase both encounter in the same room and school, with the same teacher. Far transfer is characterized by learning the concept in the classroom and transferring it, e.g. in an extracurricular activity, with another teacher.
- Temporal dimension: Reflects the time elapsed between training and transfer phases. A short time interval between learning and transfer phase corresponds to near transfer in this dimension, while a large time interval corresponds to far transfer.
- Functional dimension: The function for which the skill is positioned and the mind-set it evokes in the individual. For instance, using a concept learned in order to solve exercises for fixing a technical issue, can be considered as far transfer. Near transfer is characterized by using the concept for the purpose you have learned it.
- Social dimension: Refers to whether the task is learned and performed alone or in collaboration with others. So, near transfer occurs when the transfer phase takes place with the same social interaction as the learning phase. When this is not the case, it is far transfer.
- Modality: At the macrolevel, the task can be visual or auditory, written or verbal, linguistic or hands-on. At the microlevel, a task can be in multiple-choice format or essay format. For the dimension of modality,

> far transfer implies that the format of the transfer task has a complete other set-up than the format of the learning task, otherwise it is only near transfer.

We will use these dimensions to characterize the transfer level, near or far, under study. The differentiation between near and far transfer is crucial in order to analyse students' transfer ability. In general, near transfer is transferring to a context close to the learning context and far transfer is the opposite. We want to focus on transfer between different contexts and extracting concepts out of the original context. This far transfer requires a higher abstraction level of the students, than when near transfer is required, because they first have to extract the concept out of the original context and reorganise it in the new context (Ivanjek et al., 2016), while in the case of near transfer a lot of similarities between the two contexts appear.

Context-rich learning environments, such as in integrated STEM education, might be the key to student preparation for transfer, because of the many links that exist between concepts of these different scientific domains (National Research Council, 2012):

> It seems evident that, if we want students to achieve transferability of thinking patterns between contexts, we should provide students with different contexts in which the use of thinking patterns is analogous to a degree that is congruent with their zones of proximal development. ... [T]he attainment of transferable mental maps will be facilitated by the use of contexts for which a series of readily perceived analogies exist, where activity to explore the operation of analogy is organized, where the ideas of analogy-drawing can be mapped onto the phenomenon, and for which the students have a worthwhile, preferably extensive, experience. (Gilbert, Bulte, & Pilot, 2011; Brown, 1990)

Science practices involve scientific principles and methods, while technological and engineering practices have a problem-solving dimension. However, both science and technological practices have two prevalent reasoning strategies in common: (a) logical deduction, in case the existing knowledge framework contains the answers, and (b) analogical reasoning, in case the existing knowledge base does not suffice for solving the problem at hand (Feldon et al., 2013). iSTEM education combines these STEM practices through problem-centered, inquiry- and design-based learning within a curriculum with a considerable amount of science, technology, engineering, and math courses. This was the rationale behind the development of learning units in the scope of the research

project STEM@school (Thibaut, Ceuppens, et al., 2018). In STEM@school learning units, students employ STEM practices to connect math concepts (e.g. variable, function, equation, vector), physics concepts (e.g. velocity, acceleration, photon, reflection, force), and technology concepts (e.g. programming variables and functions) (Ceuppens et al., 2018). Therefore interest should be taken into investigating whether iSTEM students can switch between contexts and make links between crosscutting concepts in a more flexible way than their peers in a traditional STEM curriculum, in which STEM courses are taught in a more compartmentalized, less context-rich approach.

3.1.2 Transfer of concepts

Although different studies have been carried out on transfer of metacognitive skills, which also improves transfer of knowledge (Zemira & Bracha, 2014) and transfer of skills (Perkins & Salomon, 1988; Tiruneh et al., 2018), we choose to focus on the transfer of concepts. In order to transfer concepts, students do not only need to possess the necessary knowledge, they also need to know how to apply this knowledge. So, in order to complete transfer of a concept, students need to fulfill the continuum between knowledge and skill. By conceptual knowledge we mean 'the explicit or implicit understanding of the principles that govern a domain and of the interrelations between pieces of knowledge in a domain' (Rittle-Johnson & Alibali, 1999). This is important, because conceptual knowledge helps to interpret and construct models (Kober, 2015; Carberry & McKenna, 2014; T. J. Moore & Smith, 2014; Ivanjek et al., 2016; Ross & Hogaboam-Gray, 1998), which is an important skill for STEM professions (Kober, 2015). This modeling, with the help of concepts, is important, because it helps students to understand the use of strategies within a context and provides them with the opportunity to apply these strategies to a complex task (Pedersen & Liu, 2002). Since students in the iSTEM-curriculum have had the opportunity to learn how to do model thinking through the learning modules, the impact of this on their transfer ability is interesting to study.

As stated by Day and Goldstone (2012), most transfer research is designed to measure participants' application of one particular concept or skill, and student reasoning is compared to expert reasoning, which can differ a lot. This implies that most transfer studies prioritize expert knowledge while overlooking or disregarding the relationships that novice participants find relevant.

Our study actually wants to examine how novices apply concepts in different contexts, without having expert solutions as a baseline. This implies students did not had the opportunity to consult an expert about the matter and that the researchers did not compared the solutions of the students to the solutions

of the experts. This research strategy will uncover inherent transfer strategies of novices, which is an added value in order to adapt teaching methods.

Our study was done in the context of secondary education and we selected the following concepts to transfer:

- the slope of a graph,
- a programming loop,
- the area under the curve, and
- resistance.

As mentioned before, concepts include conceptual knowledge and skills, so the test items given to the students, are constructed in such a way they should use the entire continuum of the concept.

Planinic, Ivanjek, Susac, and Milin-Sipus (2013); Wemyss and van Kampen (2013); Ivanjek et al. (2016) have examined the transfer students make between mathematics, physics and other contexts for the concepts of a **slope of a graph** and the **area under the curve**. They concluded that whether or not transfer will happen, depends not only on the presence of relevant resources and information, but also on students' interpretation of the context. More particular, students are able to extract relevant information from graphs in a mathematical context and sometimes in other contexts, but not in physics contexts. This could be explained by the fact that most of the time the conceptual knowledge and skills are local (Perkins & Salomon, 1988) and associated with a specific context (Ivanjek et al., 2016). Local knowledge is the knowledge students own, but associate only with a particular setting, such as the course or the situation in which they used it. These studies show no conclusive outcome could be made, since a lot of different factors seem to have an influence. The presented study wants to be more precise about when transfer is occurring.

We haven't found any research that examines the transfer of the concept of a **programming loop** in different contexts. So, this is a gap we want to fill. Filling out this gap is interesting because programming and computational thinking is becoming important in today's society (Kalelioğlu, 2015), nevertheless, a lot of people struggle with it.

In this study, the concept of **resistance** is studied in the context of electricity and thermodynamics, since the concepts of heat and electricity are related. Both contexts have already been studied in the past. Some common student misconceptions were found across research studies on direct-current resistive electrical circuits. Students believe that a battery is a constant-current source

(Cohen, Eylon, & Ganiel, 1983; Engelhardt & Beichner, 2004), while it provides a constant voltage or potential difference. Students think a potential difference is a consequence of current (Cohen et al., 1983), and a potential difference and resistance can therefore only exist in the presence of a current (Cohen et al., 1983; Engelhardt & Beichner, 2004). They interpret a diagram of an electric circuit as pipelines through which 'electricity' flows as a kind of fluid (Engelhardt & Beichner, 2004). Consequently, students believe that current is being consumed by flowing through a resistor (Stocklmayer & Treagust, 1994), resulting in a smaller current 'after' the resistor, than 'before' (Closset, 1983). Cohen et al. (1983) investigated 9th (age 15), 11th (age 17) and 12th (age 18) graders' qualitative reasoning on functional relationships between circuit components. They found that a resistor is seen by students as an obstacle to current flow, rather than a component that draws current. Students who lack observational or experimental experiences, are often misled by the names given to circuit elements when attributing their function (McDermott & Shaffer, 1992; Viard & Khantine-Langlois, 2001). Additionally, many students are convinced of the idea that adding a resistor parallel to another one would increase the equivalent resistance (Cohen et al., 1983), while it is the other way around. This might be due to students' false perception that an increase in cross section would result in an increase in electrical resistance (Jiang, Wang, Wang, & Ma, 2018). Students also have difficulty recognizing series and parallel circuits (McDermott & Shaffer, 1992), since they are often guided by the geometry of a diagram, rather than by its electrical topology (Engelhardt & Beichner, 2004). Furthermore, they often believe that in a circuit with two parallel branches, the total current splits evenly the two branches, regardless of the resistor values in each branch (Rhöneck & Grob, 1987).

Heat is another concept that is difficult for students to grasp. To teach the concept of heat, often Carnot's analogy is used, where heat flow is compared to waterfall, in which the temperature difference is the (potential) height difference, and the conducted heat is the water flow (Haglund & Jeppsson, 2012). However, even after instruction by means of such an analogy, middle-school students keep using the words 'temperature' and 'heat' interchangeably (Arnold & Millar, 1996). The use of this analogy might also consolidate students' common misconception that heat is a substance (Baser, 2006a) or a material property (Arnold & Millar, 1996). Additionally, heat is not perceived by students as a form of energy (Prince, Vigeant, & Nottis, 2012; Wiser & Amin, 2001). In Mechanics, energy is often defined as the ability to do work. Thermal energy however, does not fit into this definition, and 'work' is not a useful concept in this context, causing students to lack a transferable definition of energy (Lancor, 2014).

Students' different representations of electrical and thermodynamical concepts,

through words, drawings, formulas, provide insight in their thinking while they are solving a problem in these contexts (Bowen, 1994). Although the analogy between 'electrical current' and 'heat flow' has long been clear to scientists (Robertson & Gross, 1958), students' ability to make the transfer of conceptions from one context to the other has, to our knowledge, not been researched before. Furthermore, studies looking at students' transfer in an integrated STEM setting are scarce (Fortus et al., 2005). This study aims to contribute to the existing research on transfer by identifying how STEM students and integrated STEM students make use of the transfer opportunities provided by the analogy between the 'electricity' context and the 'thermodynamics' context, and which scaffolding hints appear helpful in their attempt to do so. Scaffolding hints are cues meant to help students bridge the gap between their current problem-solving abilities and, in this case, the intended transfer (Rosenshine & Meister, 1992).

By documenting the scaffolding hints that were required for each of the concepts, our findings can help STEM educators in capturing students' mental models and conceptions for the studied concepts in particular contexts, but they also provide insight into which kind of phrasing might have a snowball effect, causing students to rethink their problem-solving strategy towards a more analogy-oriented approach.

3.2 Hypotheses and research questions

The described setting and research topic lead to the following research questions:

1. To what extent are students able to transfer the concepts of slope, programming loop, area under the curve and resistance from one familiar context, encountered in class, to another familiar context, not encountered in class?

2. To what extent do students refer to one context in order to solve a problem in another context?

3. Which difficulties arise during solving problems concerning the concepts of slope, programming loop, area under the curve and resistance and which of these are persistent in an attempt to transfer them? What scaffolding hints can help to overcome those difficulties?

4. Are students involved in an integrated STEM study track more capable of transferring from the one context to the other than students enrolled in a traditional STEM curriculum?

Education aims at preparing students for future knowledge application (Ivanjek et al., 2016). As a consequence, we expect students who are able to solve the problems in the familiar context encountered in class, to experience few difficulties when solving the problems in the familiar context, not encountered in class. During problem solving, we expect them to refer to contexts in which they have used the same concept before. However, this requires a certain level of metacognition, making it difficult (Veenman, Van Hout-Wolters, & Afflerbach, 2006). Guidance by hints could elicit students' metacognitive reflections (Rosenshine & Meister, 1992) and gauge whether or not students fall back on their understanding of the initially learned concept in the familiar context while solving problems in the unfamiliar context.

The chapter is structured as follows:

1. First, the research method is explained: we report on the participants, design of the test questions and matching interview guidelines, the interview setting, and the method of analysis.
2. Second, the result section is divided in four big parts, one part for each examined concept. Each part has the same structure. First, the developed test questions are presented. Than the level of transfer is discussed. Third, the analysis of the interviews is elaborated. Fourth, the performances of the students are discussed, together with the difficulties students experienced. Last, the working scaffolding strategies are presented.
3. Finally, the last part of this chapter describes the applicability of the presented study in other settings and the conclusion of the research findings.

3.3 Research methodology

This section first describes the set-up and participants, followed by the design and conduction of the interviews. Finally, the data analysis is elaborated.

3.3.1 Set-up and participants

In our study, we aimed for an in-depth investigation of students' strategies in transferring a concept. A qualitative study of a dozen students can reveal important, though not exhaustive, information on different strategies and common struggles (Baker, Edwards, & Doidge, 2012). The students were selected based on their availability and the willingness of their teachers to

provide classroom time (Henry, 1990). The only criterion employed for this sampling, was the search for students of two different study tracks: a traditional STEM curriculum and an integrated STEM curriculum. Teachers from three Flemish secondary schools in Belgium agreed to have their class of 11th grade students participate in this study.

To answer the research questions, fifteen students of grade 11 were interviewed: eight students to study the transfer ability for the concepts of slope, area under the curve and programming loop, and seven students for the concept of resistance. Two sets of interviews were conducted with each student. The eight students interviewed on the concepts of slope, area under the curve and programming loop were all enrolled in a science oriented curriculum in a Flemish secondary school in Belgium with a considerable amount of science and mathematics. Four of them were enrolled in the traditional curriculum (non-iSTEM1 to non-iSTEM4), the other four in a newly developed STEM@school curriculum (iSTEM1 to iSTEM4). The seven students interviewed on the concept of resistance were all enrolled in a technically-oriented curriculum in two different Flemish secondary schools in Belgium with a considerable amount of science and mathematics. Four of them were enrolled in the traditional curriculum and volunteered to participate (non-T-iSTEM1 to non-T-iSTEM4), the other three were the only students of that school in a newly developed STEM@school curriculum (T-iSTEM1 to T-iSTEM3). The participants are summarized in Table 3.1.

Table 3.1: Participants in the study

	Regular STEM	iSTEM	Examined concepts
General Curriculum	non-iSTEM1 non-iSTEM2 non-iSTEM3 non-iSTEM4	iSTEM1 iSTEM2 iSTEM3 iSTEM4	Slope of a graph Programming loop Area under the curve
Technical Curriculum	non-T-iSTEM1 non-T-iSTEM2 non-T-iSTEM3 non-T-iSTEM4	T-iSTEM1 T-iSTEM2 T-iSTEM3	Resistance

As explained in the introduction, in the STEM@school project, secondary school students are involved in a new course in which integrated STEM (iSTEM) is the driving force. This curriculum puts more emphasis on integrating different STEM disciplines to better show their relevance to real world problems. As elaborated by Thibaut, Ceuppens, et al. (2018), together with integration, cooperative learning, problem-based learning and learning by research and

design form the corner stones of this teaching method. Since research claims that transfer is encouraged when content is taught interactively (Nelissen, 2007), through solving realistic problems (Kober, 2015; Violante & Vezzetti, 2017; S. A. Barab & Landa, 1997), by working on a project (Ke, 2014), by modelling (Schwarz & White, 2005) and by integrating the disciplines (Wicklein & Schell, 1995; Ross & Hogaboam-Gray, 1998; M. E. Sanders, 2008; Van Merriënboer et al., 2002) it is relevant to check the results of this teaching method, which incorporated these elements, in terms of conceptual transfer.

All participating non-iSTEM and iSTEM students had been enrolled in the curriculum of their choice, traditional STEM or iSTEM, for two years (from grade 9 on). Since the beginning of grade 11, all participants are part of the same class, following the same courses. They are only split for the iSTEM-course. While iSTEM students are following the iSTEM-course, the regular science students have an extra hour of chemistry, an extra hour of physics and one hour of a mathematical seminar. In the three hours the students are separated, no curriculum guidelines are treated, these teaching hours only provide additional information or apply what they have learned in the regular classes. So the extra hours of science that students in the regular curriculum get, have no influence on the performance of their standard-based knowledge tests, since it is only additional information.

Students non-T-iSTEM1 and non-T-iSTEM4 had recently switched to the technically-oriented study track (at the start of grade 11). All other students of the technically-oriented curriculum had been enrolled in the curriculum of their choice (non-T-iSTEM or T-iSTEM) in the technically-oriented track for at least two years. In this technically-oriented study track, the students already followed a course on electricity in grades 9 and 10. They had studied the concepts of resistance, current, potential difference, (equivalent resistance in) series and parallel circuits, and had learned about Ohm's law. The grade-10 curriculum for these students included learning goals concerning the basic concepts of calorimetry: heat, temperature change, and thermal equilibrium. Hence, the students of both groups should be familiar with the particular context 'thermodynamics', though the topic of thermal conduction had only been addressed in a descriptive way. The students in the traditional technically-oriented curriculum had merely studied calorimetry through traditional physics lessons, i.e. by means of lectures, textbook exercises, and lab experiments. The T-iSTEM students were enrolled in the integrated STEM curriculum provided by the project STEM@school (Thibaut, Ceuppens, et al., 2018). In one of the learning units, students had to build a scale model of a passive house and control its indoor temperature by means of an on-off control system, as explained in Chapter 2. Hence, these students had studied the thermodynamics concepts and the mechanisms of thermal conduction in a real-world (albeit scaled) problem

in which they had to calculate temperature behavior based on the dimensions of the walls and the input power. However, as was the case for the (traditional) STEM students, the analogy between resistance in electricity and resistance in thermodynamics had not been explicitly pointed out to the T-iSTEM students neither.

So the two groups of students that will be compared per concept are involved in a different instructional strategy (Bowen, 1994). We asked the teachers to select four students of each part of the class, traditional STEM and iSTEM, who represent the whole range of performance level of this part, this to prevent bias by only interviewing to most talented iSTEM students.

All students were interviewed twice: a task-based (Maher & Sigley, 2014) combined think-aloud - prompting interview (Van Someren et al., 1994) on the selected concepts in a familiar context and a teaching-learning interview (Nguyen & Rebello, 2011a, 2011b) in which the students solved tasks in which the concepts were used in an unknown context. In what follows, we describe the development and setup of both sets of interviews.

3.3.2 Design of teaching-learning interviews

The researchers started by developing the teaching-learning interviews. Therefore a set of four problems was designed in the following stages:

1. select and define the concepts of which we wanted to test students' transfer ability. These concepts are 'slope', 'area under the curve', 'programming loop' and 'resistance'. These concepts were taught to the students in the 9th grade;
2. formulate one test item for each of these concepts in another context than the one treated in class;
3. identify the required application of these concepts in each question;
4. adapt the questions to ensure that we would test exactly these applications;
5. ask for a physics expert's opinion about the questions with regard to the intended applications of the concepts;
6. adapt the questions based on the expert's feedback, and
7. finally, check the adapted questions again with the expert.

The developed problems can be found in the results section, in the subsection where the matching concept is elaborated. The entirety of these problems is called the Concept Transfer Test (CTrT).

A written test alone would not allow to reveal all thinking processes going on in students' minds (Baauw & Markopoulous, 2004). An interview can shed light on whether or not a student recognizes a concept, and if and how he/she retrieves it from his/her memory. To conduct the teaching-learning interviews based on the designed problems systematically, an interview guideline (Goldin, 1997) was developed aiming at:

- verifying whether the student understood the questions;
- asking the student to think aloud;
- obtaining insight in how the student reasons with the concepts and whether and how he/she refers to the other context in his/her attempt to solve the questions in the current context; and
- establishing the students' response to hints.

For each problem, the guideline is developed according to the script of Goldin (1997), to make sure we explore the students' knowledge and not point them into a direction too soon. The exploration consists of four types of questions, which should be asked in the following order:

1. Posing the question (e.g. Can you tell me more about this concept?)
2. Heuristic suggestions if the response is not spontaneous (e.g. Are you going to use the graph or the formula to solve this problem?)
3. Guided use of heuristic suggestions (e.g. Do you see a connection between the text and the graph?)
4. Exploratory, metacognitive questions (e.g. Do you think you could explain how you thought about the problem?)

Taking these aims together, the interview was set up as a teaching-learning interview (Nguyen & Rebello, 2011a, 2011b). The interviewers provided scaffolding for the students in case they got stuck. Scaffolding consists of posing questions which build on previously gained knowledge (Davis, 2000). The interview was meant to accompany the Concept Transfer Test (CTrT), meaning it was used while students were completing the test. The questions in this interview guideline also underwent an iteration based on the physics expert's feedback.

An example of a teaching-learning interview guideline for one of the problems, can be found below and served for the question of the flow in the swimming pool, which is explained further.

- Read the question out loud. Are there words you don't understand?
- Solve the first question. Don't forget to think aloud!
- Can you imagine this situation in real life? Try to describe it in your own words. Are you able to make a sketch of the situation?
- What quantity is asked for? What do you know about this quantity? What do you need to know about this quantity? Is there anything in the text about this quantity? What can you learn from this information?
- What is the reference point?
- Do you recognize some aspects out of the text? Where from?
- Do you recognize the form of the formula of Q?
  - If yes, where from?
  - If no, think about the STEM or physics class.

3.3.3 Design of a task-based combined think-aloud - prompting interview

Based on the transfer problems, a set of problems probing for student understanding of the different concepts in a familiar context was designed. These are traditional text-book like problems and are also described in the results section. They were designed following the same steps as the problems of the CTrT, with specific attention to formulate the questions as similar as possible to the questions in the CTrT (Planinic et al., 2013). The questions of this test embody the same specific applications of the learned concepts as the CTrT, but in the context of kinematics or electricity. This allows us to evaluate students' ability to transfer the chosen concepts. We aim to monitor the extent to which students understand the learned concepts, and how they apply these concepts in the first place. The entirety of these problems is called the Reference Test (RT).

No interview guideline was designed for this set of interviews, as students were asked to think aloud and no additional questions were asked. Think aloud interviews require students to verbalize their thoughts while solving the problem (Charters, 2003). This verbalization provides a good image of how

students are processing information (Bowen, 1994; Charters, 2003; Nielsen, Clemmensen, & Yssing, 2002). This way of interviewing requires detailed explanation to the students in order to comfort them and not scaring them off (Bowen, 1994; Charters, 2003). The students were told explicitly that the correctness of the calculations did not matter, but that their thinking processes were most important. However, we anticipated on the fact that students do not have experience with the think-aloud method and thus would make too few verbalizations of their thinking process. So we combined the think-aloud method with prompting. With prompting we mean we ask for extra clarification when their thinking pattern is not clear to us, or asking what is on their mind when a long silence occurs (Van Someren et al., 1994), but no conceptual questions or hints are formulated.

3.3.4 Conducting the interviews

The time span between the task-based combined think-aloud - prompting interview and the teaching-learning interview was one week for the non-iSTEM, iSTEM and non-T-iSTEM students, to not cue an instant awareness of the one-to-one match between the items of the two tests. However, with the T-iSTEM students, the CTrT interviews were conducted on the same day as the RT interviews (with approximately 1.5 hours in between) because of practical considerations. The interviewers had to bear this risk of bias in mind: a swifter transfer on the T-iSTEM students' part could be due to the fact that the analogous problem-solving strategy was still readily accessible in their short-term memory. Any of the T-iSTEM students' answers that could even remotely be an indication of this fact, was intercepted by the interviewers by means of questions such as: 'Why do you say that? Why do you use that strategy?', or 'Does that remind you of something?' On the other hand, this inconvenience in the research setup could also result in meaningful findings: whether students who are presented with an analogous problem shortly after a familiar problem are capable of recognizing the analogy and relying on the strategy they just employed.

On every interview, students got all questions at the same time, on paper, together with a calculator. Students were asked to write down their answers using a smart pen, recording their notes and their accompanying talk (Van Someren et al., 1994). The teaching learning interviews were conducted by two interviewers. This set-up has the advantage that one interviewer could focus on the interview with the student and the other one could focus on the body language of the interviewee (Charters, 2003).

3.3.5 Data analysis

All interviews were transcribed verbatim. In these transcriptions, notes about body language were added.

Based on the interview data, different steps in the problem solving process were identified. When some steps can be completed with different strategies or different representations, these strategies are also identified. This is important as Bowen (1994) has argued that the use of different representations by the students can give more insight into the thoughts of students. For each step and/or strategy, we marked whether students answered spontaneously correct, correct after some hints, and for which he or she could not provide a correct answer (T. Richards, Richards, et al., 1995; Nguyen & Rebello, 2011a, 2011b). If they solved the question without any help from the interviewers, the student was classified under 'spontaneously correct'. When some hints or guiding questions were required, the student was classified under 'correct with hints'. If the student was not able to complete the question with a few hints, so detailed guidance was necessary or the answer needed to be told by the interviewers, the student was classified under 'wrong'. This bottom-up categorization gives an exhaustive overview for each student on which aspects he or she answered (T. Richards et al., 1995; Van Someren et al., 1994). The notes about body language were not explicitly analysed, but served as a supporting tool for categorization.

To analyze the interviews a third researcher was involved. This researcher did not join the interviews; so she could analyze the interviews without being biased. In this way, investigator triangulation is fulfilled (Carter, Bryant-Lukosius, DiCenso, Blythe, & Neville, 2014). When researchers disagreed during categorization, a discussion was set-up and held until everyone agreed (Campbell, Quincy, Osserman, & Pedersen, 2013).

All the information is put together in one table (Table 3.2) (Nguyen & Rebello, 2011a, 2011b). In the different rows, the table mentions the different steps and strategies/representations students can use. In the columns, the table marks whether students answer spontaneously correct, correct with hints of wrong, and this both for the RT and CTrT.

By categorizing the achievements of students in Table 3.2, some performance patterns are distinguished and can be found in Table 3.3. This table compares the achievements of students in the RT with theirs in the CTrT, and, as a consequence, provides valuable information about the transfer ability of the students. Table 3.3 shows transfer-relevant performances on steps and strategies on both tests and the conclusion that can be drawn from these sets of performances. We selected the sets of performances in Table 3.3 as being the most interesting ones for this study, because these performances can show

Table 3.2: Example of a performance table

	Spontaneously correct		Correct with hints		Wrong (unable to provide a correct answer)	
	RT	CTrT	RT	CTrT	RT	CTrT
Step 1						
Step 2						
Step 3						

Table 3.3: Analyzing transfer abilities of the students

Performance in RT →	**Performance in CTrT**	**Conclusion**
From:	to:	Indication of:
Spontaneously correct →	**Spontaneously correct**	Transfer is made
Spontaneously correct →	**Correct with hints or wrong**	Hard transfer from known context to new context
Correct with hints →	**Spontaneously correct**	Hints in RT have provided new insights and could be transferred
Correct with hints →	**Wrong**	Provided hints did not bring insights

whether transfer is occurring (Mayer, 1989). The other sets of performances, where the students answered wrongly in RT, does not provide an added value for transfer, because understanding of the basic concept in the original context is necessary in order to transfer it. On top of that, the exact teaching method in class should be known in order to draw conclusions out of it. An additional value of Table 3.3 is that it shows whether or not transfer can be scaffolded (Ivanjek et al., 2016). This is interesting for this study, because hints provide an opportunity to show which teaching strategies could help students to transfer concepts in the future. Furthermore, Table 3.3 helps to solve research question 3 in order to find out which hints help to overcome difficulties students face.

To interpret Table 3.3, the level of transfer plays a crucial role. As described by Barnett and Ceci (2002), the level of transfer is influenced by different dimensions. Before analyzing the performances of the students, it is important to find out which level of transfer we require from the students for the examined concept. In this study, we need to distinguish the transfer we already ask students to do from the class to the RT and the transfer from the RT to the CTrT. The required level of transfer for the different dimensions will be shown for each concept separately. It is important to distinguish between different levels of transfer, in order to answer the research questions, because they all ask for the reach of transfer ability of the students.

3.4 Results

The result section is divided in four big parts, based on the investigated concepts. For each concept, the same structure is used. First, the test questions related

to the concept are described. Second, the required transfer level of the students for this concept is shown on a continuum, based on the six dimension of Barnett and Ceci (2002), as explained in section 3.1.1. The places on these continua are estimated by the researchers based on the narratives of the teachers of the examined students. Third, the actual analysis of the interviews is presented in the performance table. Fourth, students' performance patterns are analyzed in more detail. A fifth paragraph describes students' difficulties and misconceptions, illustrated with excerpts from the interviews (Charters, 2003). Finally, the hints that provide enough help to scaffold students' thinking, are listed.

The fifth and sixth part will help to answer research question 3, regarding student difficulties and scaffolding hints. The performance table and patterns will help to answer research questions 1 and 2. These research questions deal with the transfer ability of students between different contexts. Research question 4 will be answered by all parts of the result section, since it entails differences between non-iSTEM and iSTEM students for all research questions.

3.4.1 Slope

We investigated the concept of slope of a linear graph with two questions in the RT and two questions in the CTrT. The questions used are described in detail in Table 3.4. We wanted to investigate how students interpret a decreasing linear graph and its slope.

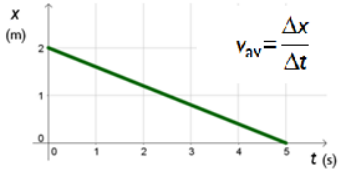
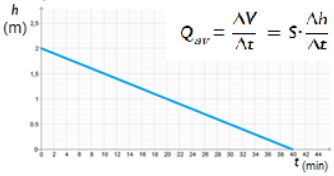
Test items

The question of the RT is situated in the context of 1D kinematics, in which students have learned to interpret such graphs in class, but only the iSTEM students have been explicitly taught the connection between slope and velocity, and applied the concept to motions of real objects (Trowbridge & McDermott, 1980). The question in the CTrT requires the transfer of the concept of slope from the context of kinematics to the context of hydrodynamics, or more precisely, from the context of a moving car to the context where water is flowing out of a swimming pool, as presented in Table 3.4.

Transfer level

Figure 3.1 gives a representation of the required transfer for this concept for each of the six dimensions of Barnett and Ceci (2002). It shows that the non-iSTEM students are required to transfer more from the class to the RT,

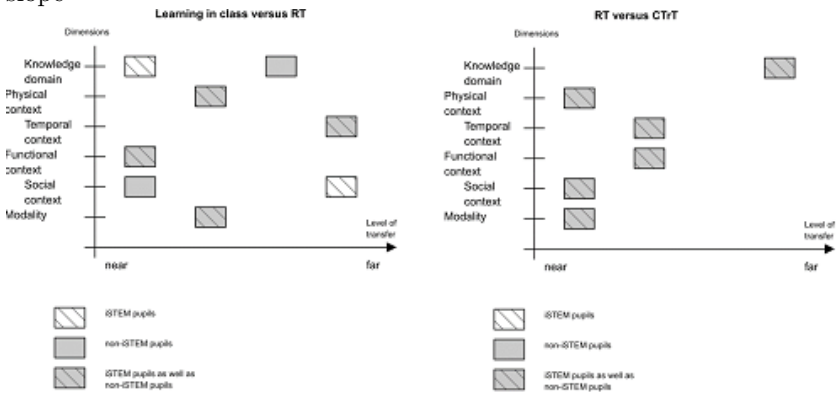
Table 3.4: Test items for the concept of slope

Reference Test	**Concept Transfer Test** (This question is based on a question in the study of Wemyss and van Kampen (2013).)
A car drives on a straight road, as presented in the graph below.  The position of the car ○ changes over time and moves towards the reference point ○ changes over time and moves away from the reference point ○ does not change over time The velocity of the car over time ○ increases ○ decreases ○ remains constant	The water level of a pool is presented in the graph below.  The water height in the pool ○ changes over time and moves towards the reference point ○ changes over time and moves away from the reference point ○ does not change over time The flow rate of the water over time ○ increases ○ decreases ○ remains constant

than to the CTrT. This could have implications for interpreting the results of the tests. As iSTEM students have been taught the concept of slope also in the context of a moving car, the required transfer from class to RT is more near for these students than for non-iSTEM students. In the non-iSTEM class, slope was taught only in an abstract context of mathematics. As a consequence, a more far transfer in the knowledge domain is required in order to solve the test question. For the dimensions of physical context, temporal context, functional context and modality, transfer from the learning phase to the RT is the same for both groups. On the contrary, the social context differs for non-iSTEM and iSTEM students, since iSTEM students have learned and applied the concept in collaborative groups, while non-iSTEM pupils have learned the concept in a traditional classroom setting. This social dimension cannot be neglected, but is less important, because the study focuses on student individual transfer abilities.

The required transfer level from the RT to the CTrT is the same for both groups of students, because the prerequisites are made equal by the RT. Though, since non-iSTEM pupils only applied the concept of slope in a physics context during the RT, the transfer to the CTrT could be harder for them.

Figure 3.1: Representation of the required level of transfer for the concept of slope



Analysis

Based on the interviews and previous studies (Ivanjek et al., 2016; Wemyss & van Kampen, 2013), we identified different steps and strategies in students' explanations for the concept of slope. Table 3.5 shows the result of this, as well as the performance of the students on these steps. The steps and strategies we extracted from the interviews were:

- STEP 1: Identification of reference point: Students can identify what the reference point on a graph is.
- STEP 2: Describing motion with relation to the reference point: Students are able to conclude that the given quantity changes towards the reference point.
- STEP 3: Determining rate of change: Students are able to identify the rate of change of the asked quantity as a constant. Students can do this by using different strategies: by the given formula (as presented in Table 3.4), by investigating the gradient of the graph (investigating the steepness), by calculating the slope for different intervals or by relying on the fact that it is a linear graph.

Students' performance patterns

Table 3.6 shows that three students (one non-iSTEM and two iSTEM) are able to explain the reference point in kinematics, yet they are unable to transfer this

Table 3.5: Students' achievements on the concept of slope

	Spontaneously correct		Correct with hints		Wrong	
	RT	CTrT	RT	CTrT	RT	CTrT
Identification of reference point	Non-iSTEM4 iSTEM1 iSTEM3				Non-iSTEM1 Non-iSTEM2 Non-iSTEM3 iSTEM2 iSTEM4	Non-iSTEM1 Non-iSTEM2 Non-iSTEM3 Non-iSTEM4 iSTEM1 iSTEM2 iSTEM3 iSTEM4
Describing motion w.r.t. the reference point	Non-iSTEM1 Non-iSTEM3 Non-iSTEM4 iSTEM1 iSTEM2 iSTEM3	Non-iSTEM1 Non-iSTEM3 Non-iSTEM4 iSTEM1 iSTEM2 iSTEM3	Non-iSTEM2 iSTEM4	Non-iSTEM2		 iSTEM4
Determining rate of change by						
Formula				iSTEM1	Non-iSTEM1 iSTEM2	
Gradient	Non-iSTEM3 Non-iSTEM4	Non-iSTEM4	 iSTEM2	Non-iSTEM1	 iSTEM4	
Slope	Non-iSTEM3	 iSTEM2 iSTEM4		Non-iSTEM3		Non-iSTEM2 iSTEM3
Linearity	 iSTEM1 iSTEM3 iSTEM4	 Non-iSTEM2 Non-iSTEM3 iSTEM3	Non-iSTEM1 Non-iSTEM2			

knowledge to the context of the water level.

Table 3.5 shows that most students do not know what a reference point is, not in the RT, nor in the CTrT. However, when the reference point is explained to them, they are able to set up a correct reasoning about the motion towards the reference point. Despite the fact that we explained the concept of reference point to all students in the RT, some are still unable to explain the reference point in the CTrT.

Another conclusion that can be drawn from Table 3.5 is that only a few students use the same strategy to construct the right answer on the rate of change in the two contexts. This is remarkable, because we expected students to use the same representations to solve both problems, since the concept behind it is the same. These performance patterns could imply they use more given data when the context is less familiar for them, and as such require more extensive analytical processes (Schuwirth et al., 1999) or as stated by Ivanjek et al. (2016), students

Table 3.6: Transfer abilities of students for the concept of slope

RT	CTrT	Conclusion	Topic	Number of students
Spontaneously correct	Spontaneously correct	Transfer is made	Towards reference	6
			Rate of change by gradient	1
Spontaneously correct	Correct with hints or wrong	Hard transfer from known context to new context	Reference	3
			Towards reference	1
Correct with hints	Spontaneously correct	Hints in RT have provided new insights and could be transferred	Rate of change by linearity	1
Correct with hints	Wrong	Provided hints did not bring insights	Rate of change by slope	1

tend to think more creatively outside a known context. This can be explained by the fact that a new context does not trigger previous gained knowledge immediately, so other thinking strategies need to be activated (Planinic, Milin-Sipus, Katic, Susac, & Ivanjek, 2012). Non-iSTEM1 and iSTEM2 student, for instance, try to solve the question in the RT with the known formula. Since they are not familiar with the formula in the CTrT, they use other strategies like interpreting the graph, in order to solve the transfer question.

Students' difficulties

During the teaching learning interviews, some remarkable explanations of the students were noticed. These explanations revealed persistent misconceptions and difficulties students have. Below these are described and related to common student difficulties mentioned in literature.

Reference point Some students define the reference point as the point where the motion starts, as can be seen in the excerpt below. This was done by four students in the RT, so in the context of the moving car, and by four students in the CTrT, so in the context of the swimming pool.

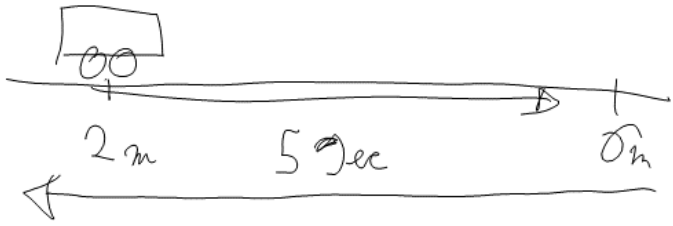
> **Student:** Yes... I think the car... Away from the reference point, because the car starts at 2 meters... Oh no, the car moves towards the reference point. Wait...
>
> **Interviewer:** What is the reference point?

Student: The point at which the car starts, normally... Wait...

This student difficulty has already been elaborated in previous research (Bollen, De Cock, Zuza, Guisasola, & van Kampen, 2016; Wemyss & van Kampen, 2013; Aguirre, 1988) . Though, in the research of Bollen et al. (2016) and Wemyss and van Kampen (2013) a distinction can be made between the context of motion of the ball and motion of the water level. Their studies showed that students had difficulties with the reference point in the context of kinematics, but had no problem with the everyday context of the swimming pool. The study presented here cannot confirm this finding for our participating students. The difference of students analysis of the two contexts can be due to the fact that the swimming pool has a natural reference point (the bottom), while the reference point when studying a motion can be chosen free and student can struggle with this. In the test item in this study, the reference point is indicated by the origin of the graph, so in this case, students cannot choose the reference point.

Drawing When we ask the students to represent the motion of the car in a drawing, five out of eight students draw the x-axis initially from 2 m to 0 m, because 2 m is the starting point of the car. This is remarkable, because, at this point, we already discussed with them that the reference point is x = 0 m. Figure 3.2 illustrates this representation of the students, with the upper axis as the position-axis in the first place. Only after some hints and questions, the student drew the lower axis as the position-axis and realized the upper arrow is the direction of the velocity.

Figure 3.2: Sketch of the motion of the car, made by a student



When we asked students to make a sketch of the water level in the swimming pool, a sketch as presented in Figure 3.3 was drawn by the non-iSTEM2 student and the iSTEM3 student made a similar one. This sketch seemed not to be helpful for students, which is not surprising because it shows no relevant information. For example, the decrease of the water level is not visible, nor the

water level itself. The sketch seems to be only the intersection of the swimming pool.

Figure 3.3: Sketch of the water level, made by a student



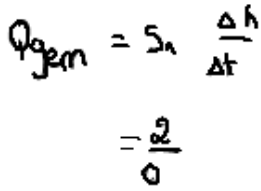
Quantities versus units Two out of eight students answer with the unit when asked for a quantity, which illustrates confusion between quantity and unit, as illustrated by the excerpt below. This error reveals a problem with different representations of the same concept since they mix up quantities and units. Students should be able to fluently move back and forth between these representations in order to recognize and understand the concept (Osborne, 2002).

> **Interviewer:** Yes, which are the quantities?
>
> **Student:** Meter and second.

Interval-point confusion In the RT, two students who follow the traditional STEM curriculum forget about the Δ in the formula of velocity, while in the CTrT two students from the regular and two students from the iSTEM curriculum make the same error. When students forget about the Δ, they just divide two single points by each other, instead of dividing the subtraction of two points, as illustrated by the notes of the students in Figure 3.4. This is a very common confusion by students (Ivanjek et al., 2016; Trowbridge & McDermott, 1981; Hadjidemetriou & Williams, 2002b) and is described as an interval-point confusion (Leinhardt et al., 1990).

In the modules of the iSTEM curriculum, specific attention is given to this student difficulty. Since no iSTEM student had a problem with it in the RT, it could be argued this extra attention has paid off in the known context. But these students had a hard time transferring this knowledge, since two of them made this mistake in the CTrT.

Figure 3.4: Students' notes while calculating the slope



Flow The flow in the water level question is something that is not explicitly taught in class. So, this context is unfamiliar for the students, though easy to imagine (Planinic et al., 2013). Still, the concept of 'flow' seems to be difficult to describe mathematically in terms of area and height. In this unfamiliar context, we see the following difficulties. Firstly, some students, four out of eight, argued that the slope of the graph was the flow and forgot the area of the pool, as is already illustrated in Figure 3.4.

Secondly, while some students forgot about the area of the pool, others gave explicit attention to it, but got totally confused about it. This was the case with four students, some of them first forgot about the area and then got confused after some hints to include the area, others kept the area in mind from the beginning, but struggled with it. They had no idea how to deal with this constant area of which they did not have numerical values, as can be seen in the excerpt below.

> **Student:** Wait... Oh no, no, no, it's the height. Oh no, you cannot determine that, because you don't know the area of the swimming pool... Well, not the ground surface.
>
> **Interviewer:** No, that's true... But, what if we say... What do you think that the surface of the swimming pool... Do you think it's going to change?
>
> **Student:** No...
>
> ...
>
> **Interviewer:** Is there something of the formula you could calculate with the given graph?
>
> **Student:** Well... The surface of... Oh no. I don't know, because you have two unknowns... The surface...

A third difficulty, which only arose with the CTrT, was that students thought the flow was decreasing over time, because the graph was descending, as is

illustrated in the excerpt below. This confusion has also been found in the research of Bollen et al. (2016) and Hadjidemetriou and Williams (2002a), who have analyzed this as a slope-height confusion. It could also been a confusion between speed and distance (Wemyss & van Kampen, 2013). Based on the interviews, it is hard to tell which confusion has arisen with the students.

> **Student:** Yes. Ah, wait... Isn't that just... Hmmm...
> I think... That your... Flow... No, decreases.
>
> **Interviewer:** Why do you think that?
>
> **Student:** Because your height... Is also decreasing. So your...
> Your... Volume is surface multiplied by the height, right?

Scaffolding strategies

Table 3.5 shows that some students could get to the correct answer with hints. Analyzing these hints, we see three scaffolding questions or prompts that supported students' thinking. These are:

- Asking them to look at the shape of graph.
- What quantities are on the axes of the graph?
- Asking them to indicate intervals on the graph.

Main findings regarding the concept of slope

To provide an answer to research questions 1 and 2, about transferring concepts and referring to known contexts, Table 3.5 and Table 3.6 provide some insights. A lot of students can determine the direction of motion, also in the new context. On the other hand, few students use the learned concept of slope in both RT and CTrT. This may be an indication of not fully understanding the concept of the slope and its' usefulness. Moreover, a lot of students use different problem solving strategies in the CTrT than in the RT. Probably, this is due to the fact that students do not see similarities between both contexts and so are forced to use all given information in order to solve the question. As a consequence, we can conclude they do not refer to other contexts with a similar problem.

During the interviews, some difficulties with the concept of slope arose. The reference point seemed to be an unknown or unfamiliar concept for students. A lot of them refer to the starting point as being the reference. As a consequence, students had a hard time sketching the motion, because they started the axis at

the starting point instead of on the reference point. While this is not wrong, the reference point in this test item is indicated by the origin of the graph. Another confusion students face is between quantities and units. This confusion should be solved in order to provide the student with scientific literacy. As seen in earlier literature, we also see in our data the point-interval confusion appearing. This confusion seems to be more persistent in the CTrT than in the RT. This could imply students know how to handle the formula in a known context, but do not grasp the actual meaning of it, and as a consequence, fail to apply it in an unknown context. In the CTrT, students had to calculate and interpret the flow. They struggled doing so, probably because the flow is an unfamiliar context and they did not link it to the slope. So with this summary, research question 3 is answered for the concept of slope.

Our fourth research questions wants to make a distinction between non-iSTEM and iSTEM students. For the concept of slope, few differences could be found. Although, a remarkable difference could be found for the use of intervals while calculating the slope. While almost all iSTEM students apply the formula correctly in the RT, which is a known context for them, the interval-point confusion arises in the CTrT. This difference is not visible with the non-iSTEM pupils.

3.4.2 Area under the curve

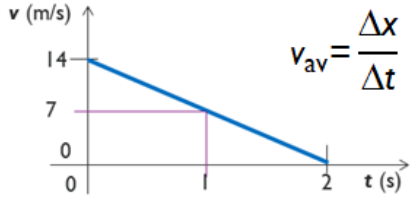
Test items

Two questions that can be solved using the 'area under the curve' are designed: one in the context of 1D kinematics, to determine the displacement of a car from a v(t)-graph, the other in the context of work. The questions are shown in Table 3.7.

Transfer level

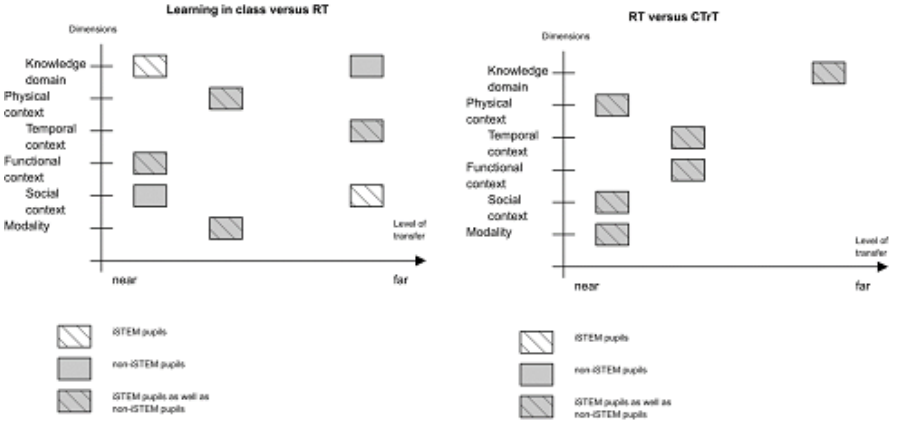
Equal to the transfer level of the previous concept, Figure 3.5 shows that the non-iSTEM students are required to transfer more from the class to the RT, than to the transfer test. iSTEM students have been taught the concept of area under the curve in the context of a moving car. In the case of the non-iSTEM students, the concept of area under the curve has not been taught explicitly. They needed to use the standard formulas in order to calculate the required quantities. This is why we estimate the transfer in the knowledge level as more far than with the concept of slope. The area under curve is not even been

Table 3.7: Test items for the concept of area under the curve

Reference Test	**Concept Transfer Test** (This question is based on a question in the study of Nguyen and Rebello (2011b))
The velocity of a car, driving on a straight road, is presented in the graph below.  Determine the displacement of the car between 1 and 2 seconds.	The force of the spring on the bullet, is presented in the graph below.  Determine the work done by the spring between positions 15 and 20 cm.

taught in the math class for non-iSTEM students, in contrast to the concept of slope.

Figure 3.5: Representation of the required level of transfer for the concept of area under the curve



The required transfer level from the RT to the CTrT is the same for both groups of students, because the prerequisites are made equal by the RT. Though, since non-iSTEM students only applied the concept of area under the curve in a physics context during the RT, the transfer to the CTrT could be harder for them.

Analysis

Based on the interviews, we identified different strategies that were seen in students' explanations for the concept of area under the curve. Table 3.8 shows the result of this, as well as the performance of the students on this steps and strategies. Only one step could be identified, with different strategies. The step and strategies we extracted from the interviews were:

- STEP: Calculating result: Students can derive the displacement in the RT or the work in the CTrT. They can do this by filling in the given formula, as shown in Table 3.7, or by calculating the area under the curve.

Table 3.8: Students achievements on the concept of area under the curve

	Spontaneously correct		Correct with hints		Wrong	
	RT	CTrT	RT	CTrT	RT	CTrT
Determining rate of change by						
Formula	Non-iSTEM1 Non-iSTEM2 Non-iSTEM3	Non-iSTEM1 Non-iSTEM4 iSTEM1 iSTEM3	Non-iSTEM4 iSTEM4	Non-iSTEM2 Non-iSTEM3 iSTEM2		iSTEM4
Area under the curve	iSTEM1 iSTEM2 iSTEM3					

Students' performance patterns

A few different thinking patterns can be distinguished. If we have a look at Table 3.8, we can analyze this as shown in Table 3.3, resulting in Table 3.9.

Table 3.8 shows that although students of the iSTEM course calculate the displacement out of a v(t)-graph with the area under the curve, they use the formula for calculating the work of a F(x)-graph. So they are able to use the concept of area under the curve in a known context, but they do not transfer this concept to an unfamiliar context. Previous research (Nguyen & Rebello, 2011a) showed the same issue.

Students' difficulties

During the teaching learning interviews, some remarkable explanations of the students were noticed. These explanations revealed difficulties students have

Table 3.9: Transfer abilities of students for the concept of area under the curve

RT	CTrT	Conclusion	Topic	Number of students
Spontaneously correct	Spontaneously correct	Transfer is made	Quantity by formula	1
Spontaneously correct	Correct with hints or wrong	Hard transfer from known context to new context	Quantity by formula	1
Correct with hints	Spontaneously correct	Hints in RT have provided new insights and could be transferred	Quantity by formula	1
Correct with hints	Wrong	Provided hints did not bring insights	Quantity by formula	1

and misconceptions that are persistent. Below, we describe the difficulties and misconceptions that arose and compared these with common student difficulties mentioned in the existing literature.

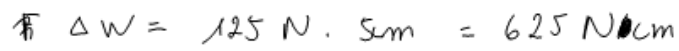
Average Students struggled to calculate the average between two points of a graph. This might be explained by the teaching strategies used in mathematics. For calculating the average in mathematics, students get, most of the time, a series of numbers of which they need to calculate the average. Calculating the average between two points of a graph, requires other cognitive strategies and so is harder for students, because it is an extra step to extract the two relevant points out of the graph and they did not practice this in class. We did not expect students to get stuck at this point.

Some students initially argue that the average between two points on the curve is equal to the highest of the two points, as can be seen in the excerpt below. This mistake arose by three students in the RT and five students in the CTrT. We could argue this error is also an interval-point confusion (Leinhardt et al., 1990), because students consider just one point instead of calculating the average of the interval.

> **Interviewer:** We are looking for the average speed between the two moments in time.
>
> **Student:** Euhm... 7 meters per second?
>
> **Interviewer:** Is that the average? Is the speed during the whole interval 7 meters per second?
>
> **Student:** I don't think so. Euhm...

Unit of work Two out of eight students indicate as unit of work N/m. This because it sounds more familiar to them and they did not check the units while filling in the formula. Figure 3.6 and the excerpt below show this error. In the excerpt, the interviewer interpreted the body language of the student and concluded the student was not familiar with this notation.

Figure 3.6: Student's notes when calculating the work. This students first wrote down N/cm and corrected it afterwards in N.cm



Student: Ah, Newton per meter, no, wait... Huh?? Euh...

Interviewer: Almost, but it is not totally correct.

Student: Yes, Newton multiplied by meter. (Surprised)

Interviewer: Yes, Newton multiplied by meter. It is not because it sound a little bit odd, that it is not correct.

Quantities versus units Also for this question, we see three out of eight students confuse quantity and unity. This confusion also arose with the concept of slope. The excerpt below shows an example of this.

Interviewer: What will be the quantity?

Students: It will be Joule.

Scaffolding strategies

Again, some students answered correctly after some hints, as shown in Table 3.8. Analyzing these hints, we see four scaffolding questions or prompts that help construct students' thinking. These are:

- Asking them to look at the shape of the graph.
- What quantities are on the axes of the graph?
- Asking them to indicate the specific intervals on the graph.
- How do you calculate the average in mathematics?

Main findings regarding the concept of area under the curve

The difference between non-iSTEM and iSTEM students, as stated in research question 4, is remarkable here. All iSTEM students solved the question in RT by using the concept of area under the curve, while none of the non-iSTEM students did this. This is not surprising, because the non-iSTEM students did not learn about this concept. Though, it is surprising to notify that none of the iSTEM students used the concept of area under the curve in the CTrT. This finding immediately answers research questions 1 and 2, because these students were not able to see the connection between the two contexts and as a consequence, did not refer to it, nor were able to transfer it.

Research question 3 is about difficulties and misconceptions. Similar to the difficulties with the concept of slope, students also have trouble distinguishing quantities and units. Moreover, they even have trouble deducing the right units when calculating work. Another remarkable difficulty seemed to be the calculation of the average based on a given graph. Probably, this is due to the fact that students are taught to calculate the average out of numbers and not out of graphs. They struggle to transfer this concept and need to be reminded how they normally calculate the average in math class.

3.4.3 Programming loop

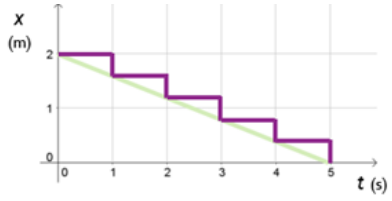
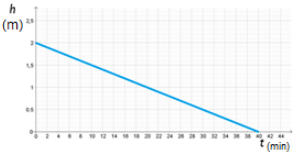
We investigated the concept of a programming loop with one question in the RT and one question in the CTrT. The used questions are described in further detail in Table 3.10.

Test items

The question requires students to show their logical reasoning through programming. Students need to declare the variable and use a while loop. Programming is a discipline which is only taught to the iSTEM students. More specifically, in grade 9, they had learned how to program in the context of kinematics. For instance, students had to program the velocity and acceleration of a car, based on calibration experiments. The students following the regular science curriculum have no experience with this. So, for the non-iSTEM students, the RT is when they learn the concept and transfer could only occur in the CTrT. In the CTrT, students need to transfer their programming skills from a kinematics context to the context of water levels, as presented in Table 3.10.

Although the concept is not taught in traditional STEM curriculum (non-iSTEM), the researchers took it into account because programming is an important skill for developing higher-order thinking, such as algorithmic problem solving skills (Kalelioğlu, 2015).

Table 3.10: Test items for the concept of a programming loop

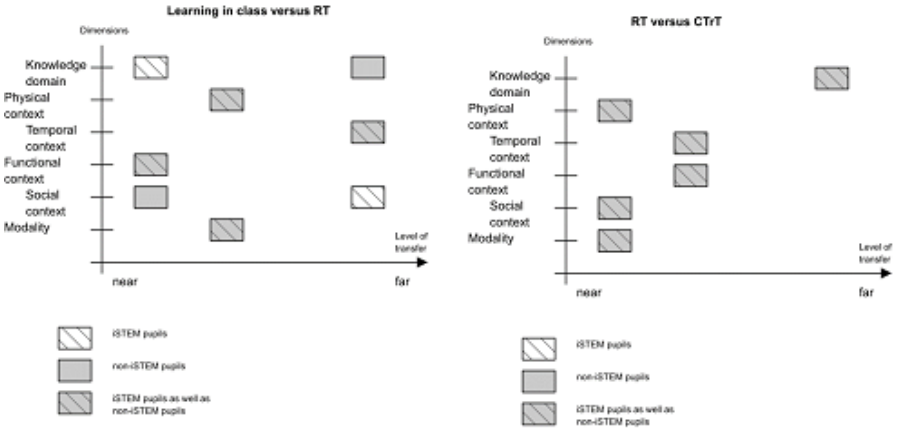
Reference Test	Concept Transfer Test
You want to present graphically the motion of the car by building the graph below in real time.  Construct the programming code and call x the variable that represents the position (in meters). Use the appropriate numerical values where necessary.	The water level of a pool as a function of time is presented in the graph below  You want to present graphically the height of the water by building the graph in real time. The computer needs to draw one point of the graph with a time interval of 4 minutes. Construct the programming code and call h the variable which represents the height of the water (in meters). Use the appropriate numerical values where necessary.

Transfer level

Figure 3.7 shows that the non-iSTEM students are required to transfer more from the class to the RT, than to the transfer test, just as with the other studied concepts. This could have implications for interpreting the results of the tests. iSTEM students need a more near transfer from class to RT, because they have been taught the concept of programming loops in the context of a moving car. In the case of the non-iSTEM students, the concept of a programming loop has not been taught. This is why the transfer level of the knowledge domain is the most far reaching.

Just as in the other cases, the required transfer level from the RT to the CTrT is the same for both groups of students, because the prerequisites are made equal by the RT. Though, since non-iSTEM students only applied the concept of a programming loop in a physics context during the RT, the transfer to the CTrT could be harder for them.

Figure 3.7: Representation of the required level of transfer for the concept of a programming loop



Analysis

Based on the interviews, we identified different steps that were seen in students' explanations for the concept of a programming loop. Table 3.11 shows the result of this, as well as the performance of the students on these steps. The steps we extracted from the interviews were:

- STEP 1: Declaring variable: The student knows it is necessary to and how to declare a variable
- STEP 2: Use of a loop: The students see it is recommended to make use of a loop

Students' performance patterns

A few different thinking patterns can be distinguished. If we have a look at Table 3.11, we can analyze this as shown in Table 3.3, resulting in Table 3.12.

Since the non-iSTEM students never had a lesson of programming before, it is hard to judge whether transfer has occurred or not.

The performances of the iSTEM students though, can be judged. They know, for instance, that they need a loop in the RT as well as in the CTrT, as presented in Table 3.12.

Table 3.11: Students achievements on the concept of a programming loop. Students who did not realize a certain step was necessary, not even after a lot of scaffolding hints, are not included in the table for that step.

	Spontaneously correct		Correct with hints		Wrong	
	RT	CTrT	RT	CTrT	RT	CTrT
Declaring variable	Non-iSTEM1 iSTEM1 iSTEM4	Non-iSTEM3 Non-iSTEM4 iSTEM1	iSTEM2 iSTEM3	Non-iSTEM2 iSTEM3		Non-iSTEM1 iSTEM2 iSTEM4
Use of a loop	iSTEM1 iSTEM2 iSTEM3 iSTEM4	Non-iSTEM2 Non-iSTEM4 iSTEM1 iSTEM3 iSTEM4			Non-iSTEM1	Non-iSTEM1 Non-iSTEM3 iSTEM2

Table 3.12: Transfer abilities of students for the concept of a programming loop

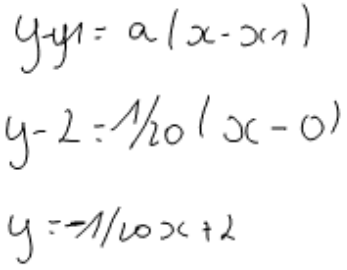
RT	CTrT	Conclusion	Topic	Number of students
Spontaneously correct	Spontaneously correct	Transfer is made	Declaring variable	1
			Use of a loop	3
Spontaneously correct	Correct with hints or wrong	Hard transfer from known context to new context	Declaring variable	2
			Use of a loop	1
Correct with hints	Spontaneously correct	Hints in RT have provided new insights and could be transferred		
Correct with hints	Wrong	Provided hints did not bring insights	Declaring variable	1

Table 3.11 shows that few useful hints were given to the students. A lot of hints were provided for the students, but even with these hints, students were unable to solve the problem. This could be explained by the fact that students are unfamiliar with the concept of a programming loop, especially the non-iSTEM students. As a consequence, the scaffolding questions do not help the students, but make it even more complicated for them, because they are not able to answer these questions. So instead of bridging the gap between the contexts, the gap might becomes bigger.

Students' difficulties

Slope A lot of students, four in the RT and five in the CTrT, calculate the slope of the graph as positive. Figure 3.8 shows this struggle with the slope, since the slope is positive in the second line and becomes negative in the third line. In order to correctly calculate the slope of a graph in an unknown context, this requires interpreting both the graph and equation and shifting between it, in order to find a link between them (Leinhardt et al., 1990).

Figure 3.8: Student's notes while determining the function of the graph



Used variables Another remarkable fact is that students tend to think with x and y instead of the variables on the axis. This could be explained with the fact that teachers often give the general formula or graph, with x and y (Woolnough, 2000). This implies students struggle to transform the formulas to the given variables (Yeatts & Hundhausen, 1992), as shown in the excerpt below. This difficulty arose with two students in the RT and four students in the CTrT.

> **Student:** Euh... x is... t is equal to... (writes down x = t = 0) Yes, they never put that in a program, two times equals to. Euh... x... You can say that x is t and that one has a starting value of 0.

Scaffolding strategies

Table 3.11 shows that some students need some hints to answer the question correctly. Analyzing these hints, we see some scaffolding questions or prompts that help construct students' thinking. These are:

- Asking them to look at shape of the graph.

- Asking them to indicate the specific intervals on the graph.
- Asking them to imagine they had to explain to a class mate how to draw the graph.
- What about the sign of the slope?

Main findings regarding the concept of a programming loop

It is really hard to answer the research questions for this concept, since students are unfamiliar with it. It is only possible to answer research question 3, about the difficulties and scaffolding hints. Also in this problem, students have trouble calculating the slope. The problem here is not a point-interval confusion, but students struggle with the sign of the slope, since it is a descending graph (Planinic et al., 2012; De Bock, Van Dooren, & Verschaffel, 2015). We could conclude they do not link the formula with the graph. Another difficulty seems to be the naming of used variables. Students tend to think that only variable x and y can be used. This could be a consequence of teaching mathematics with only these two variables.

Unfortunately, the provided hints did not help the students to overcome these difficulties. Since they are too unfamiliar with the concept of programming, the hints were not able to bridge the gap.

3.4.4 Resistance

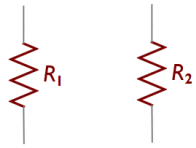
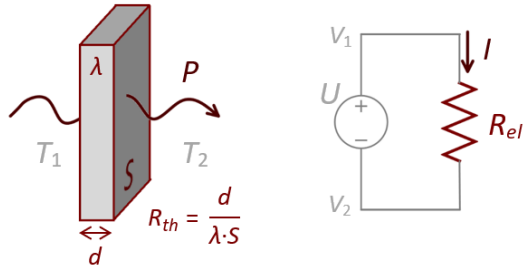
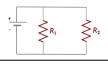
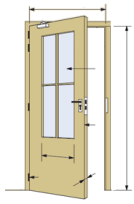
Test items

The test items of the RT and the CTrT are shown in Table 3.13. Although the tests were conducted separately, they are shown next to one another in Table 3.13 to demonstrate their one-to-one match.

Transfer level

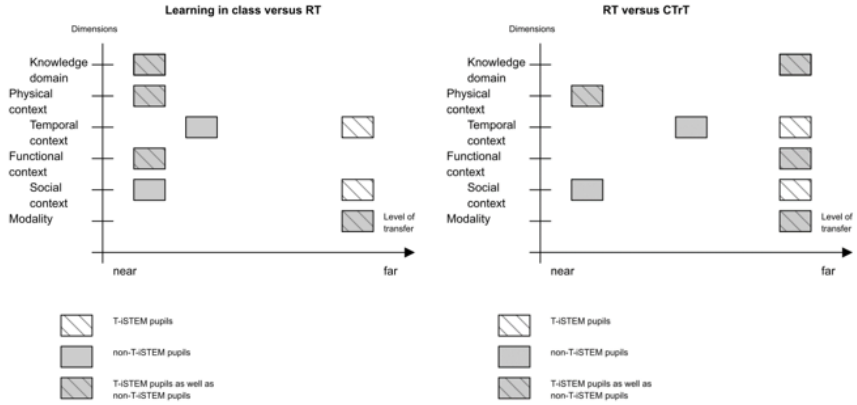
Figure 3.9 shows the required levels of transfer. In this presentation the relative distance can give an indication on how far students had to transfer the requested skills. The farthest transfer between the classroom learning situation and the RT on the one hand, and the CTrT on the other hand, was required from the participating students on the knowledge dimension, as students had to switch from the context of electricity to the context of thermodynamics. As can be seen in Figure 3.9, the time interval between the classroom learning and the RT

Table 3.13: Test items for the concept of resistance

<table>
<tr><td>Reference test</td><td>Concept Transfer Test</td></tr>
<tr><td>Imagine two electric resistors
R_1 and R_2 as presented below.</td><td>A wall with a thickness d (in m), thermal conductivity coefficient λ (in $\frac{W}{m \cdot K}$),
and surface S (in m^2), is for a thermodynamics problem what a resistor is for an
electricity problem. With a heat flow rate P (in $\frac{J}{s}$) with an indoor temperature T_1
and an outdoor temperature T_2, the wall will thus behave as a thermal resistance,
which we call R_{th} (in $\frac{K}{W}$).
Look at the schematic below:</td></tr>
<tr><td>
</td><td>
</td></tr>
<tr><td></td><td>Fill in following table relying on the analogy between the thermal situation and the
electric situation (Robertson & Gross, 1958):
<table><tr><td>Thermodynamics</td><td>Electricity</td></tr><tr><td>$T = T_1 - T_2$</td><td>…</td></tr><tr><td>… = $\frac{\Delta_{eq}}{\Delta t}$</td><td>$I = \frac{\Delta q}{\Delta t}$</td></tr><tr><td>$R_{th}$</td><td>$R_{el}$</td></tr><tr><td>… = …</td><td>$I = \frac{U}{R_{el}}$</td></tr></table></td></tr>
<tr><td>When is the substituting electric resistance the largest:
in a series circuit of the two
resistors, or in a parallel circuit of the two resistors?</td><td>When is the total thermal resistance the smallest:
in a series configuration or in a parallel
configuration of two identic walls?</td></tr>
<tr><td>In the electric circuit presented in the figure below,
the value of resistor R_1 is 1200Ω.
Determine the value of resistor R_2 if you know that the battery
supplies a voltage of 5 V, and the total current of the circuit
is 3 A.</td><td>In a wooden door ($\lambda_H = 0,4 \frac{W}{m \cdot K}$) with a thickness of 10 cm, a glass window
($\lambda_G = 0.82 \frac{W}{m \cdot K}$) is inserted with the same thickness. The total door surface
is $S = 1.86 m^2$.
Determine the surface of the glass window so that the amount of heat
ΔQ, that passes through the door per second, is only 165 J at an
indoor temperature of 22°C and an outside temperature of 4°C.</td></tr>
<tr><td></td><td></td></tr>
</table>

was much longer for the T-iSTEM students than for the non-T-iSTEM students, as the T-iSTEM students had to retrieve knowledge they had stored away for at least two months during summer vacation, while the non-T-iSTEM students had been practicing their skills in electricity during the three months prior to the RT. However, the time interval between the RT and the CTrT was smaller for the T-iSTEM students compared to this time interval for the non-T-iSTEM students. Furthermore, for all students, the third item of the CTrT required farther transfer than the second item of the CTrT. On the social dimension, the test situations created a whole new, different setting from the classroom learning situation for the iSTEM students, as they had to carry out the exercises individually during the test, instead of in a cooperative project with peers. For both the non-T-iSTEM and T-iSTEM students the test situations differed from

Figure 3.9: Representation of the required level of transfer for the concept of resistance



the classroom learning situation on the modality dimension because of the requested oral clarification and the apparent 'supervision' of two researchers who were unfamiliar to them, as opposed to the usual exercises in the presence of their teacher.

Analysis

In the analysis, we distinguish between the three questions asked. The first test item is about filling out the matching table, test item 2 is about the symbolic calculation of resistors and test item three is about the application of the concept of resistors. The first question has only a component in the CTrT, so no comparison could be made. The analysis of test item 2 can be found in Table 3.14, and of test item 3 in Table 3.15.

The second test item required participants to recollect the formulas for the equivalent resistance of two resistors connected in series and parallel. To answer the question, the participants first and foremost had to know what a series and a parallel configuration of two resistors look like.

The third test item required participants to identify the configuration of two given resistors. Next, they had to combine the formula for the equivalent resistance of two parallel circuited resistors, which they had already used in the first test item, together with Ohm's law or Newton's law of cooling (the discrete variant of Fourier's law), which they had to retrieve from memory or look up in the table they had completed in the introduction.

Table 3.14: Students achievements on the concept of resistance, test item 2. Students who did not realize a certain step was necessary, not even after a lot of scaffolding hints, are not included in the table for that step. If the students tried multiple strategies while solving the test items, all attempts are registered.

	Spontaneously correct		Correct with hints		Wrong	
	RT	CTrT	RT	CTrT	RT	CTrT
Equivalent resistances R_{eq}						
recall of formula $R_{eq,s}$	Non-T-iSTEM2 T-iSTEM1	Non-T-iSTEM2 T-iSTEM1				
recall of formula $R_{eq,p}$	Non-T-iSTEM2 T-iSTEM1	Non-T-iSTEM2 T-iSTEM1				
configuration drawing	Non-T-iSTEM4			Non-T-iSTEM4		
$R_{eq,s} > R_{eq,p}$						
recall	Non-T-iSTEM3 T-iSTEM1 T-iSTEM2					
analogy reasoning		Non-T-iSTEM1 Non-T-iSTEM2 Non-T-iSTEM3		T-iSTEM1		Non-T-iSTEM2
real-life interpretation		Non-T-iSTEM1 Non-T-iSTEM3				Non-T-iSTEM1
filling in example numbers	Non-iSTEM2	Non-iSTEM2	Non-T-iSTEM1 Non-T-iSTEM3			

Table 3.15: Students achievements on the concept of resistance, test item 3

	Spontaneously correct		Correct with hints		Wrong	
	RT	CTrT	RT	CTrT	RT	CTrT
Parallel circuit						
recognition	Non-T-iSTEM1 Non-T-iSTEM2 Non-T-iSTEM3 T-iSTEM1 T-iSTEM3			Non-T-iSTEM1 Non-T-iSTEM2 Non-T-iSTEM3 T-iSTEM1 T-iSTEM3		
use of formula $R_{eq,p}$	Non-T-iSTEM1 Non-T-iSTEM3 T-iSTEM1 T-iSTEM2	Non-T-iSTEM2	Non-T-iSTEM2	Non-T-iSTEM3 T-iSTEM2		Non-T-iSTEM1 T-iSTEM1
Ohm's / Fourier's law						
Use of formula	Non-T-iSTEM3 T-iSTEM1 T-iSTEM2 T-iSTEM3	T-iSTEM1		Non-T-iSTEM3		T-iSTEM2 T-iSTEM3

Students' performance patterns

A few different thinking patterns can be distinguished for test item 2 (Table 3.16).Two students managed to successfully give the formula for equivalent resistance of two series and two parallel resistors in the RT as well as in the CTrT without needing any prompts or hints. They were thus able to fluently transfer the concept of resistance from the 'electricity' context to the 'thermodynamics' context.

Table 3.16: Transfer abilities of students for the concept of resistance, test item 2

RT	CTrT	Conclusion	Topic	Number of students
Spontaneously correct	Spontaneously correct	Transfer is made	Eq. resistance R_{eq}	2
			$R_{eq,s} > R_{eq,p}$	2
Spontaneously correct	Correct with hints or wrong	Hard transfer from known context to new context	$R_{eq,s} > R_{eq,p}$	1
			Config. drawing	3
Correct with hints	Spontaneously correct	Hints in RT have provided new insights and could be transferred	$R_{eq,s} > R_{eq,p}$	2
Correct with hints	Wrong	Provided hints did not bring insights		

In the RT, three students had remembered correctly from class that a series configuration of two resistors would result in the largest equivalent resistance. However, two of them were unable to retrieve this knowledge in the CTrT.

Five students who had immediately recognized the pictured circuit as a parallel circuit of two resistors in the RT, only managed to recognize the configuration of the glass window and the wooden door in the CTrT as a parallel configuration when explicitly being asked. Although all students had just answered the previous question about series and parallel configuration of two thermal resistances, this first test item had cued none of them to spontaneously think about the second test item in terms of resistances and how they are configured. Four students who had spontaneously used the formula for the equivalent resistance of two parallel resistors in the RT, did not even recollect the formula, or used the formula only when suggested by the interviewers in the CTrT.

Table 3.16 concludes that only a few students managed to make the transfer from the 'electricity' context to the 'thermodynamics' context, and a few others needed hints to do so. The table also shows that the T-iSTEM students did not outperform the non-T-iSTEM students in this respect.

A few different thinking patterns can be distinguished for test item 3 (Table 3.17).

Similar results were found for the other formula that was required to solve item 3. Of the four students who had spontaneously used the equation of Ohm's law to find an answer to item 3 of the RT, only one student spontaneously realized that he had to use the thermal equivalent, i.e. Fourier's law, in item 3 of the CTrT (T-iSTEM1). Other students had to be told explicitly or be pointed

Table 3.17: Transfer abilities of students for the concept of resistance, test item 3

RT	CTrT	Conclusion	Topic	Number of students
Spontaneously correct	Spontaneously correct	Transfer is made	Law-equation use	1
Spontaneously correct	Correct with hints or wrong	Hard transfer from known context to new context	Config. recognition	5
			$R_{eq,p}$ formula use	4
			Law-equation use	3
Correct with hints	Spontaneously correct	Hints in RT have provided new insights and could be transferred	$R_{eq,p}$ formula use	1
Correct with hints	Wrong	Provided hints did not bring insights		

towards the introductory table of test item 1 of the CTrT in which they had constructed this equation before.

Table 3.15 thus indicates that students' attention had to be directed towards the analogy in order for them to make the transfer. However, their transfer did not extend beyond recognition of characteristics, and a deeper search for underlying principles did not occur. Table 3.17 concludes that, overall, transfer from the 'electricity' context to the 'thermodynamics' context involving multiple formulas and calculations, was rather hard for most of the participating students.

Students' difficulties

During the teaching-learning interviews, we detected correct and incorrect student conceptions, some of them related to the ones found in the literature. The misconceptions were not very pronounced (sometimes students were just guessing), and some emerged only among a few students, while others exhibited the correct ideas. Nevertheless, it is interesting to see how some conceptions were transferred or rectified across contexts.

Analogy Student non-T-iSTEM4, who was one of the two students who were enrolled in the technical study track only in grade 11, clearly struggled with electrical concepts and employed analogies with other contexts to make sense of the problem questions in the 'electricity' context. He first reasoned in a 'waterfall' context and was then helped by the analogy with the 'thermodynamics' context while trying to complete the CTrT table. Furthermore, this student showed evidence of grasping what energy physically means: the ability to maintain equilibrium in a system (Lancor, 2014).

Recollection All students seem to have a lot of problems to recollect information from class in order to solve the question in the RT. These recollection problems are about the fact that voltage is a difference in potential and that electric current is the amount of electric charges passing through the conductor's cross section in a certain time interval.

On top of that, none of the students in this study understand the word 'substituting resistance' while it should be a common concept in electricity. As a consequence, the interviewers needed to explain this concept during every interview. Previous studies have also found that students are not familiar with this concept (Viard & Khantine-Langlois, 2001; McDermott & Shaffer, 1992).

Sloppy wording Four out of seven students interchangeably use the phrasings 'is the same', 'remains the same' and 'becomes zero', as illustrated in the excerpts below. It is hard to detect whether these careless formulations are just lapsuses or real misconceptions

> If V_1 would equal V_2, then the current would remain the same.

> The voltage across two resistors in parallel remains the same.

Another example of this sloppy wording is the interchangeable use of temperature and heat. Arnold and Millar (1996) reported on this issue before and also in this study we found two students facing this problem.

Energy Two out of seven students have no transferable definition of energy. They only describe energy as the ability to do work. This difficulty is reported before by Lancor (2014). Moreover, these students have no clue that heat is a sort of energy (Prince et al., 2012; Wiser & Amin, 2001). They tend to think it is a substance (Baser, 2006a) or material property (Arnold & Millar, 1996).

Potential difference Cohen et al. (1983) has reported already that students tend to think that potential difference is caused by current. The excerpt below illustrates that this misconception is also present by one student in our study. The other students make a correct interpretation of the relation between potential difference and current, in the RT as well as in the CTrT.

> There is a current flowing to keep V_1 and V_2 unequal.

Resistance Two students participating in this study face some difficulties with the concept of resistance, as the excerpts below illustrate. The wrong statements made by the students are already studied in previous research (Cohen et al., 1983; Engelhardt & Beichner, 2004; Closset, 1983).

> If there is no temperature difference, there is no resistance or isolation.

> Current is smaller 'after' the resistor than 'before'.

> Just as a waterfall is impeded by a stone, current is impeded by a resistance.

One student is having difficulties with the effect of a parallel resistor on the equivalent resistance, as already found in literature (Cohen et al., 1983). The excerpt below illustrates this difficulty.

> If I apply Ohm's law, the equivalent resistance will be too small.

Geometry Five students were misguided by their mental image of an electric diagram, when making the analogy to thermodynamics. Some students copied the image of the electrical diagram straight to the thermodynamics context, as illustrated in Figure 3.10. Others correctly indicated the serial placement of walls, but stated that the parallel placement would be the same but with more space in between the walls, as illustrated in Figure 3.11. This misguidance is studied before in literature (Engelhardt & Beichner, 2004; Day & Goldstone, 2012; McDermott & Shaffer, 1992).

When solving test item 3, all but one student needed hints to recognize the set up as a parallel circuit of resistors in thermodynamics. This is remarkable, since we discussed series and parallel circuits with them in test item 2. The inability to recognize series and parallel circuits is discussed in previous literature (McDermott & Shaffer, 1992), but only in the context of electricity.

Thermal conductivity Three students do not interpret thermal conductivity as a material property in test item 3 in the CTrT, as illustrated by the excerpt below.

> I can just add (or subtract) the thermal conductivity of glass (λ_{glass}) with the one of wood(λ_{wood})

Figure 3.10: Student's transfer from the electrical diagram to the thermodynamics context by copying the image of the diagram. The block represent the walls, while the arrow represents the heat flow.

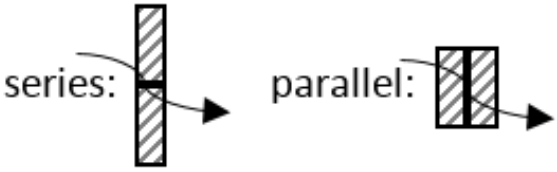
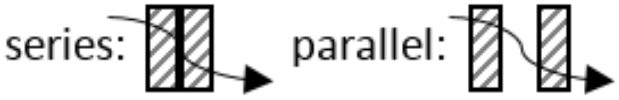


Figure 3.11: Student's transfer from the electrical diagram to the thermodynamics context with a correct series placement, but wrong parallel placement. The block represent the walls, while the arrow represents the heat flow.



None of the students made a drawing of the door with indications of the given data, although this might have helped them to distinguish the two resistances, their configuration, and their properties. Furthermore, students were overlooking useful formulas, such as

$$R_{eq} = \frac{R_{glass} \cdot R_{wood}}{R_{glass} + R_{wood}}$$

and

$$P = \frac{\Delta V}{R_{eq}}$$

All of the students needed hints before they started using the analogy of Ohm's law. They were mainly searching for easily accessible formulas, such as the ones mentioned on their test paper, in which they could plug and chug the quantity values given in the problem statement, hoping to bump into the final answer. They did not recollect or use one of the previously determined underlying principles, although these should have been readily accessible in their working memory from the previous test item.

Scaffolding strategies

Some students answered correctly after some hints. In these hints, the interviewers had to point from the table to the figure, and vice versa:

- What is the cause of the heat flow through the wall?
- What would happen if V_1 would equal V_2?
- Then, what would happen if T_1 would equal T_2?
- Can you give an example of a thermal resistance in real life?
- What is the unit of 'heat flow rate'?
- Which quantity is expressed in Joule? Maybe think back to Mechanics.
- What is this quantity called in case of heat transfer?

Because students did not always try to imagine the different resistor configurations or started guessing without being able to give a sound explanation, some interview prompts on the RT and some hints in the teaching-learning interviews on the CTrT urged them to try to make sense of what was being asked in test item 2, by means of drawing or gesturing:

- What does a series configuration look like? And a parallel configuration?
- Can you draw this configuration for us?
- How is the current flowing through the resistors in each configuration?
- How is the heat flowing through the walls in each configuration?
- Do you remember the formula of the equivalent resistance of two series-circuited resistors in electricity?
- You say series configuration results in the highest resistance value. Can you proof that to us?

This last hint was required when students tended to corroborate the fact that two parallel resistors have the smallest equivalent resistance by the fact that in the formula they had learned in class, R_{eq} is situated in the denominator:

$$\frac{1}{R_{eq,p}} = \frac{1}{R_1} + \frac{1}{R_2}$$

The superficial resemblance of the first items of the RT and the CTrT did not cue students to detect the resemblance among the second items of the two tests, namely the parallel configuration of two resistors. Thus, to recognize the applicability of the equivalent-resistance formula in the CTrT, students needed the scaffolding hint:

- In which configuration are these materials placed with respect to each other?

Once this question was popped, they all correctly recognized the parallel configuration, but failed to use this insight, not realizing that knowing the configuration could help them in solving the test item.

Next to the anticipated hints, additional hints on the CTrT involved pointing towards the formula or towards the problem statement:

- What exactly are we looking for?
- Do you see a formula that contains this variable on your paper?
- Maybe have look at the table you completed. Can you see a useful formula in there?
- No, the given S is the total surface, not the one we are looking for. But maybe you could write the one we are looking for as a function of this S?
- Can you just add these two λ-coefficients like you are doing?

Main findings regarding the concept of resistance

We studied to which extent technically-oriented STEM students are able to transfer the concept of resistance from the context of electricity, in which the concept had been taught in class, to the context of thermodynamics, in which the students had not encountered this concept before, as mentioned in research question 1. A first conclusion is that students are not able to employ a concept with the same fluency in a less familiar context (thermodynamics) than they do in the context in which the concept was dealt with in class (electricity). Students need support and guidance if we want them to employ the concept in a less familiar setting. Furthermore, students' awareness of the analogy does not cue them to grasp it and to retrieve analogous formulas or principles related to the concept. This finding is in accordance with Novick and Holyoak (1991) who found that students' successful mapping of two analogous problems did not suffice for successful transfer of the solution strategy.

During the student interviews, we also registered to what extent students refer to the 'electricity' context in order to solve a problem in the 'thermodynamics' context, as part of research question 2. We found that students regularly refer to their classroom learning situation for solving problems concerning the concept of resistance. In our study, this was obvious from statements like 'we have seen that in Physics' or 'if I remember correctly from what we have seen'. This might have been facilitated by the fact that the tests and interviews were administered in contexts that had been studied in class, but also in the same physical environment, namely their classroom (Barnett & Ceci, 2002). For solving problems in the 'thermodynamics' context however, they do not refer to or rely upon exercises they recently made in an 'electricity' context test, not even when the question phrasings resemble each other and require the same kind of formulas. Remarkably, the less technically-trained student in this study was helped by hints referring to the 'thermodynamics' context for solving questions in the 'electricity' context. Students sometimes rely on or even invent other analogies in their attempt to make sense of a problem other than the presented analogy, which is an efficient problem solving strategy (National Research Council, 2001). This finding raises the question whether difficulty with transferring a concept is inherent to the context in which it was taught. For example: will a student more easily transfer from a context he/she feels more affined to, and if so, how can we shape STEM education that gives students a sense of ownership over the contexts in which concepts are taught?

This study furthermore investigated the strategies and conceptions students adopt in solving problems regarding the concept of resistance in their attempt to transfer this concept, as stated in research question 3. Students tend to apply different strategies in different contexts. Jiang et al. (2018) found that in fostering students' conceptual understanding of equivalent electrical resistance, using logical reasoning and mathematical deduction is more successful than using analogies. Our findings, however, suggest that students rely on other strategies in the 'thermodynamics' context. In the 'electricity' context, in which the concept was learned initially, students indeed rely on memorization from classroom experiences and on mathematical deduction. However, when trying to transfer the learned concept to the less familiar 'thermodynamics' context, they first try to make sense of what the concept represents in this context, by interpreting its meaning in real-life. Cued by scaffolding hints, they then make use of the analogy between the two contexts. This might be due to the near transfer that is required in the first context, in which students fall back on well-practiced routines based on the superficial features they recognize from classroom learning, while the second context asks for far transfer, in which they have to make connections through reflective thought (Perkins & Salomon, 1988). Some student misconceptions found in the literature, are persistent, e.g. no understanding of the concept 'equivalent resistance' (Viard & Khantine-

Langlois, 2001; McDermott & Shaffer, 1992). However, students also exhibit correct insights, e.g. no potential difference results in no current (contrarily to Cohen et al. (1983)). Our results show that, whereas concepts and principles are not transferred easily by students, on the plus side: neither are misconceptions.

Overall, students seem to exhibit a rather novice problem-solving behavior in a context in which they are not used to apply a learned concept. Novices' knowledge is often fragmented and lacks conditions of applicability (Mestre, 2002). Unlike expert problem solvers, who first take a perspective, and try to detect and exploit the underlying analogous principles in a less-familiar context (Day & Goldstone, 2012) (e.g. resistor configuration or Ohm's law), students quickly look for formulas into which they can plug the given information, without inspecting and modeling the underlying structures and analogies (Kuo, Hull, Gupta, & Elby, 2013; Dufresne et al., 1997).

We compared two groups of students in their attempt to transfer the concept of resistance from the 'electricity' context to the 'thermodynamics' context: four students enrolled in a traditional curriculum (in which STEM courses are taught in a less context-rich, more isolated way), and three students enrolled in an inquiry- and design-based integrated STEM curriculum (in which STEM learning content is interconnected through an overarching theme), as stated in research question 4. Although transfer of scientific concepts as a result of context-rich, design-based instruction has been evidenced before (Fortus et al., 2005), we found that students enrolled in the integrated track did not outperform the students in the traditional track. Even the shorter time lapse between the RT and the CTrT did not give the T-iSTEM students a head start. The lack of obvious effects in our study might have several causes. Firstly, due to practical considerations, the students participating in our study were not randomly selected. Except for one other student, the three interviewed T-iSTEM students were the only students in their class, while the four interviewed non-T-iSTEM students were students who had volunteered to take part in this study from a class of more than 20 students. Although it seemed as if each of the two samples of students more or less represented the whole range of performances (very good - good - insufficient - poor), we were not able to verify and compare the students' average school results. Secondly, from an interview with the grade 9 and 10 teachers of the T-iSTEM students we conducted in the scope of a later study (not published yet), it appeared that these teachers had not found the time or motivation to apply more integrated and innovative teaching strategies. Their statements testified of a rather teacher-centered approach and revealed that they had not employed opportunities for more integration of STEM content (such as between 'electricity' and 'thermodynamics') as suggested by STEM@school, the integrated STEM program in which they participated. Furthermore, while some physics and mathematics content had been integrated, mechanics or electricity

had still been taught as separate courses. This led us to doubt whether the T-iSTEM students were more prepared in flexibly connecting multiple disciplines than the other students.

3.5 Discussion

The goal of this study was to investigate students' ability to transfer concepts learned in one context to another context. More precisely, following research questions were asked:

1. To what extent are students able to transfer the concepts of slope, area under the curve, programming loop and resistance from one familiar context, encountered in class, to another familiar context, not encountered in class?
2. To what extent do students refer to one context in order to solve a problem in another context?
3. Which difficulties arise during solving problems concerning the concepts of slope, programming loop, area under the curve and which of these are persistent in an attempt to transfer them? What hints can help to overcome those difficulties?
4. Are students involved in an integrated STEM study track more capable of transferring from the one context to the other than students enrolled in a traditional STEM curriculum?

3.5.1 Research conclusions

First, regarding the transfer of concepts they have learned in one familiar context to another familiar context in order to solve a problem, it seemed impossible to conclude something about the transfer ability of students for a whole concept. Students barely succeed in transferring a whole concept to a new context. But, when looking in more detail at different steps and strategies, we can make some conclusions about students' transfer ability. Some students are able to transfer some steps and strategies to another context. However, often they use a different solution strategy in the familiar context not encountered in class, than in the familiar context. Our findings are in line with the research findings of Ivanjek et al. (2016), who showed that students use different problem solving strategies in different contexts. Furthermore, as Planinic et al. (2013) and Ivanjek et al. (2016) found before, whether or not transfer will happen, depends on a lot

of different factors, so it is hard to tell why the transfer did not occur. No difference in transfer ability could be found between non-iSTEM and iSTEM students.

Second, we asked whether students refer to one context in order to solve a problem in the other context. It seemed that students were referring to the RT when doing the CTrT to justify why they use a certain problem solving strategy. This happened 15 times, of which 10 were correct references. Students did not often refer to the class context. However, when they were struggling, referring to the abstract context in which they learned the concepts, sometimes helped them out. In the test of resistors, students made more references to the class context than students did in the test about slope, area under the curve and programming loop.

Third, we asked for difficulties while solving the test and which of these are persistent to the transfer test. Moreover, we are interested in what hints can help to overcome those difficulties. The difficulties and incorrect strategies that we saw in the interviews were:

- Wrongly stating that the reference point is the starting point of the movement;
- Drawing a one-dimensional position graph oriented from 2 to 0 meters;
- Confusion between quantity and unit;
- Point-interval confusion;
- Difficulty in making abstraction of a constant factor in a formula;
- Calculating the average based on a graph by taking only one point on the graph;
- Wrongly stating the unit of work;
- Not considering the sign of the slope;
- Consistently using x and y instead of the given variables;
- Interchangeable use of the phrasings ‘is the same’, ‘remains the same’, and ‘becomes zero’;
- Wrongly stating that there is always a current flowing;
- Wrongly stating that if there is no temperature difference, there is no resistance or isolation;
- Wrongly stating that current is smaller ‘after’ the resistor than ‘before’;

- Interchangeable use of ‘temperature’ and ‘heat’;
- Misguidance by the geometry of an electric diagram in the geometry of heat resistors; and
- Wrongly stating that you can just add (or subtract) the thermal conductivity of glass with the one of wood.

The confusion between quantity and unit and the point-interval confusion arose for more than one concept. The other difficulties were specific to each concept.

Most of these difficulties are not new, and already mentioned before in literature. These difficulties seemed quite persistent from RT to CTrT and arose even more often in the CTrT, indicating that they are not ‘overcome’ but show up again in unfamiliar contexts. It is remarkable that few iSTEM students face these difficulties in the RT, but more of the students have trouble with the difficulties in the CTrT. So it seems to be that the interpretation of concepts and difficulties is still linked to the context, despite the iSTEM teaching approach.

In some cases, these difficulties could be overcome during the interviews by pointing students to specific parts of the assignment, in the graph or the formula, or by making abstraction of the concept and asking how they did it in class and as such explicitly linking to known situations (Inventado et al., 2018; Novick & Holyoak, 1991). The fact that some difficulties could be overcome easily by providing scaffolding, might be an indication that those students had already an intermediate partially correct, level of understanding (Rosenblatt & Heckler, 2011).

Our findings again show that transfer does not occur spontaneously or easily, so explicit attention is needed (Wicklein & Schell, 1995). This difficulty to transfer may be due to the fact that lots of knowledge students possess is inert and as such is hard to activate in new contexts (Kehne & Fechner, 2017a; Bubou et al., 2017). This requires enough different contexts and applications of the concepts are provided to students in which they are prompted to apply the concept. Moreover, our results indicate that small focused questions could support scaffolding for students to transfer ideas to new contexts.

3.5.2 Applicability

The developed test items proved to be appropriate to monitor students’ transfer skills. By matching the RT and the CTrT, and making sure the teaching-learning interview provides scaffolding for students, some interesting transfer performance patterns and difficulties are revealed, namely students use different

problem solving strategies in the RT than in the CTrT and when the knowledge gap is too big, scaffolding is not useful.

In order to ensure the testing of exactly the same steps and strategies while varying only the context, the questions of RT and CTrT were formulated as isomorphic as possible. We cannot tell whether students made transfer from what they have learned in class, or transferred from what they have picked up during the RT based on the visual similarities between the RT and CTrT questions, such as the same graphical representation, or the same verbalization of the question. This could result into a certain bias when we make inferences about transfer ability, although transferring based on visual similarities is also a type of transfer (Day & Goldstone, 2012). In the future, this problem could be solved by first performing the CTrT and afterwards the RT. As a consequence of this sequence, students can only transfer from class context.

Another possible bias arose during the interviews. The set-up was to use the think-aloud method during the RT, but due to time issues (Van Someren et al., 1994) because students had difficulties with solving the problems and verbalizing their thoughts, some help during problem solving was given to them. In the beginning, this help was only to verbalize their thoughts. When struggling remained, also help in terms of content is provided. When examining the level of transfer required for the test, we conclude that more far transfer is required from class context to RT than from RT to CTrT, especially for the non-iSTEM students. This could explain why a think-aloud interview without prompting or help did not work out for the RT. Similarly, the interview guideline for the teaching-learning interview could not always be adopted, because students showed other thinking patterns which were not taken into account prior to designing the guideline. Student interviews with scaffolding hints might encourage students to make random guesses and just wait for help from the interviewer. As was done in our analysis, observations from such interviews should always be considered in the light of this effect. Future studies could provide an interview guideline in advance, which takes this problem into account.

We only selected one or two questions for testing a particular concept. However, the best way to detect differences in problem solving abilities between students of different curricula is to create a test with a large number of short answer cases (Schuwirth et al., 1999). Since this was not possible in this set-up, guessing while answering the questions is avoided by asking for clarification of the given answer. The interviewers ask the students to explain how they came to the answer. In that way, guessing can be excluded. Future research should consider the option to use more short answer cases in order to distinguish between students.

Another aspect to take into account is the timeframe. The tests were conducted

in the 11th grade, while the concepts of slope and circuits are already taught in the 9th grade. This long time between learning the concepts and the interview about transferring the concepts can have several implications. Students have learned a lot of other concepts in the meantime, which have provided them more background knowledge. This could facilitate transfer. The context of work, on the other hand, is only taught in the 10th grade, so has had less time to grow in students minds. So it might be harder for students to transfer to this context. Students also could have done enriching extracurricular activities, such as maker camps, which could have enabled them to transfer some concepts. This is a disadvantage of the long time lapse between learning the concept and the test to transfer the concept. It is recommended to elaborate this kind of research closer to the learning phase, so it is easier to tell from which setting students are transferring.

Another remark is about the comparison in research question 4. We wanted to compare students enrolled in an integrated STEM program (STEM@school) with students in a traditional curriculum to see if integration and interconnection of STEM disciplines via inquiry and design equips students with a higher context flexibility. However, the extent to which the integration and student-activating strategies had been established in class appeared to be quite different from what was expected from schools participating in STEM@school. For instance, not all teachers used a coaching approach, not all students were given the same freedom in designing, not all schools had the same infrastructure, and some teachers dropped exercises especially focusing on integration and transfer. As a consequence, since the developed teaching strategy is not always as intended, it is hard to examine the effect of it (Bybee et al., 2006).

Potential bias occurs with the T-iSTEM students. The interviews on the CTrT of this group of students had to be carried out on the same day as the ones on the RT. However, the tests in this study are designed to investigate students' transfer of underlying concepts and principles instead of their transfer of surface features. Therefore, they would ideally have been administered with a time interval of one or two weeks. With a time lapse of two weeks, the researchers can be fairly sure that the verified knowledge in the 'electricity' context would not have been forgotten by the students by the time they tackle the 'thermodynamics' test. Meanwhile, the researchers would reduce the chance of students' immediate recognition of the one-to-one match of the test-items' phrasings, i.e. the chance of mere transfer of surface features. The other student groups had one week between the RT and CTrT, so the bias is less.

A last remark is about the amount of participants. This study is conducted with fifteen students in Flanders, which implies no quantitative, nor generalizable results can be presented, though interesting qualitative results emerged. The aim of the study was to present qualitatively the transfer ability of students as well

as the difficulties students struggle with for well-defined concepts. Consequently, this study can be a preface for other, quantitative, studies. The difficulties and categorizations presented in this study can serve as a starting point for developing other tests, which can result in a quantitative analysis (Prince et al., 2012). The triangulation of qualitative and quantitative evidence is important in educational research because of the many parameters to deal with (Christie & de Graaff, 2017). The exposed difficulties, for instance, can serve as suitable distracters for multiple-choice questions in a research environment, not in the classroom (Shernoff et al., 2017). These distracters can provide a clear inside in the way students think about or apply a concept. This is interesting to take into account in future teaching approaches.

3.5.3 Recommendations in order to facilitate transfer

The overarching question in training for transfer is: How can we prepare students to recognize cues for the applicability of their knowledge (Lobato, 2006)? The findings from our study offer some clues for important instructional strategies, which we formulate in the following recommendations.

STEM education should train students in conceptual modeling as a scientific analysis and problem-solving technique (Schwarz & White, 2005). Before diving straight into thoughtless calculation, students should first try to model a given problem through causal reasoning and reflection (Perkins & Salomon, 1988). To start with, STEM education should make students familiar with the characteristics of a model (Carberry & McKenna, 2014; Schwarz & White, 2005). A model can have different representations (Van Driel & Verloop, 1999). One of them we found lacking in our study, was drawings. Our research made clear that students did not make this drawing spontaneously. When asked for, they made a drawing, but in such a way they did not benefit from it. Students should be trained in making appropriate drawings, because drawings can be a powerful tool in trying to capture a problem (Carberry & McKenna, 2014) and should become an automatism among students' problem-solving strategies. As students seem to prefer the strategy of real-life interpretation in a less-familiar context, crystallizing this mental model into a drawing or diagram might consolidate or refute the conclusions drawn upon this interpretation. As constructing a model implies interpretative choices (Goldstone & Day, 2012), they can provide more insight into students' thinking processes. Furthermore, a model can be developed in different levels of abstraction and has as function to explain and predict how a system reacts to certain events. It forms a basis upon which new hypotheses for inquiry can be derived (Van Driel & Verloop, 1999; Lancor, 2014; Haglund & Jeppsson, 2012), a feature which should be demonstrated by STEM teachers and practiced by their students more frequently. A more

abstract model will help students to apply their system skills in new, unfamiliar context, and as such facilitate transfer (Yeatts & Hundhausen, 1992; Boersma et al., 2011; Van Merriënboer et al., 2002; Canu, Duque, & de Hosson, 2016). In the case of electricity concepts for example, Tarciso Borges and Gilbert (1999) plead for more quantitative (mathematical) and microscopic modeling of electrical concepts, in which causal relations and interactions are articulated (e.g. a potential difference causes charges to move, and thus current to flow).

STEM education should train students in metacognitive reflection and analogical thinking. Instead of merely learning facts, students should primarily learn to think in terms of what they already do know and understand. This study revealed the need for scaffolding hints that ask students what they are doing (and why) and that urge them to rely upon the given analogy. These scaffolding hint helped them to solve the test item, and in some cases, students even transferred the gained knowledge of the scaffolding hints to the transfer test item. STEM education should include more analogies and should scaffold students to reflect upon them, for example by having students construct a comparison table under the guidance of the hints presented in this study. In the context in which the student feels more comfortable, difficult principles can be explained and extrapolated. Analogies then become a vehicle for conceptual change (Posner, Strike, Hewson, & Gertzog, 1982). But rather than forcing students to conceive a system from a perspective or context generated by teachers, research literature advocates for having students generate their own analogies (Lobato, 2006). Student-generated analogies are a measure of how students conceptualize new content (Lancor, 2014): 'Constructing one's own analogy serves to (a) make new situations familiar, (b) represent the problem in the particulars of the individual's prior knowledge, and (c) stimulate abstract thinking about underlying structure or patterns' (Wong, 1993). Also in our study, we saw that students construct their own metaphors and analogies when trying to make sense of new information in terms of what they already understand (Lancor, 2014). These analogies helped them to solve the test items. Blanchette and Dunbar (2000) and Haglund and Jeppsson (2012) found that student-generated analogies are often more elaborated in terms of underlying relational structures, than teacher-generated analogies. Moreover, when students are presented with pre-generated analogies, they tend to focus more on superficial features (Blanchette & Dunbar, 2000). Student-generated analogies, on the contrary, are often superficially dissimilar but contain different types of deep structural features and relations (e.g. if X then Y) (Blanchette & Dunbar, 2000). The construction of analogies consists of (1) assimilation, i.e. fitting new and correct information with own existing conceptions, and (2) accommodation, i.e. studying and explaining cognitive conflicts that are encountered (Posner et al., 1982). When students are encouraged to articulate these actions, they are gradually trained in independently accessing, mapping, and adapting analogies

in function of their prior knowledge. However, they should also be supported in evaluating the applicability, the effectiveness, and the constraints of the analogies they constructed while solving problems (Feldon et al., 2013; Karpov, 2003). Assessment of students' associative abilities in constructing analogies can in turn provide a measure of their creativity (Benedek et al., 2012).

STEM education should build in explicit links between STEM disciplines (Ivanjek et al., 2016; Kolodner et al., 2003; Pearson, 2017; Starr, 2008; Day & Goldstone, 2012; Valtorta & Berland, 2015; Dare et al., 2018; Starr, 2008), through inquiry- and design-based learning. Teaching for transfer asks for an approach which 'inspire[s] students to be intellectual entrepreneurs who proactively create their own opportunities for leveraging their prior knowledge' (Goldstone & Day, 2012). Therefore, instead of treating every context as a whole new domain with its own scientific laws (DeHaan, 2009; Lancor, 2014), instructional strategies should involve more bridges between contexts. Crosscutting concepts (such as 'resistance', 'slope', 'conservation of energy'), rather than procedures (Chappell & Killpatrick, 2003), can provide these crossdisciplinary bridges. Opportunities to learn and apply such concepts should not be left unexploited (Goldstone & Day, 2012). We advocate for an integrated and student-activating approach towards STEM instruction, since it encourages students to take ownership over their learning and to connect different disciplines in order to solve a complex inquiry or design problem (Thibaut, Ceuppens, et al., 2018; Kelley & Knowles, 2016; Fortus et al., 2005). These purposeful connections students have to make, will lead them to understand the applicability and transportability of what they are learning, and eventually to transfer their concepts. In our study, we noticed a lack of these connections between disciplines, what made it hard for students to transfer the concepts.

Teaching strategies that can support transfer are: making exercises in completely different contexts (Ivanjek et al., 2016; Nelissen, 2007; Kober, 2015; Shepard, 2000; Ross & Hogaboam-Gray, 1998; Holland et al., 2018; Dufresne et al., 1997; Starr, 2008; Fortus et al., 2004) and linking concepts to real world examples (Trowbridge & McDermott, 1980; Woolnough, 2000; Nelissen, 2007; Shepard, 2000), using different representations (Merrill, 2002), rehearse previous gained knowledge (Ayas & Demirbas, 1997), provide scaffolding (Mayer, 2004; Tiruneh et al., 2018) and sometimes teaching a concept in a decontextualized manner (Day & Goldstone, 2012; Wemyss & van Kampen, 2013; National Research Council, 2001; Starr, 2008; Kaminski, Sloutsky, & Heckler, 2009; Kehne & Fechner, 2017a; Fosnot & Perry, 1996).

In short, in spite of the limitations of our research setup, our study exposed some interesting patterns in students' attempt to transfer from one context to the other. Students need scaffolding hints that remind them of the existing analogy between the two contexts, even when this analogy is made explicit

to them. Even when they are aware of the analogy, they barely exploit the principles underpinning both problem contexts. They sometimes use other strategies, such as real-life interpretation or generation of other analogies, to make sense of a problem in a less-familiar context. This way of problem solving should be accommodated by STEM education that embeds and interconnects learning content in context-rich environments, in which students are constantly stimulated to articulate and model their conceptions, for example through self-generated analogies. Supplemented by the scaffolding hints that appeared helpful, the RT and CTrT tests and the interview guidelines developed in the scope of this study are readily employable as instruments to assess students' transfer ability, and can form a template for future research on transfer across other contexts.

Chapter 4

Design and implementation of an assessment strategy

This section is based on:

Goovaerts, L., De Cock, M., Dehaene, W. (2016). Assessment of STEM-design challenges: review and design. *Key Competences in Physics Teaching and Learning*, Institute of Experimental Physics, University of Wroclaw.

and

Goovaerts, L., De Cock, M., Struyven, K., Dehaene, W. (2018). *Choice and practice of assessment within an iSTEM teaching approach.* Manuscript submitted for publication.

An integrated STEM teaching approach sets other goals than a subject-specific science approach. In order to reach these goals, STEM-design challenges are designed and described in Chapter 2. To solve those challenges, students need to use their knowledge of all STEM-disciplines. Knowledge and concepts needed to solve the challenges are covered in the standard curriculum. But to solve the STEM-design challenge properly, students will need to show how going through the design process has taught them several concepts. This design process is one of the goals set by iSTEM. Such a goal requires an adapted assessment strategy, since assessment methods in subject-specific classes are mostly focused on one discipline (Pearson, 2017). On top of that, the assessment methods in subject-specific classes cannot capture the required competencies, nor the outcome of

an open-ended task (Aschbacher & Alonzo, 2006; Pellegrino & Chudowsky, 2003; National Academies of Sciences, Engineering, and Medicine, 2017; Austin, Hirstein, & Walen, 1997; Gratchev & Jeng, 2018). So, this, possibly implicit, procedural knowledge should be assessed by process evaluation (Debs & Kelley, 2015).

This chapter consists of two parts: the development of a suitable assessment strategy for students in the iSTEM class and mapping of the used assessment strategies in iSTEM classes. In order to develop a suitable assessment strategy for iSTEM classes, first, current evaluation strategies are reviewed in literature and analysed. Literature on Problem Based, Project Based and Inquiry Based Learning provides a range of evaluation instruments that might be useful to evaluate STEM-design challenges (Berland, 2013). Next, a brief design will be presented on how the guidelines for evaluating students in a STEM-design challenge were developed, based on the literature findings. This evaluation instrument was designed as an iteration between a bottom-up, starting by the challenges, and a top down approach, starting from the known literature. The designed assessment instrument has to be usable for summative as well as formative assessment. This first draft is presented to assessment experts and adapted based on their feedback, resulting in an assessment strategy. Before mapping the used assessment strategies in iSTEM classes, the developed assessment strategy is presented to the participating teachers in the STEM@school project. It only served as an example assessment strategy for the teachers, since it was important not to oblige teachers to use a certain assessment strategy. Afterwards, the used assessment strategies, the characteristics of the used assessment strategies and the argumentation of the teachers were examined and compared to each other.

4.1 Design

The framework of iSTEM is based on a constructivist view of learning, which implies the knowledge and skills are actively constructed within students minds. This implies other assessment methods are necessary, as mentioned by Shepard (2000): 'The measurement approach to classroom assessment, exemplified by standardized tests and teacher-made emulations of those tests, presents a barrier to the implementation of more constructivist approaches to instruction'. So, in order to facilitate iSTEM, matching assessment methods should be developed.

Students in iSTEM courses face other challenges than students in subject-specific courses. For example, the process students will go through to solve the STEM-design challenge is seldom linear (Capraro, 2008). Students continually

have to check their progress or results with the plan they made in the beginning and make corrections or adaptations if necessary so that steps can be repeated or left out (Bernholt, Rönnebeck, Ropohl, Köller, & Parchmann, 2013). On top of that, teams should be encouraged to take risks and to make mistakes, and the teams will not be penalized for making mistakes, because making mistakes is considered to be a learning experience (Brewer & Mendelson, 2003; Woolnough, 2000). As a consequence, other competencies should be assessed. A competency is described as a collection of skills, attitudes and knowledge that can be applied in concrete situations ("GOK Observatie-instrument [GOK observation instrument]", n.d.).

In this section, relevant assessment criteria of process evaluation in literature are examined, as well as practical examples where these criteria are used. Based on these criteria and practical examples, an assessment strategy that can be used to evaluate students in the iSTEM-course is designed. The assessment strategy aimed at non-subject-specific aspects of the STEM course, such as planning, improvements, collaboration, etc, therefore content-specific criteria were not included. This knowledge can be tested separately in the traditional courses. Moreover, the presented assessment materials can be used across curricula and projects, so that domain-general strategies stay within their context (R. E. Bennett, 2011; van Petegem & Vanhoof, 2002).

4.1.1 Literature review

To start the design of an appropriate assessment strategy for students working on iSTEM-design challenges, a literature review was carried out. The focus of the developed assessment instrument is on process evaluation, which implies follow up students while working on a design-challenge. Therefore, we searched for literature on assessment that have common aspects with our approach, such as Project Based, Problem Based and Inquiry Based Learning. We only performed a narrative review in order to get a brief overview (Uman, 2011). Based on this literature, we formulate criteria for the assessment of STEM-design challenges and review some examples in literature against these criteria.

Criteria for process evaluation

In order to select relevant ingredients, scientific educational papers are read, and the assessment aspects extracted. The educational papers are found by following searching terms: assessment, portfolio, peer assessment, formative assessment. To be considered relevant, aspects should provide an added value, such as feasibility, differentiation and provide more information than knowledge

tests. Based on these issues, criteria for analysing assessment methods are extracted. These nine criteria are:

- input of the students,
- observations of the tutor,
- peer assessment,
- transparency,
- grade in dialogue with the students,
- feedback,
- grading scale,
- multiple assessors, and
- team effectiveness.

These criteria are explained in more detail, motivated and linked to the literature below.

Shepard (2000) argues that it is essential to collect students' work and journals, in order to assess more open-ended performance tasks, in which they have to reason critically, solve complex problems and apply their knowledge in real-world contexts. This *input of the students* should make their reasoning clear. Self-and peer-assessment is also a way to receive input of the students, but is treated separatly in this study.

Another essential element for data gathering according to Shepard (2000), Pellegrino and Chudowsky (2003) and Doppelt (2009) is the *observation of the students by the tutor*. These data can be gathered by informal, on-going assessment. This allows teachers to provide assistance as part of the assessment. The hard part of this assistance as part of the assessment is that the balance between the mentor's roles of coach and assessor is hard to find and should be carefully maintained (Driessen, Van Der Vleuten, Schuwirth, Van Tartwijk, & Vermunt, 2005). The mentor should coach the students in a way that their learning process is maximized. On the other hand, the mentor should evaluate this learning process of the students. These roles conflict.

A criterion to analyse the assessment is *peer assessment*, since it is an efficient method to assess students' learning in a problem-based learning setting (Gijbels, Dochy, Van den Bossche, & Segers, 2005). So far, peer assessment is not established in Flemish secondary schools. Nevertheless, a lot of benefits can

be coupled to peer assessment (Topping, 1998). It increases variety and interest, activity and interactivity, identification and bonding, self-confidence and empathy for others (Topping, 1998). On top of that, peer assessment can develop teamwork skills and promote active rather than passive learning. It can also develop verbal communication skills, negotiation skills and diplomacy. Although students might have a hard time during the peer assessment process, because their opinion is socially influenced and they are not used to assess their peers, they admit that it is helpful to develop critical thinking. For the teacher, peer assessment can help with the differentiation of individual contributions to small-group projects. In order to get honest evaluations, it is important to make the peer review process simple. Possible aspects to assess team members are: ability to work in group, amount of effort, dependability, intellectual contribution and overall contribution to the project (Subramanian, 2015). Coupled to peer assessment, self-assessment can be interesting for both student and teacher to influence learning (Loyens & Gijbels, 2008; VLOR-Vlaamse onderwijsraad-Raad secundair onderwijs, 2004). It increases students' responsibility for their own learning and makes the relationship between teachers and students more collaborative. An extra benefit seems that students become more interested in the criteria and substantive feedback than in their grade per se (Shepard, 2000). Although self-assessment is perceived even more difficult for students than peer assessment, it tends to be more reliable than peer assessments (Topping, 1998).

In several research publications, *transparency*, *feedback*-mechanisms and use of *grading scale* of a given assessment strategy are described together. An assessment strategy is transparent when guidelines and rubrics are provided and when the evaluation criteria are explained to the students in advance (Gulikers, 2006; Hattie & Timperley, 2007). Driessen et al. (2005) and Bernholt et al. (2013) found that evaluation tools such as guidelines and rubrics and formative assessments to guide the feedback to the students (Mostrey, 2011) and shape instructional decisions are essential elements in the assessment process. According to Shepard (2000) and Hattie and Timperley (2007), effective assessment provides feedback specifically targeted toward improvement. On top of this, Shepard (2000) notices that students become more interested in evaluation criteria when they have to assess themselves. Therefore it is important to have explicit assessment criteria. The criteria should be that transparent so that students can learn to evaluate their own work in the same way that their teachers would. To create this transparency, displaying learning goals in five levels, argued with description and grading scale, is a possible solution (VLOR-Vlaamse onderwijsraad-Raad secundair onderwijs, 2004).

Driessen et al. (2005) found that student involvement in the decision process is essential in the assessment process. This *grade in dialogue with the students* is important in order to ensure student's commitment and incorporate their view

on their own performance (Chang & Tseng, 2011). When students are involved in the decision process about their grades, their dedication is higher. This kind of discussion also allows the student to communicate a different point of view to that of the mentor. The discussion between the mentor and the student will be enriching for both.

Asking *multiple assessors* to evaluate is an effective strategy in order to improve interrater reliability in assessment, according to Driessen et al. (2005). The different raters should have a good overview of the students' skills, competences and learning process. To accomplish this, the raters should observe and be able to evaluate the students. This is time consuming and thus only feasible when multiple teachers are given the iSTEM class together.

To completely evaluate, all pillars of the STEM@school approach (integration, inquiry and design, problem-centered and cooperative learning) should be covered. One of them is cooperative learning. So also the functioning of the collaborative group should be assessed. This *team effectiveness* can be evaluated using three outcomes: Creativity, collaboration and productivity (Brewer & Mendelson, 2003).

Practical examples

The nine criteria selected above, summarized in Table 4.1, serve the baseline for reviewing practical examples described in literature. We searched for papers with the keywords Problem Based, Project Based or Inquiry Based learning in combination with assessment. A review paper (Belland, French, & Ertmer, 2009) that reviewed the same kind of papers we were looking for, but on other criteria, such as validity and reliability of the assessment instrument, was found. We used this review paper as a source of inspiration, selected the papers that were relevant to our search based on the teaching approach, content of assessment and feasibility in classrooms, and added a few recent papers.

In Table 4.1, some practical examples are collected and evaluated based on the chosen criteria. It is hard to find literature on assessment methods that can be used in classrooms. Most assessments found in literature use a written report or exam to assess the problem solving skills of students. Half of the examined assessment strategies use input of the student as well as observations of the teacher. This combination can be very useful, because it combines artifacts and written reports of the students as well as their attitudes observed by the teacher. Few strategies use peer evaluation or feedback. Grades given in dialogue with pupils is not used in any of the practical examples.

Table 4.1: Literature review of some assessment criteria

		Input of the students	Observation of the tutor	Peer assessment	Transparancy	Grade in dialogue	Feedback	Grading scale	Multiple assessors	Team effectiveness
PRACTICAL EXAMPLES	Université de Sherbrooke (Hebert & Bravo, 1996)		x		x		x	x		
	School of Economics and Business Administration (Maastricht) (Segers, 1997)	x								
	School of Educational Science (Leuven) (Segers & Dochy, 2001)	x	x	x	x			x		
	Bowman Gray school of Medicine of Wake Forest University (B. F. Richards et al., 1996)		x					x	x	
	Training of doctors (Melbourne) (Sanci et al., 2000)	x	x				x		x	
	STEM project based learning (Capraro, 2008)	x	x	x	x					
	School in the southwestern United States (Pedersen & Liu, 2002)	x						x	x	
	Harvard Medical school (G. T. Moore, Block, Style, & Mitchell, 1994)	x	x					x	x	
	Developed iSTEM assessment method (This work)	x	x	x	x		x	x	x	x

4.1.2 First draft of an assessment strategy

Based on the criteria extracted from literature in the previous paragraph, an assessment strategy to evaluate student performance in iSTEM-design challenges is developed. This strategy is three dimensional: evaluation on group level, on individual level, and self and peer assessment. The assessment strategy is multidimensional because teachers indicate they want to assess group work as well as the individual student in order to grade each student individually. The evaluation instrument consists of rubrics and is designed as an iteration between bottom-up and top-down approximation. The bottom-up started by the iSTEM-design challenges. The top down approach started from the known literature. The decision to use a rubric for assessment is supported by previous research. As stated by S. G. Puente and Jansen (2017) and Lönngren, Adawi, and Svanström (2017), well-described rubrics make the assessment more transparent and they can be used as a tool for learning and giving feedback (VKW-VVKSO, 2005;

"GOK Observatie-instrument [GOK observation instrument]", n.d.). Moreover, rubrics are suitable to support inquiry-based learning (Bernholt et al., 2013). In Table 4.1, this new developed iSTEM assessment strategy is compared with other practical examples from literature, according to the criteria from literature, explained in the previous section.

An overview of the different parts of the new developed assessment strategy can be found in Table 4.2.

Table 4.2: Overview of the assessment strategy

	Frequency	**Who**	**How**	**To assess**
Group Evaluation	Weekly	Tutor	5 levels, described in rubrics	Collaboration To handle problems
Individual Evaluation	Beginning Middle End	Tutor	5 levels, described in rubrics	Schedule Adaptations Improvements How it went
Self- and peer assessment	Middle End	Students	Divide a total of points to the team members and themselves	Creative ideas Active participation Honour commitments

Group level

As part of the process, the student team's effectiveness should be assessed. The group can be evaluated by observations of the teacher. The teacher assesses the group on their collaboration and how they handle problems as a group, as can be seen in Table 4.3. The grading scale is a rubric divided in levels. Each level is described, which makes the evaluation more transparent. This evaluation is suggested to be done on a weekly base when groups are working on the iSTEM design challenge.

Individual level

The individual evaluation of the student's process is performed with short reports, written by the students in the beginning, middle and end of the module. These reports are assessed using the rubric presented in Table 4.4 and Table 4.5. Table 4.5 is an assessment when the project is finished. The assessment includes the critical view students have on their own planning and whether or not they can estimate what change are necessary. So, following the planning is

Table 4.3: Rubric on the group level

	Level 1	Level 2	Level 3	Level 4	Level 5
Collaboration	There is a lot of arguing within the group, so no consultation is done, and everyone does what he \she thinks needs to be done	One leader decides who will do what, without listening to the rest of the group.	Because of disagreements in the group, the group decides to give everyone an individual task.	Sometimes, discussions get tough, but eventually the group can continue the work as a group.	The collaboration proceeds smoothly and discussions are solved in a calm way
Handle problems	The group doesn't think when problems arrive, the team doesn't find a solution and addresses directly to the tutor, even with the smallest problem.	The group doesn't think thoroughly about solutions for emerging problems. The first conceived solution seems the best, which is mostly not the case.	The group thinks thoroughly about solutions for emerging problems, but needs always confirmation from the tutor.	The group thinks thoroughly about solutions for emerging problems. When no good solution comes up, the group waits too long to get advice from the tutor.	The group thinks thoroughly about solutions for emerging problems. When no good solution comes up, the group addresses to the tutor in time, so they won't waste too much time

not the most important thing, being critical about it is, especially as a novice in creating plannings. As such, it is possible to assess the process they go through.

Self and peer assessment

To avoid peers overrating each other (Topping, 1998) or giving each group member the same score, an alternative self and peer assessment is used. Students have to give themselves and their team members a score on three different topics: creative ideas, active participation to design and meet to the agreements. Extra questions can help students to give a correct score. For creative ideas, following questions can be posed. Who has the most original ideas? Who has multiple solutions? For active participation to design, following question could be posed. Who builds the design? Who thinks about the design? Who dares to think critical about the design? Grading how they meet the agreements can be done by following question. Who is able to comply with the agreements within the group?

Grades can be chosen free, but for each topic only a limited total of total points can be distributed. The total point should not be dividable by the number of group members. For example, if you have a group of four students, the total points that can be distributed are 15. So students cannot score every group member the same.

Table 4.4: Individual assessment (part 1)

		Level 1	Level 2	Level 3	Level 4	Level 5
After week 1	Realistic schedule	The schedule is definitely not feasible in time span and order.	The schedule is feasible in time span, but the order is not correct.	The schedule is not feasible in time span, but the order is correct.	Most of the schedule is realistic, although some steps have an incorrect time span.	The schedule is definitely feasible in time span and order
	Completeness schedule	The schedule contains (almost) no intermediate steps to reach the final goal.	The schedule contains irrelevant intermediate steps to reach the final goal.	The schedule contains some good and some irrelevant intermediate steps to reach the final goal.	The schedule contains most of the intermediate steps to reach the final goal.	The schedule contains all of the necessary intermediate steps to reach the final goal.
After week 3	View on own schedule	The student can't situate his work in his own schedule.	The student has troubles situating his work in his own schedule.	The student can situate some aspects of his work in his own schedule.	The student can situate most aspects of his work in his own schedule.	The student can perfectly situate his work in his own schedule.
	Adapt schedule	The student can't tell how and when he had to adapt the schedule.	The student can tell when he had adapted the schedule.	The student can tell when and where he adapted the schedule, but has trouble to explain how and why.	The student can tell how, when and where he adapted the schedule, but has trouble to explain why.	The student can perfectly tell when, where, how and why he has adapted his schedule.
	Improvements	The student can't make any suggestions to improve in the future.	The student makes suggestion for improvement at aspects who are already good.	The student makes suggestion for improvement at aspects, but these won't improve anything.	The student makes good suggestions for improvement, but forgets some aspects.	The student makes good suggestions for improvement.

Table 4.5: Individual assessment (part 2)

		Level 1	Level 2	Level 3	Level 4	Level 5
After week 6	Went well/ went wrong	The student can't tell what went well and what went wrong during the process.	The student can only tell what went well, but forgets what went wrong.	The student can only tell what went wrong, but forgets what went well.	The student can tell what went well and what went wrong during the process, but forgets some aspects.	The student can perfectly tell what went well and what went wrong during the process.
	Improvements	The student can't make any suggestions to improve in the future.	The student makes suggestion for improvement at aspects who are already good.	The student makes suggestions for improvement at aspects, but these won't improve anything.	The student makes good suggestions for improvement, but forgets some aspects.	The student makes good suggestions for improvement.

4.1.3 Consulting experts

The assessment method was shown to four assessment experts in Flanders, all whom have been publishing in peer-review journals on topic of assessment. It was a conscientious choice to consult experts who are aware of the Flemish educational system, because they are in the best position to estimate the consequences in classrooms. The experts shared their knowledge and opinion about the presented assessment method with the help of a semi-structured, individual interview (Emans, 2002; Campbell et al., 2013).

The assessment methods are sent in advance to the experts and presented briefly before the interview starts. Subsequently, the assessment method is discussed in more detail, objective per objective. The discussed objectives are:

- Students work systematically;
- Students refer to relevant learning content;
- Students reflect on the assignment and look critically at the result;
- Students reflect on the assignment and look critically at the process; and
- Students formulate concrete (= practical/feasible) adjustments / suggestions towards the future.

The preconditions for the assessment strategy are:

- Feasible in a real classroom environment; and
- independent from learning content.

For each section and each of the assessment methods, the following questions are posed to the expert:

- Do you think this objective is adequately covered here?;
- Do you think the different levels are sufficiently described and different from each other in order to make a distinction?; and
- What adjustments would you suggest to test this objective even better?

The most common feedback of the experts was to use student-friendly language, so the rubrics can also be used as a tool for self- and peer-assessment. Another recommendation was to take an even number of levels, because the experts

argued that with an odd number of levels, everyone will be in the intermediate level. On top of that, it was recommended to only have one insufficient competency level and more sufficient levels. This with the argumentation that the distinction in insufficient levels is less necessary, in comparison to sufficient levels as they are more informative and motivating. A last recommendation was to provide multiple assessment methods, so that teachers could chose the method that fits best with their thoughts, teaching style and beliefs.

The recommendation to use student-friendly language and use rubrics for self- and peer-assessment is also supported by literature (Herro et al., 2017). Literature also confirms the suggestion to provide an even number of measures (Diefes-Dux, 2018).

4.1.4 The assessment strategy

Based on these suggestions, the initial assessment method is translated into three different assessment methods and further refined, each with the same underlying objectives. A focus in the assessment instruments is on the insights of the planning of the students, in order to follow their problem-solving process (Wallin et al., 2016). At the end of the process, also the result is taken into account (Wallin et al., 2016). The themes that come forward are the same as in the first draft of the assessment strategy, only rearranged into: draft planning, adjustment planning, collaboration and result. The assessment methods became checklists, performance lists in continua and rubrics (Heerink, 2011). Checklists are easy to go through, but are fragmented. Performance lists show the progress of a student, which is the heart of learning (Pellegrino & Chudowsky, 2003). Rubrics are descriptive and divided in categorical levels, and as such easy to read and interpret (van Petegem & Vanhoof, 2002; Bauer & Cole, 2012), but require more time-effort to design and use (Heerink, 2011). All methods contain the same self- and peer assessment, based on grading between -1 and 3. These assessment methods are presented as such to the teachers. Below, all methods are elaborated.

Self- and peer-assessment

The self-and peer-assessment is the same for all methods and based on van Petegem and Vanhoof (2002). Students have to assess themselves and their peers in four categories:

- Contribution to a positive atmosphere in the group;

- Contribution to group discussions;
- Contribution to the product; and
- Willingness to listen to other members of the group.

Students need to give a score to themselves and their peers, ranging from -1 to 3. This is an odd number of levels, but with the average out of the center, so students do less tempted to choose the average. The meaning of each score can be found below:

- 3: The contribution of the student for this theme is above average.
- 2: The contribution of the student for this theme is average.
- 1: The contribution of the student for this theme is below average.
- 0: The student has no contribution for this theme in the group.
- -1: The student counterworks the group for this theme.

So students give themselves and their peers in the collaborative group scores for each of the categories above. Teachers can decide how this score will count in the final score of the students.

Checklists

When teachers decide to use the checklists, they receive some competencies and criteria, of which they need to judge whether the student or the group has reached it (1) or not (0). The criteria and competencies are listed below. Teachers can choose themselves whether students need to make a short report or presentation about these topics, or to assess this through observation.

Draft planning

- The presented planning is feasible within the provided time frame.
- The presented intermediate steps have a logical sequence.
- The presented intermediate steps are relevant.

Adjustment planning

- The students can explain in which phase of the planning the project is.
- The students can explain what needs to be adapted in the planning.
- The students can explain why the planning needs to be adapted.
- The students can explain when they adapted the planning.
- The students can explain which phase of the planning needs to be adapted.
- The students can reflect about possible improvements of the planning during the process.
- The students can suggest relevant and feasible improvements.

Collaboration

- Discussion are socially correct.
- Discussion are constructive.
- The group works active towards a solution of the problem. Independently, but they call for help when necessary.
- Students act upon feedback.

Result

- Students can reflect on what went well, during the whole process.
- Students can reflect on what went wrong, during the whole process.
- Students can suggest relevant and feasible improvements.
- Students are critical about themselves.
- Students are critical about others.
- Students can tell how the different STEM-components have worked together while accomplishing the challenge.

Performance lists with continua

When teachers decide to use the performance lists, they receive a file with sliders which can range from the worst until the best performance for the criterion or competency. The ends of the continua are described below. Teachers can choose themselves whether students need to make a short report or presentation about these topics, or to assess this through observation.

Draft planning

- The presented planning is not feasible within the provided time frame. ↔ The presented planning is feasible within the provided time frame.
- The presented intermediate steps have no logical sequence. ↔ The sequence of the intermediate steps is perfectly logical.
- The presented intermediate steps are totally not relevant. ↔ The presented intermediate steps are all relevant.

Adjustment planning

- The students can't explain in which phase of the planning the project is. ↔ The students can perfectly explain in which phase of the planning the project is.
- The students can't explain what needs to be adapted in the planning. ↔ The students can perfectly explain what needs to be adapted in the planning.
- The students can't explain why the planning needs to be adapted. ↔ The students can give a good explanation why the planning needs to be adapted.
- The students can't explain when they adapted the planning. ↔ The students can perfectly explain when they decided to adapted the planning.
- The students can't explain which phase of the planning needs to be adapted. ↔ The students can explain which phase of the planning needs to be adapted.
- The students don't reflect about possible improvements of the planning during the process. ↔ The students reflect about possible improvements of the planning during the process.
- The students are not able to suggest relevant and nor feasible improvements. ↔ The students can suggest relevant and feasible improvements.

Collaboration

- Discussion are not socially correct. ↔ Discussion are socially correct.
- Discussion are destructive. ↔ Discussion are constructive.
- The group doesn't works active towards a solution of the problem. ↔ The group works active towards a solution of the problem. Independently, but calls for help when necessary.
- Students ignore feedback from others. ↔ Students act upon feedback.

Result

- Students can't reflect on what went well, during the whole process. ↔ Students can reflect on what went well, during the whole process.
- Students can't reflect on what went wrong, during the whole process. ↔ Students can reflect on what went wrong, during the whole process.
- Students can't suggest relevant and nor feasible improvements. ↔ Students can suggest relevant and feasible improvements.
- Students can't be critical about themselves. ↔ Students are critical about themselves.
- Students can't be critical about others.↔ Students are critical about others.
- Students can't tell how the different STEM-components have worked together while accomplishing the challenge. ↔ Students can tell how the different STEM-components have worked together while accomplishing the challenge.

Rubrics

The assessment method consisting of rubrics, consists of four themes: Draft planning (Table 4.6), Adjustment planning (Table 4.7), Collaboration (Table 4.8) and Result (Table 4.9). Teachers can choose themselves whether students need to make a short report or presentation about these topics, or to assess this through observation.

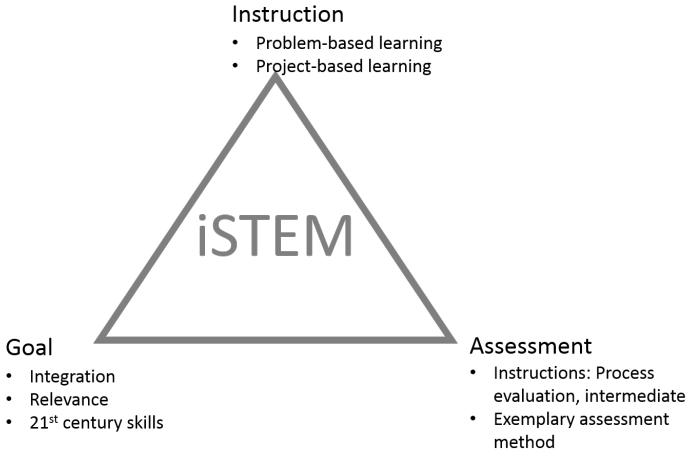
4.2 Choice and implementation of an assessment strategy in classes

As mentioned before, authentic problems are the starting point. By trying to solve them, students experience that problem-solving processes are seldom linear (Bernholt et al., 2013; Capraro, 2008; Guzey, Moore, Harwell, & Moreno, 2016) and it obliges students to use their knowledge from the traditional courses and construct new knowledge. Moreover, this method allows students to take risks and leaves room for making mistakes (Brewer & Mendelson, 2003; DeLuca & Lari, 2013).

As constructive alignment states (Biggs, 1999, 1996; Gibbs & Simpson, 2004; Cain et al., 2018), when goals and teaching approach are adapted, the assessment strategy should also be adapted in order to connect with the teaching approach and goals. So, in the case of iSTEM, an ongoing, integrated assessment is the most suited, because it gives the best representation of students' competencies, since it is project-based, and as such in line with the teaching approach (Czerniak et al., 1999).

The STEM@school project team (Thibaut, Ceuppens, et al., 2018) developed the iSTEM goals as well as the iSTEM teaching approach with matching learning materials together with teachers. After the development, the learning materials were handed to other teacher teams to implement. For the assessment method, some general guidelines about frequency and integration of assessment, and the assessment method were provided. These are merely offered as examples that they could use or adapt to their teaching needs, if considered desirable. As a consequence, teachers have a lot of freedom in choosing their assessment method, since they only received some instructions and an exemplary assessment method, as presented in Figure 4.1. This makes this study different from other studies about assessment in project- and problem-based learning, where the assessment method is imposed to the teachers, for example in the study of S. G. Puente and Jansen (2017). Previous research has also shown that a course relying on constructivist principles, requires more deep-level assessment, which means conceptual knowledge and skills should be tested instead of repetitious exercises (Loyens & Gijbels, 2008). So, we want to investigate how teachers adopt the given freedom, how they integrate deep-level assessments and which assessment methods they chose for what reasons. This will provide insights into pedagogic-didactic reasoning related to integrated STEM.

Figure 4.1: Theory of constructive alignment applied to iSTEM



4.2.1 Theoretical framework

The theory of constructive alignment claims that goals, instruction and assessment should always be connected with each other (Biggs, 1999, 1996), as shown in Figure 4.1, because this alignment improved student outcomes (Cain et al., 2018). So, when the instruction is adapted, for instance using an integrated STEM teaching approach, assessment should also be adapted. Otherwise, it is hard to detect the effects of the new teaching approach, because if there is no alignment new competencies will not be assessed (Marx et al., 2004; van de Watering, 2006). Moreover, students will only learn the concepts and skills that will be assessed (Walsh, 2007; Biggs, 1996; Nightingale, Carew, & Fung, 2007; Dochy et al., 2003; Meyers & Nulty, 2009), which results in a surface approach to learning when the alignment is not fulfilled (Biggs, 1999; X. Wang et al., 2013) and so when new competencies are not assessed, students will not acquire them.

Constructive in constructive alignment incorporates the fact that students need to build their knowledge. They need to be actively involved and construct their knowledge by experiences and learning activities (Walsh, 2007).

Assessment methods aligning to constructive learning theory can be analysed based on the framework of Segers et al. (2006). The seven characteristics of Segers et al. (2006) can be placed on continua, since different levels of implementation are possible. We chose the use these characteristics instead of the criteria of the previous section because these characteristics are more

feasible for qualitative research. On top of that, the previous characteristics were used to analyse assessment strategies in literature and now the assessment strategies in classes need to be examined. These characteristics posed by Segers et al. (2006) are:

- authenticity,
- number of measurements,
- levels of comprehension,
- dimensions of intelligence,
- relation to the learning process,
- responsibility, and
- goal.

Authenticity refers to the format of the evaluation and can range from decontextualised to contextualised assessment. Decontextualised assessment refers to objective tests without authentic problems, but just recapturing the theory or sec application of it. Assessment forms in which this mostly occurs are short answer, multiple choice, fill-in blank. Contextualised assessment on the other hand implies an authentic problem to solve, in which different solutions and paths to the solutions are applicable, when given a thorough argumentation. Assessment formats that support this kind of thinking are for example the use of portfolio (Driessen et al., 2005; Doppelt, 2009; Chang & Tseng, 2011; Biggs, 1999) or logbook (Leslie & Gorman, 2017), or performance assessment.

The second continuum, of the characteristic *number of measurements*, refers to the frequency of assessment moments and can range from a single measurement to multiple measurements.

Levels of comprehension focuses on the different levels of competence, ranging from low to high. Low level comprehension implies knowledge reproduction, whereas high level comprehension is defined by higher-order and 21st century skills.

Dimensions of intelligence are the subject of the next continuum. This continuum ranges from few to many. According to Gardner and Hatch (1989), each human being is capable of seven relatively independent forms of informations processing. These are logical mathematical, linguistic, musical, spatial, bodily-kinesthetic, interpersonal and intrapersonal. Gardner and Hatch (1989) explains these forms by comparing them to professions and

attitudes. For instance, the logical mathematical form is typical for scientists and mathematicians, poets and journalists are representations of the linguistic form, composers and violinists of the musical form, navigator and sculptor of the spatial form, dancer and athlete of the bodily-kinesthetic form, therapist and salesman of the interpersonal form and finally a person with detailed accurate self-knowledge is a representation of the intrapersonal form.

A fifth characteristic is focusing on the *relation to the learning process*, which means the embeddedness of the assessment in the learning process. This continuum can range from isolated assessment to integrated assessment. By integrated assessment, we mean that assessment is not separated from other learning activities, but is embedded.

The next characteristic refers to who is *responsible* for the assessment. This can range from teacher to student and any combination with significant others, resulting in self- and peer- assessment or assessment by an external person.

A last continuum ranges from assessment of learning to assessment for learning and is referred to as *goal of the assessment*. Assessment for learning refers to the regulation of the student's learning, while the goal of assessment of learning is to decide about student's progress and competencies. In the model of Segers et al. (2006), metacognition is not explicitly mentioned. In our interpretation of the model, this is included in assessment for learning, because metacognition implies reflection about learning and as such facilitates learning for the future.

With the study in this section, we want to examine how students, enrolled in the iSTEM course, are assessed. Thereby we take into account the perceptions of students and teachers. The overall question is: How do teacher teams align goals, instruction and assessment, and make sure this triangle is constructive for the students, meaning it helps students in their learning? More precisely, the following research questions are posed:

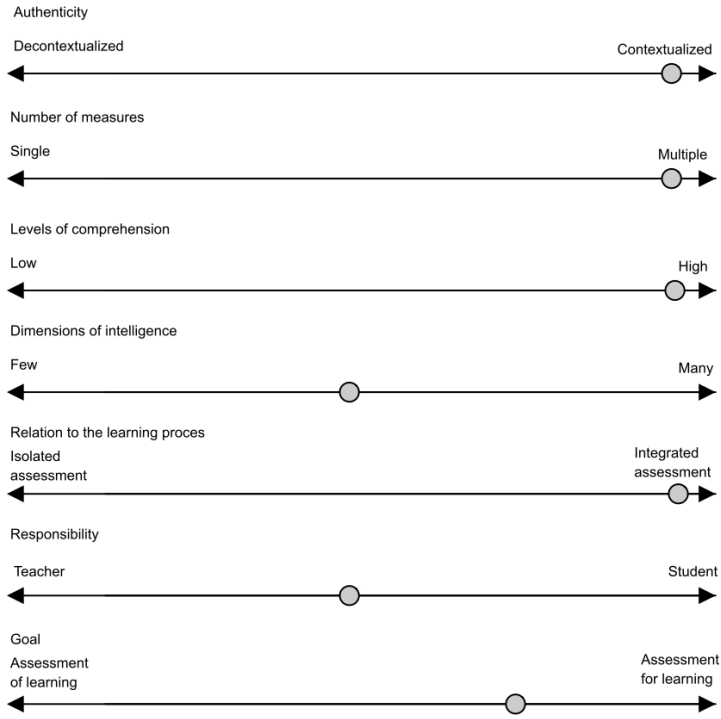
1. Which assessment method do teachers choose in the iSTEM course?
2. Which theoretical grounding do they use to justify their choice for the assessment method?
3. What are the catalysts and barriers that teacher teams experience to implement a new assessment method?
4. How do students experience the assessment method related to the iSTEM classes?

Although teachers receive the same learning modules and assessment instrument, we expect their assessment methods to vary widely. Nevertheless, we hypothesize

that the focus is on assessment for learning, given the directions of suggestions, examples of assessment methods and the framework of STEM@school.

Based on the characteristics of iSTEM, the researchers of STEM@school hypothesize the assessment method to look like Figure 4.2 on the scales of Segers et al. (2006). This hypotheses is supported by literature findings, as explained next. Authenticity is an important characteristic when assessing. More contextualized assessment methods, such as portfolios, enhance deeper approaches to learning by students, when compared with multiple-choice tests (Segers, Gijbels, & Thurlings, 2008). This is also supported by Schuwirth et al. (1999), who claims that a diagnostic test with short-answer and multiple-choice type of questions are inadequate to assess students' problem solving ability and by Hassan (2011), who claims that engineering assessment tasks are laboratory work, project assignments, final examination, presentations, performances and exhibitions. Therefore we expect the assessment method connected to the iSTEM teaching approach to be contextualised rather than decontextualised. Gijbels et al. (2005) stated that a valid assessment method in a problem- and project-based teaching method should evaluate students' problem-solving competencies in an assessment environment that is congruent with the PBL learning environment. This is why an assessment of iSTEM students should include a high level of comprehension and is integrated. This claim is strengthened by Montrieux (2012) who found that integration of the assessment encourages ownership, active involvement, deeper learning and constructive feedback. Also van Petegem and Vanhoof (2002), van de Watering (2006), Shepard (2000), Montrieux (2012), Miedijensky and Tal (2009) and Birenbaum et al. (2006) support integrated assessment as part of an assessment culture. An assessment culture strongly emphasizes the integration of assessment and instruction (Birenbaum, 1996). Assessment strategies that are not embedded in the learning, are not part of an assessment culture. Another characteristic of this assessment culture is the active role of the student. So the responsibility should be more in hands of the student (van Petegem & Vanhoof, 2002; Rosenshine & Meister, 1992; Greeno et al., 1996) than it is nowadays. Since the students take more responsibility for their own learning, they also appeal other than only the logical mathematical dimension of intelligence (van Petegem & Vanhoof, 2002), such as the inter- and intrapersonal dimensions. Since students also have to report on their work and design artifacts, the linguistic and spatial dimensions are also important. These developing dimensions should also be assessed. Not only different dimensions should be assessed, they also should be assessed multiple times, to get a clear view on students' abilities (National Academies of Sciences, Engineering, and Medicine, 2017). The decision to not only assess for learning, but also of learning, is supported by Segers (1997) and Birenbaum et al. (2006). They found indications that despite the growing interest in alternative assessment, the measurement of conceptual understanding

Figure 4.2: Desired characteristics of the assessment method based on iSTEM design



still is important.

As stated by National Research Council (2001), research is necessary to explore how new forms of assessment can be made feasible in classrooms and how they affect student learning, teaching practices and educational decision making of secondary school teachers. This paper can provide some answers for the aspects about feasibility, student learning and teaching practices. Teachers receive freedom in choosing and adapting new forms of assessment methods in a innovative iSTEM learning environment, encountering 21st century skills. Furthermore, this study incorporates the experience of the students with this assessment methods, because the perception of the teacher depends on the reaction and cooperation of the students. As a consequence, the experience of the students is an important factor to take into account.

4.2.2 Method

Setting

As mentioned before (Chapter 1), in the Flemish educational system, educational objectives are imposed by the government. However, teachers have a lot of freedom in choosing how they organise teaching and learning to achieve these objectives. Furthermore, teachers are responsible themselves to evaluate whether each student has achieved the objectives by means of classroom assessments (van Petegem & Vanhoof, 2002). No central exams are organised in Belgium, so the decision on whether a student passes, is the responsibility of the teacher teams in the schools. This implies teachers can choose, how they assess the students during their course. This gives a lot of freedom to the teachers, but implies also a lot of responsibility.

Participating schools implemented a new course, iSTEM, containing learning modules developed in a cooperation between teachers, researchers, engineers and scientists, based on the STEM@school framework. This iSTEM course is implemented in different curricula, general and technical, that exist in Flanders. In this course, students need to solve a real world problem through research and design. For instance, students are confronted with a STEM-design challenge or problem (Berland, 2013; Thys et al., 2016) in which they need to address their knowledge and skills of all STEM-disciplines, in order to complete the challenge. Since participating in research and design requires scientific, mathematic and technological knowledge, the content of these courses is rearranged in order to obtain alignment between the separate courses and the iSTEM course. Furthermore, teachers in the iSTEM course adopt the role of a coach instead of an omniscient teacher. This teaching approach focuses on other aspects of learning, such as problem solving skills, taking risks and making mistakes. So besides the focus on integrating knowledge, the iSTEM course also provides attention to competencies and attitudes. These integrating thinking strategies, implied by the newly proposed teaching approach, are not common in the current classes in Flemish secondary education, so teachers have a hard time to assess these strategies, especially because it requires more than product assessment, process assessment should also be included (Hassan, 2011).

Procedure

In a first phase of the STEM@school project, teaching/learning materials were designed and made available to teachers. Based on these materials, a method for student assessment aligned with the newly design teaching method was

proposed to the teachers. Consequently, the proposed assessment method is handed to the teachers after one year of implementation.

The distribution of the learning modules and assessment method can be seen as a structured intervention. Several information moments were organised to explain the learning modules and assessment method. On top of that, help desk sessions were provided. Most of the participants of these information sessions were not involved in the development of the learning materials or assessment method. Therefore, this extra information about the learning modules and assessment method was necessary in order to translate the assessment into concrete actions or activities (Gulikers, 2006; Aschbacher & Alonzo, 2006). Teachers were also made aware that adaptations were allowed, in order to make the assessment method more valid, reliable or feasible. This is in line with the suggestions of R. E. Bennett (2011) and Shepard (2000) that, in order to give teachers ownership of the materials, they should be able to adapt materials, but they need the proposed method as a model to do so. This adaptation is also suggested to close the gap between research and classroom practice (National Research Council, 2001). As a consequence, teachers have the freedom to choose their assessment method, with the given information and exemplary assessment method in mind (R. E. Bennett, 2011).

Data collection

In order to find out about the assessment methods used during iSTEM in classroom settings, teacher interviews are conducted, student questionnaires are administered, and assessment instruments and field notes are collected. Interviews are conducted with teacher teams about their assessment practice in the iSTEM course. But, since relying on self-reported practices of the teachers does not always create a realistic image, triangulation is recommended (Thurmond, 2001). In order to gather the necessary information for triangulation, different sets of data are collected, also referred to as data source triangulation (Carter et al., 2014). So during the interview, the assessment instruments of the teachers are also collected and discussed in order to find a match between the assessment strategy and instruments of the teacher. Moreover, along with the teacher interviews, questionnaires are administered to the corresponding students, to grasp their impressions of the used assessment. The data collection is completed with field notes which have been taken during the past three years, about the instruction and implementation of the iSTEM material. These field notes were taken during school visits, intervision moments with other schools and discussions with teachers, coordinators and principals.

Interviews The teachers were interviewed at a moment of their choosing. The interview was set-up as a semi-structured interview with open-ended questions and the whole interview was recorded (Emans, 2002; Campbell et al., 2013; Van Someren et al., 1994), as presented below. The goal was to investigate used assessment methods in the iSTEM course. To be more precisely, questions rose about which assessment methods are used, why the teachers chose it and how they experienced it, corresponding to research questions one, two and three. Teachers were told beforehand that the interview is intended to map and understand current assessment practices. This is important to avoid socially desirable answers (Emans, 2002). It was also a conscientious choice to do face-to-face interviews and no interviews by phone. The non-verbal language is too important to miss (Emans, 2002).

The interview started by asking the background of the teacher team. Next, the used assessment methods, content of the assessment, frequency of measurements and number of assessors are discussed. After that, their impressions about the used assessment methods was questioned. We asked for the positive and negative impressions. When the used assessment methods in classroom practice are fully discussed, we asked for their opinion on the proposed assessment methods. This question was posed in the end of the interview to keep focus on their assessment practice instead of the proposed one. The final question was about the opinion of the school about assessment and the support they receive for that. This sequence of questions was chosen to comfort teachers and start with facts before asking for opinions.

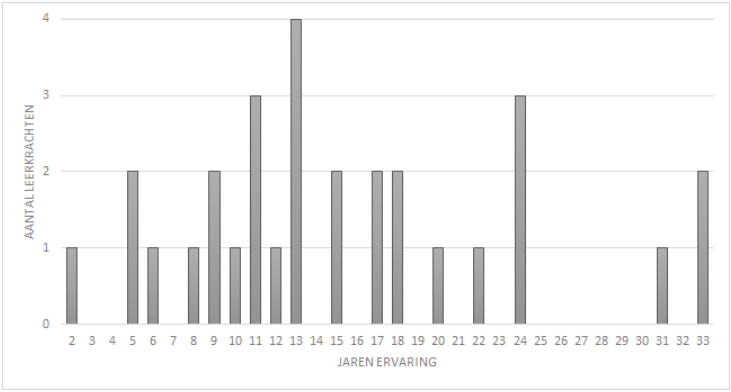
- What is your name?
- What is your education?
- How many years of teaching experience do you have?
- Did you ever had another job than being a teacher? If so, which one and how long?
- Which courses are you teaching at the moment?
- Which assessment method do you use in iSTEM?
- Who assesses who? Does the teacher always assesses the pupils? Do the pupils assess each other?
- How many times do you assess the pupils?
- How many teachers are assessing the pupils during the iSTEM course?

- Did you showed or gave the assessment instrument beforehand to the pupils? If so, did the pupils adapt their behavior to it?
- What are your learning goals in the iSTEM course?
- What are the advantages of the assessment method of your choice?
- What are the disadvantages of the assessment method of your choice?
- Why did or didn't you use the proposed assessment method?
- The proposed assessment method includes peer assessment, do you have any experience with that?
- The proposed assessment method includes clear feedback to the pupils, do you have any experience with that?
- Have you used already any kind of alternative assessment?
- What was missing or was not that good at the proposed assessment method?
- What is the school's point of view about alternative assessment?

Questionnaires In order to answer research question four about the students' experience, questionnaires are given to the them. Although an in-dept interview with the students would provide more insights in their experience with the assessment, a short questionnaire results in a high response rate and require minimal effort of the students (Leslie & Gorman, 2017). As a consequence, this questionnaire is the most efficient way to obtain feedback from the students. These questionnaire consists of five short questions:

- Can you describe how you are assessed in the iSTEM course?
- On a scale from 1 to 10, with 10 being a perfect match, to what extent do you feel this assessment method is in line with the way of teaching during the iSTEM course?
- Do you sometimes receive verbal feedback?
- Do you take into account the given feedback for assessment moments in the future?
- Do you take into account the course goals during the course?

Figure 4.3: Distribution of the years of experience of the teachers



The goal of this questionnaire is twofold. First, the questions serve to check whether the assessment experiences of the students are in line with the aimed assessment method of the teacher. Second, we want to examine how students are experiencing the assessment.

Participants

Interviews were conducted in 12 schools with 20 teacher teams, in total 30 teachers. The schools and teacher teams were randomly selected out of 30 participating schools in the iSTEM project STEM@school. Teacher teams are defined as teachers who provide the iSTEM course in co-teaching. In most of the participating schools, the iSTEM course is given in co-teaching, so most of the times, the interviews were duo interviews. Sometimes, due to practical arrangements, different teachers teams of the same school contributed together to the interview. The teacher teams all taught iSTEM classes in secondary schools in the 3rd, 4th or 5th year (K9, K10 or K11).

Along the interviewees, ten teachers have an educational bachelor degree in science, mathematics and/or technology, twelve teachers are engineers, five teachers have another master degree in science or mathematics and four teachers have a technical professional bachelor degree. The years of teaching experience vary between two and thirty-three, with an average of 15,4 years. The distribution of the years of experience can be found in Figure 4.3.

Not only the teachers provided information, also their students filled in a survey. The survey is filled out by 269 students who follow the iSTEM course in grade 9, 10 or 11. The questioned students are 16 years old, on average.

Data analysis All interviews were transcribed verabatim and anonymized. Schoolnames are replaced by a letter, and teacher teams by the grade in which they teach. To analyse the interviews, the first author started to read one interview and deducted statements out of the text that reflect the assessment strategy and opinion about assessment of the teacher teams. Then, the next interview is read and statements are deducted out of it, and so on. When all interviews are analysed a first time for deducing statements, a vertical alignment is made. This vertical alignment results in ten themes. Some of these themes are questioned explicitly, other arose spontaneously when teachers were talking. In those themes, the statements are grouped and put into a matrix (T. Richards et al., 1995). The researchers had the opportunity to indicate for each statement whether or not this statement was confirmed (+) or debunked (-) by the teacher team. This indication is not only based on the interviews, but also the assessment instruments and field notes are taken into account. In order to prevent researchers bias, the matrix is filled out by the first author and another researcher, so not only data source triangulation is obtained, but also investigator triangulation (Thurmond, 2001). They each did an individual analysis. After individual analysis of the researchers, results are put together and discussed in order to come to complete agreement (Campbell et al., 2013). A part of this matrix can be found in Table 4.10, containing one theme and two schools.

Besides interviews of the teachers, assessment instruments and field notes, also student questionnaires are part of the data. These questionnaires are analysed separately, because the answers are compared to the statements of the teachers. Each question of the questionnaire is analysed separately. For the yes/no-questions, the number of affirmative, negative and partly affirmative answers is counted for each class. For the open answer questions, statements are made, in the same way as for the interviews. The statement can also be confirmed (+) or debunked (-).

So the analysis of the raw data, results in a filled out matrix. Then, this matrix is analysed horizontally and vertically. The horizontal analysis allows to compare schools for each statement separately. While the vertical analysis correlates the different statements within one school and teacher team. The results from the matrix are supplemented with excerpts from the interviews and questionnaires, because it describes the results more naturally and qualitative (Charters, 2003).

4.2.3 Results

The result section will first elaborate on the used assessment strategies by teachers. After that, the assessment practices of the interviewed teacher teams are placed on the seven dimensions of Segers et al. (2006). These dimensions are discussed one by one and the differences between the teacher teams are discussed. Moreover, the experiences of the students are coupled to the statements of the teacher teams. Finally, some remarkable findings from the interviews, which do not fit in the continua are presented.

So, the first part will provide an answer to research question 1 about the used assessment methods in iSTEM. The following section, will provide answers for the other three research questions about the reasons why teachers chose for it, the catalysts and the barriers, and this coupled to the experiences of the students in iSTEM.

Used assessment strategies

All the information given to the teachers, can result in four possible assessment strategies or a combination of these:

- use of proposed checklists,
- use of proposed performance lists with continua,
- use of proposed rubrics, and/or
- use of own assessment method.

Table 4.11 gives a representation of the used assessment methods. From this enumeration, it seems that teachers prefer a broad evaluation, meaning different assessments are combined. Teachers report, during the interviews, this results in more objective scores for the students, but at the same time in scores which are almost equal for the whole group. This can be explained by the fact that every student has an assessment method in which he or she can show his or her competencies in a better way, and scores better on that one, but less good on the others and so everyone obtains almost the same score. Teachers also report that this broad assessment with a lot of attention for feedback is very time consuming. And finally, teachers have the impression that some students can hide in the group, consisting of 3 to 5 students, since this course is only group work.

Another finding is that only 5 out of 20 teacher teams use or used one of the proposed assessment methods. Most teacher teams indicate they already found

a feasible assessment method, since the proposed method was distributed a year after implementation of the learning modules. Since implementation of the learning modules was already timeconsuming, they did not want to put extra time in changing the assessment method.

The teacher teams that used the proposed assessment methods gave some feedback on it. Teachers report on specific tools instead of on the assessment strategy itself. This indicates teachers struggle with actual implementation. One of the teacher teams that used the proposed assessment method in the past stated that they want to be transparent to the students and as a consequence want an online tool to show students' progress. Now they have to download and upload the document for each student group, which costs too much effort. This is illustrated below, by an excerpt from the interviews. The other teacher team that has used a proposed assessment method in the past preferred an assessment method that was more grafted to the curriculum guidelines. As a consequence, they stopped using the tool.

> We once experimented with the system you proposed, the one with the sliders. Actually, that was really good, because you could specify enough with one sentence each time. But we also work online, so we can share and so students can see it immediately. (...) It did not work in Google Docs, because you can't write macros in it. I adapted it for one part of the assessment, but that requires a lot of work. *(School A, K9-K10-teacher)*

Those teacher teams who did use the developed assessment instruments were enthusiastic about it, in general. Below are some excerpts from the interviews supporting this statement.

> I liked it that they could see for themselves that there was an evolution in it. *(School D, K10-teacher, used performance lists)*

> I think hard work is being done in the STEM class. And I think that is also due to the assessment and the way of follow-up and the way of giving feedback, I think. *(School D, K9-teacher, used performance lists)*

> I use this sheet as an example and then I can simply give points and estimate whether it is sufficient or not. I think that is very easy to work with. ... I even went searching for other rubrics to assess their presentation. *(School B, K9-K10-teacher, used rubrics)*

Despite the fact that we want to make a feasible assessment instrument, some of the teachers who used the proposed assessment method still argued it was too much of an administration to fill out.

Although the proposed assessment method is only used in a few teacher teams, it is still interesting to investigate how all teacher teams actually did the assessment in class. What assessment methods did they use and are there similarities with the proposed method?

A second finding is that teacher team D (K11) does not seem to do an assessment, based on the presented table. In fact, they do an assessment, but it is a special one. Before each grading moment, the teacher team has a discussion with each student individually about their work. After this conversation, the teacher team grades the student. They do not use any criteria or goals, but just look at the progress of the student.

A third finding is about the grading. All teacher teams, except for one, give grades to the different aspects they assess. So the total grade students receive for their iSTEM course is a calculation that takes all separate grades into account. Teacher team G (K9) applies a different assessment, but only gives a global score. The tests and tasks are scored separately, but students only receive one score for the presentation and project report. The teacher team prefers to adopt a more holistic assessment, as illustrated by the excerpt from an interview below.

> During grading, we take a look at the project. To the concept. (...) At this moment, grading is based on... How should I call it? On their project report, if that is complete. Based on the car they built. Grading the big concept. So we don't use partial points on that. *(School G, K9-teacher)*

A final finding about the chosen assessment methods in iSTEM classrooms is about school F. In this school, all teachers involved in experiments in science have discussed a rubric in order to assess the practical work and attitude during experiments. But, when asked for it, teachers tell reluctantly that they do not use it, as illustrated in the excerpt from an interview below. So teacher teams are making efforts to change assessment, but these changes do not always make it to the classrooms.

> **Interviewer:** How do you assess students during an experiment? Do you have a kind of rubric or something else?

> **Teacher:** Officially or in practice? (Laughing) We did construct a rubric last year with our teacher team. But I haven't used it, actually. *(School F, K10-teacher)*

Application of the assessment framework

In the section of the theoretical framework, a framework about assessment (Segers et al., 2006) is presented. In this section, we study how the framework is implemented in classroom practice. Each characteristic of the framework is discussed separately and teacher teams are placed on the continua of the framework based on the interviews, assessment instruments and field notes. These continua are helpful to answer research questions 1, 2 and 3 about the assessment practices of the teacher teams. A link with the experiences of the students is made in order to answer research question 4. On the continua, the most common classroom practices are indicated with a square and the desired practice is indicated with a circle.

As mentioned in the method section, ten themes arose from a bottom-up categorisation (Van Someren et al., 1994; T. Richards et al., 1995; Van Someren et al., 1994) of the interviews. In Table 4.12, the themes are presented horizontally and matched with the characteristics of the framework, presented vertically. More detailed criteria to place the teacher teams on the continua, are elaborated in the corresponding paragraph. Some themes do not have a match with a characteristic of the framework, and as a consequence, will be explained separately.

Goal We will start with the analysis of the 'goal' dimension, since it is important to understand the goal before analysing the rest of the assessment strategy. We include metacognition in this dimension, since the model of Segers et al. (2006) does not include this and we think it is an important aspect.

The characteristic 'goal' from the framework, has a clear match with the theme 'objectives' from the interviews. These objectives are the learning goals teachers want their students to achieve. They can include curriculum guidelines, required skills and higher order thinking skills.

From the interviews, it seems teacher teams have trouble to clearly set their objectives for the iSTEM course. Nevertheless, students report in the questionnaire they take into account the objectives while working in the iSTEM course.

The objectives mostly mentioned by the teacher teams are the curriculum guidelines. Although a difference is noticed between teachers in the general secondary curriculum and teachers in the technical secondary curriculum. The curriculum guidelines in the technical secondary curriculum describe some attitudes and competencies that are typical for their future studies or jobs. So teachers tend to assess these attitudes often and give a lot of importance to it, as illustrated by the excerpt from the interviews below.

> We extracted the competencies out of the curriculum guidelines and elaborated them. Only the ones that match engineering, of course. Those are assessed. *(School J, K9-K10-teacher)*

While teachers of the general secondary curriculum mostly refer to content related curriculum guidelines to assess students, as illustrated by the excerpt from the interviews below.

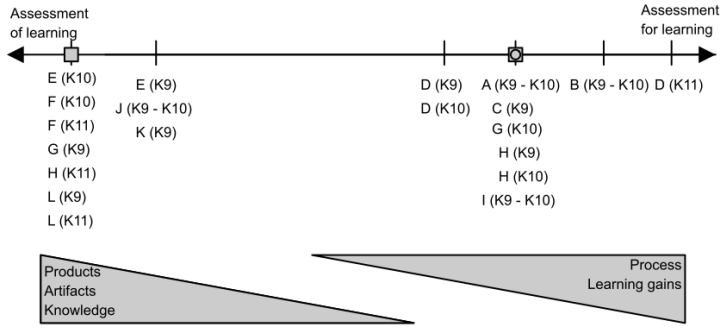
> Actually, each class, we look for the curriculum guidelines of specific courses in that specific class. *(School L, K10-teacher)*

Besides the theme of 'objectives', also 'feedback' and 'adjustment of the students' can be linked to goal. As a matter of fact, the goal the teacher team tries to reach, has an impact on the way they give feedback and the way students will react on it.

Taking the analysis of the interviews into account, Figure 4.4 can be drawn. On this continuum, two big groups of teacher teams can be distinguished. One at the left end of the continuum and one at the right end of the continuum. The main difference between those two groups is that the group on the left assesses the products, artifacts and knowledge, of the students, while the group at the right assesses the process and gives feedback on the interim work while working on the challenge in the hope students will learn from it. During the interviews, this difference arose as a duality between the role of the teacher as coach and as assessor. Teacher teams in the right end of the continuum experience this duality as a struggle, because they want to give students time to learn, but in the mean time they have to score their performance because the system requires this, as illustrated in the excerpt below.

> But it is important that they learn it, and we see a learning process. But personally, I think it is hard to give a score to that. *(School C, K9-teacher)*

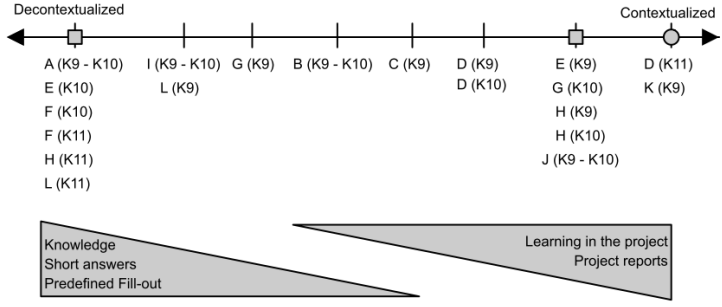
Figure 4.4: Schools on the continuum of goal



Authenticity As can be seen in Table 4.12, a link pops-up between 'authenticity' and the 'format & content of assessment' theme from the interviews. The format and content of assessment is already described per teacher team in Table 4.11. This results in Figure 4.5. The assessment methods of the interviewed teacher teams cover the whole continuum, with two points were multiple schools strand. One of these points where multiple teacher teams strand, is in the beginning of the continuum, with a decontextualised assessment method. These teams make use of tests with short answers or predefined fill-out reports, without a context.

The teacher teams on the other end of the continuum all use the project itself and the report of the project as an assessment, and so a project-based assessment. Teacher team D(K11) even goes a step further and does not require a project report, but only uses the project and the attitude of the students in the project.

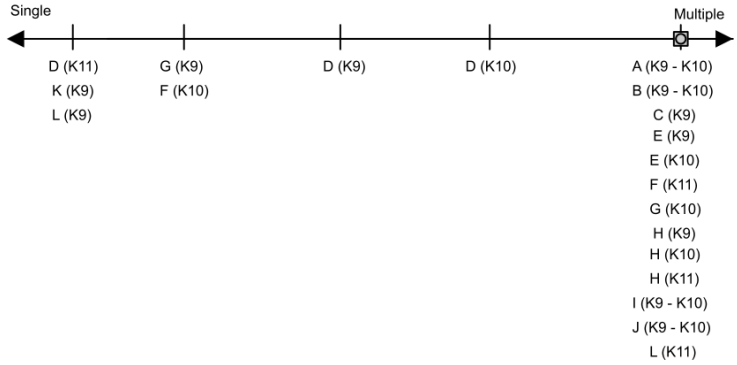
Figure 4.5: Schools on the continuum of authenticity



Number of measurements Also the characteristic 'number of measurements' shows a one-to-one relationship with a theme from the interviews, namely

'frequency'. The answers of the teacher teams are analysed and put on the continuum. Figure 4.6 shows the whole range of number of measurements is covered, but with a pith of the matter at the end of the continuum, with multiple measurements. This pith of the matter is exactly what we would expect while teaching iSTEM, as shown in Figure 4.2. These teacher teams assess their students every week, coupled with feedback. On the other end of the continuum, a teacher team reports to only assess the students once, linked to the obligatory scoring report, each two months. The teachers indicate it is impossible to assess the students more often, since they need the time to dive into the project and get to work with it.

Figure 4.6: Schools on the continuum of number of measurements

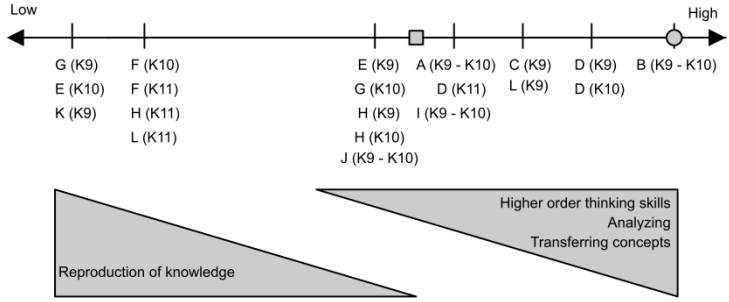


Levels of comprehension The characteristic 'levels of comprehension' is linked to the teacher team theme 'format and content of assessment'. As mentioned before, the format and content of assessment is shown in Table 4.11 and projected on the continuum. This continuum, in Figure 4.7, is fully covered, with a majority of teacher teams centered around the middle of the continuum. These schools try to find a balance between knowledge reproduction and higher-order thinking skills testing. On the left end of the continuum are teacher teams which do not ask for anything more than knowledge reproduction. On the other end, a teacher team asks students to analyse a programming code and improve it, or to set up an integrated question for a test, as illustrated in the excerpt from the interviews below. These are clear indications of higher-order thinking skills, as also stated by Klaassen (2018).

> We asked for a link with the other courses. They needed to draft an integrated question about the subject matter. The question to

them was: Which question would you pose in order to assess the whole subject matter? *(School B, K9-K10-teacher)*

Figure 4.7: Schools on the continuum of levels of comprehension



In settings where higher level of comprehension are assessed, goals, instruction and assessment are better aligned. Indeed, the iSTEM teaching approach focused on higher order thinking skills and assessment should be in line with that. Remarkably, students also notice this alignment. Students in classes at the right side of the continuum report a higher match between instruction and assessment in the questionnaires, than students in classes at the left side of the continuum.

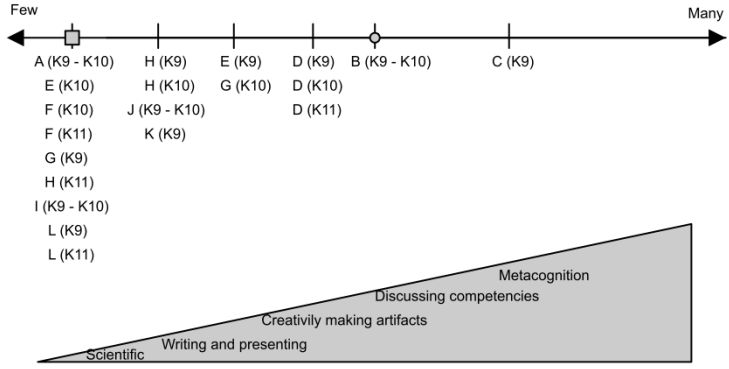
Dimensions of intelligence Among the themes that arose from the interviews with the teacher teams, 'format and content of assessment' and 'self- and peer-assessment' are the ones that match with 'dimensions of intelligence'. As can be seen in Figure 4.2, the iSTEM teaching approach does not aim to address all dimensions of intelligence. When looking at Figure 4.8, the majority of the schools only addresses one dimension, which is the logical-mathematical. Also the linguistic, spatial, interpersonal and intrapersonal dimensions could get attention, shown by teacher team C(K9) in the excerpt of the interviews below. These teachers demand a personal reflection every week, an artifact with corrections, collaboration and a general report. These weekly reflections keep students' attention on their learning progress (Diefes-Dux, 2018).

Interviewer: You just showed me the assessment instrument you use. It is with goals of which you indicate whether it is good, partially good or not good. Do you also assess other things?

Teacher: That is indeed the case for every project, but we also assess other stuff. For instance, they also make a project report every time, including a reflection and answers to some questions we

pose. (...) The reflection questions are also included. On top of that, they have write an individual reflection each day. *(School C, K9-teacher)*

Figure 4.8: Schools on the continuum of dimensions of intelligence



Relation to the learning process Aspects of the 'relation to the learning process' can be found in 'format and content of assessment', 'feedback' and 'adjustment of the students'.

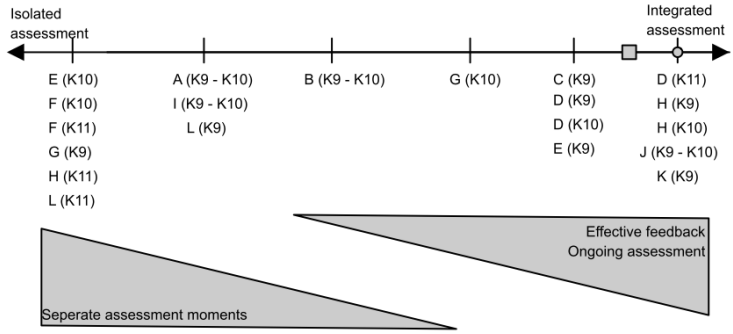
The format and content of assessment has a clear link with the relation to the learning process. When the assessment is done separate from the project, and students need to take a sec knowledge test, this assessment is not integrated.

Assessment is also more integrated when feedback is given. Almost every teacher team reports to give feedback weekly. Only giving feedback is not enough to be of great value for the students. The time frame in which the feedback is given, to what it is given and to whom, has a big influence (Segers et al., 2008). This influence can be seen in the adjustments of the students. Feedback is only of great value when it is given in such a way that students can use it in order to improve their knowledge, artifact or solution (Guzzomi, Male, & Miller, 2017; El-Maaddawy, 2017; Leslie & Gorman, 2017; van de Watering, 2006; Segers et al., 2006; Hattie & Timperley, 2007).

Figure 4.9 shows the interviewed teacher teams cover the whole continuum with their assessment. The teams on the left end of the continuum provide separate, individual tests to assess students. While the teachers on the right end assess students while they are working at their project.

Teachers as well as students report in interviews and questionnaires, that students do adapt their behavior and artifact to the feedback they receive.

Figure 4.9: Schools on the continuum of relation to the learning process



Teachers find this very rewarding, because giving feedback is time consuming, but when they find out students get to work with it, it is worth the effort. The excerpt below is from the questionnaires of the students

> **Question:** Do you take into account the given feedback for assessment moments in the future?
>
> **Answer student:** Yes, because I want to grow and feedback helps with that.

Responsibility In this study the responsibility is interpreted more broadly than only the person who is grading. The near form of responsibility of the student would only include self- and peer-assessment. Because this is the only form in which students are responsible for their own grading. The more broad view also includes whether students are responsible for their own learning, and as a consequence, for their own scores (VLOR-Vlaamse onderwijsraad-Raad secundair onderwijs, 2004; Tandogan & Orhan, 2007; de coopération et de développement économiques, 2015; Haglund & Jeppsson, 2012). Thus, the characteristic 'responsibility' is not only linked to the theme 'assessors', but also to 'adjustment of the students', 'transparency' and 'self- and peer- assessment'.

Transparency of assessment is important in order to give responsibility to the students. As long as they have no clue on what they are assessed, they can not keep this in mind and, as a consequence, are not able to take responsibility. The examples on the continuum will clarify this.

The majority of the interviewed teacher teams operate in co-teaching. Most of these teachers indicate they do the evaluation together, although this brings along some practical difficulties, such as finding time together, not being able

to assess right after the course, etc. This difficulty is illustrated by the excerpt of the interviews below. But this 'deliberating upon their students' is a strong instrument to make standards for them and for the students (Emden & Sumfleth, 2016). On top of that, they indicate it is impossible to see and hear everything during the course, so they want to discuss the grading and share responsibility concerning the assessment.

> **Interviewer:** Do you give grades afterwards? Do you sit together after the class?
>
> **Teacher:** That's impossible. Immediately after the iSTEM class, an other class follows. I have a hard time to keep on track. We just walk around with paper and pencil, and take notes. *(School H, K9-teacher)*

Only a minority of the teacher teams report they do not assess the students together, but divide the assessing work. It seems to be that this is especially the case when teachers make use of formal assessment methods, such as tests or tasks, so the work can be easily split, as illustrated by the excerpt of the interviews below.

> Sometimes my colleague evaluates this test and I will do the next one. In that way, the grades are equal and it is independent from the evaluating teacher. *(School H, K11-teacher)*

Approximately half of the teacher teams report they hand the assessment criteria beforehand to the students. The assessment criteria they mention are the steps needed to be completed and the sections that need to be present in the report. Other criteria about the quality of the work are not communicated. Only a minority discusses the goals or assessment procedure of the course with the students. The goals are the objectives of the course and can consist of knowledge, attitude or skills. This is in line with previous research (van Petegem & Vanhoof, 2002). This can be explained by the fact that teachers have a hard time formulating goals for their course, as mentioned before. When they are questioned about it, they reply with the assessment criteria, as illustrated in the excerpt from the interviews below.

> **Interviewer:** You say you write down some criteria for yourself. Do you share these with the students?
>
> **Teacher:** During an experiment, we do. We say: 'Write a report and make sure these points are in it'. We don't give a predefined

> fill-out report. They get an assignment and what needs to be in their report. *(School H, K11-teacher)*

Although few teachers are transparent about their assessment, all teachers have the awareness that being more transparent about their assessment, would improve the course quality and students' learning.

When teacher teams communicate the assessment criteria to their students, teachers notice students use this as a checklist when writing a report. This is in line with literature (Lönngren et al., 2017).

Few teachers integrate self- and peer-assessment in their assessment methods. They justify this by indicating that their students act immature and just give their friends a high score, or discuss what scores they need to give to each other in order to obtain the highest possible score, as illustrated by the excerpt from the interviews below.

> In the past, I asked the students to assess. What happens then? For instance, during an experiment, their self- and peer- assessment, they gave each other extreme high scores, because they want high scores. (...) With this, I could not fairly estimate their contribution. *(School J, K9-K10-teacher)*

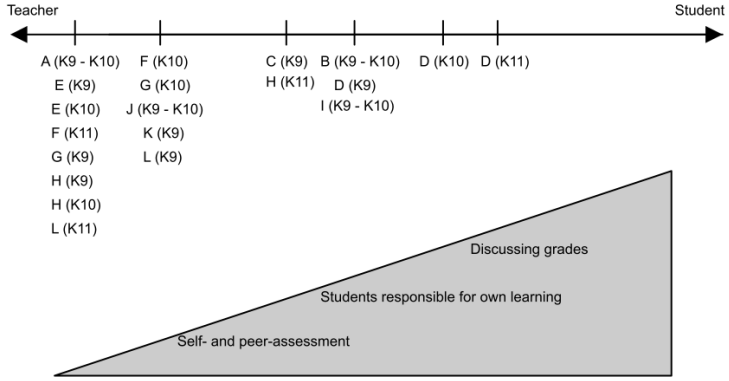
On the other hand, other teacher teams indicate students are mature enough to do a self- and peer-assessment, but they just need to get used to it and grow in learning how to assess. For example, one school starts with a strict assessment format in the 3rd year of secondary education (K9), in which students need to give a verbal self- and peer-assessment. The next year, a self- and peer-assessment with scores needs to be filled out by the students. In the 5th year, grades are given to students during a conversation the student has with his or her teachers in which the learning progress and effort is being discussed, also called collaborative assessment (van Petegem & Vanhoof, 2002), as illustrated in the excerpt from the interviews below. These teacher teams report an upward learning curve in assessing with their students.

> It were good conversations. It was a two-way conversation. We say 'in our perception you work in that manner'. Then the conversation starts and the student confirms or disclaims that. (...) I had the feeling that it was a mature conversation. We really discussed the key findings. *(School D, K11-teacher)*

The continuum of responsibility is shown in Figure 4.10. Most teacher teams keep the responsibility of the assessment and learning to themselves. These are

the teacher teams on the left end of the continuum. While teams are moving to the right on the continuum, more autonomy and so responsibility is given to the students. The first step to give some responsibility to them is with the use of self- and peer-assessment. When we analyse the assessment method of teacher team D(K11), we noticed that they have a conversation with the students in order to grade them. This is more than self- and peer-assessment, and requires some clear insights about assessment from the students. The teacher teams in the middle of the continuum tend to give responsibility to the students in learning. For example, students have to find their own path in solving the proposed challenge and so have to decide themselves what they need to learn for this. None of the teacher teams puts full responsibility to the students.

Figure 4.10: Schools on the continuum of responsibility



Extra relevant themes from the interviews As mentioned in Table 4.12, two themes from the interviews, 'grading' and 'previous experience of the teacher with assessment', could not be linked to the framework of Segers et al. (2006). However, they have a big influence on the assessment practices of the teacher teams and are elaborated below.

Grading Grading incorporates the importance of assessing students with scores for the students, parents, teachers and schools.

The majority of the teacher teams find scores important to keep students motivated. These teacher teams report that students do not make enough effort when they do not get a score on their performance. This is also supported by literature findings (Segers et al., 2006; Gibbs & Simpson, 2004). Despite the fact that a single score is insufficient to describe students' performances (Berkowicz & Myers, 2018), teacher teams indicate scores have a remarkable

impact on parents and the decisions of the teacher teams. Parents grew up with score reports and find them important as such and the teacher team only takes the scores into account when they have to decide whether a student will pass.

Teachers report a struggle to coach and grade the students at the same time. Teachers have to help students complete the challenge, and at the same time evaluate the process students go through. Some teachers try to separate these two role, by sometimes helping the students and take time at other moments to assess the students. But since helping students is time consuming, no time is left for grading. The next story makes this struggle more clear.

> One teacher team came up with an innovative idea about scoring students. They propose to grade students during the course and making these scores visible to the students. The score can be adapted when students succeed in doing a better job during the rest of the course. The teachers are enthusiastic about it, but it seems hard to bring it into practice, because a lot of time during the course is spend on helping students with their artifacts, so not much time remains for grading during the course.

Two schools, however, are an exception to the statements made above. One school has banished all scores. Students only receive a color, green, orange or red, to indicate how they performed during the courses. The ultimate goal of this school in the near future is to grade all curriculum guidelines separately with this color scale. The management of the school has taken this decision, without hearing the teachers. This results in frustrations with the teachers, as illustrated in the excerpt below.

> **Teacher:** But even when you assess, you can't motivate them with the assessment method used in this school. It is all about a positive sentence on their grading report. And a color. From this year on, no more scores are put on the grading report. That's a heated discussion.
>
> (...)
>
> **Interviewer:** Did you have any experience with alternative assessment before this system is used?
>
> **Teacher:** *(frustrated)* I teach for five years in this school and I had to use a different assessment system each year. *(School L, K9-teacher)*

Another school does use scores for all courses, except for the iSTEM course. This course is assessed with an attitude report on which students receive letters

ranging from A to F, to indicate how well they demonstrated their attitudes. The school has made this decision to make a clear distinction between the other courses and the iSTEM course. The teacher of this last school claims that students are more motivated and creative when no score is coupled to their performance.

The more teacher teams shift to an assessment culture, the more they experience a tension between assessing and coaching, as also mentioned by Black and Wiliam (1998). Teachers indicate ongoing assessment is time consuming, and they could use their time more efficient by helping the students. This is illustrated in the excerpt below.

> One teacher walks around with paper and pencil, taking notes to assess. Than I wonder: 'What are we doing?' Students are working and we walk around and score. I really don't like that. You have to spend time at it, while you can use your time in a better way: to coach. *(School H, K9-teacher)*

Previous experience of the teacher with assessment The category of previous experience is about how teachers assessed students before the iSTEM course took place. The focus here is to examine whether teachers have already used an alternative assessment method, such as rubrics, peer-assessment, sliders... In general, everything else than correcting a task, test or report with a correction key can be seen as a form of alternative assessment (van Petegem & Vanhoof, 2002).

Only teacher teams of technical secondary schools report the use of alternative assessment in previous teaching experience and so also use this in the iSTEM course. Teacher teams of the general curriculum are not so experienced with alternative assessment methods. When asked about this, they report they subtract points during laboratory sessions when students do not close their lab coat, as illustrated in the excerpt below. That is the only form of 'alternative assessment' they sometimes use. Unfortunately, this does not align goal, instruction and assessment.

> For example, when someone wears a lab coat, but the coat isn't closed properly, I subtract points. (...) And next time, it will be fined harder. *(School H, K9-teacher)*

4.2.4 Discussion

From the analysis of the interviews with the teachers, questionnaires with the students, assessment instruments and field notes, it is clear that teachers are aware of the changes in the assessment method needed to constructively align assessment, goals and instruction in iSTEM. Despite of this awareness, teachers still want to stick to the familiar assessment methods and find it difficult to align objectives, instruction and assessment. Perhaps, teachers are gradually leaving traditional assessment and get engaged in new modes of assessment, as stated by Segers and Dochy (2001). As a matter of fact, Christou et al. (2004) reported that teachers resist change, unless it will significantly benefit themselves and their students. Unfortunately, not all teachers are convinced of the benefits of this in iSTEM.

When discussing the format and content of the assessment with teachers, in order to answer the first and second research question about the assessment methods used in iSTEM and the reason why they chose for it, they realise it is important to assess broadly, including knowledge, skills and attitudes, as mentioned before by literature (S. M. G. Puente et al., 2013; Eastwell, 2002). Although this consciousness is present, teachers still prefer to have a formal assessment tool that obliges students to write something down either in a report or at a test, so they can assess it formally, as also shown by Nightingale et al. (2007) and Diefes-Dux (2018). Research also indicates that teachers are struggling with the fact that the assessment is not done by a report or test or something written on paper (Heerink, 2011). Teachers rely on these assessment methods because they are familiar with it (National Research Council, 2001). They also feel these fill-out reports and tests are more fair, because they can have one teacher to do the assessment for a certain test and the other teacher for another test. In this way they think the assessment is more reliable. Though, it is possible that this assessment is not reliable, since it is not always aligned with the goals and instruction of the course. This assessment strategy is best to avoid.

Despite this lack of reliability, literature indicates students also prefer this formal assessment (van de Watering, 2006). Teachers, on their behalf, indicate they feel more comfortable with this formal way of assessing. It also seems this broad assessment with multiple measurements results in bad distribution of overall scores. Students score nearly the same, but individual difference can be noticed in the partial scores. The reason therefore is twofold. First, Heerink (2011) and Schalk and Bruning (2014) suggests not splitting up too much while assessing, to avoid this generalisation. Second, every student has his/her favorite assessment methods and when assessments vary, everyone will get his/her most and less favorite assessment method and as a consequence will

result in the average (Birenbaum, 1996).

In order to answer research question three, about catalysts and barriers for a new assessment method, the interviewer asked for the objectives and time-investment on the iSTEM class. The analysis shows that teachers have trouble to clearly set their objectives for the iSTEM course. This could partially explain the trouble teacher teams have with constructive alignment and integrating a new assessment method, since setting the objectives is an important first step for assessment (Pellegrino & Chudowsky, 2003; Biggs, 2014; Borrego & Cutler, 2010). Another barrier for this new way of assessing is the investigated time. Teacher teams want to give regular feedback and be transparent about the assessment because they believe in the advantages of it, but this is time consuming, as confirmed by the research of van Petegem and Vanhoof (2002). On top of that, teacher teams experience a lack of time for planning meetings with other teachers about the assessment, as also stated by Ríordáin et al. (2016). Teacher teams are aware of the fact that giving feedback can have powerful and positive effects on achievement (National Research Council, 2001; Van Merriënboer et al., 2002), but only when there is a potential gain by responding to that feedback (Guzzomi et al., 2017; El-Maaddawy, 2017; Leslie & Gorman, 2017; van de Watering, 2006). The weekly feedback given by almost all teacher teams to the students corresponds to what is described as desirable by assessment experts (Pellegrino & Chudowsky, 2003). Transparency, on the other hand, is present when the student receives all the needed information to prepare and perform the perfect task or assignment (van Petegem & Vanhoof, 2002). This is important because it has a positive influence on students' learning processes (Segers et al., 2006). In this category, we also make a distinction between assessment criteria and goals. In general, the category of transparency is about whether students receive the objectives integrated into the assessment instrument at the beginning of the course. This is important, because only when they have a clear indication about what is assessed, they can take this into account. But, being transparent on the assessment criteria and goals is not enough for students. The extra information in feedback is important for them, because it seems to be hard for them to interpret criteria as such (Segers & Dochy, 2001; Eckman et al., 2016). Despite these advantages of transparency and feedback, only a minority of the teachers in the present study discusses the goals or assessment procedure of the course with the students. This is in line with previous research (van Petegem & Vanhoof, 2002). Also this can be explained by the fact that teachers have a hard time formulating goals for the newly implemented iSTEM course, as mentioned before. When they are questioned about it, they reply with the assessment criteria. Furthermore, teacher teams are struggling with the assessment culture, since they need to be coach and assessor at the same time. They want to help and guide students in order to facilitate learning, but at the same time they need to assess the

students. The further teacher teams are shifting to the assessment culture, the more they are struggling with this contradiction.

Teacher teams also indicated a lot of barriers to implement self- and peer-assessment. A lot of teachers already tried it, because literature indicates that it is important for students and not only because they do learn from receiving feedback, but also from giving feedback (H. L. Christiansen, 2015). These learning gains are more meta-cognitive, personal and professional (Montrieux, 2012; Tal & Miedijensky, 2005). Moreover, this assessment is also important for teacher teams to get a good impression about the group dynamic (Subramanian, 2015). On the other hand, social elements, such as friendships or dominance, can influence the peer-assessment (Montrieux, 2012), as shown by the experiences of the teacher teams. This is supported by Segers and Dochy (2001). Segers and Dochy (2001) claim students are able to do a self- and peer-assessment, but students have mixed feelings about being capable of assessing each other in a fair way, and so they need some training and experience with it (Montrieux, 2012; Segers et al., 2006), as one teacher team proved with a progressive assessment.

Research question four is about the experience of the students with the used assessment method. Students report they take into account the objectives while working in the iSTEM course, but we found that teacher teams are struggling with formulating the objectives. This contradiction can be explained by the fact that students mix up objectives and instruction (Abrahams & Millar, 2008). They probably take into account the instructions of the teacher, but have no clue about the objectives. Furthermore, most students report to get to work with the received feedback, some of them to get a higher score, others indicate it helps them to get better competencies.

Constructively aligning goals, instruction and assessment seems to be hard for teachers, as already stated by Nightingale et al. (2007). But when teacher teams try to complete the alignment, higher order thinking skills are assessed and students report a match between instruction and assessment. The alignment can be facilitated when teachers start by setting clear goals (Waldrop, 2015; Kober, 2015). We do see that teacher teams are trying to align the assessment with the curriculum guidelines. This results in a discrepancy between the technical and the general curriculum. The technical curriculum guidelines contains more skills and competencies, besides knowledge, while the curriculum guidelines of the general academic track focus mostly on knowledge, and less skills and competencies. This discrepancy in curriculum also creates a discrepancy in assessment strategy. Most technical teacher teams incorporate more alternative assessment methods, in comparison to their colleagues of the general academic track, since these alternative methods are necessary in order to fulfill the curriculum guidelines.

When looking at the distribution over the characteristics of Segers et al. (2006), almost the whole range is completely covered by the teacher teams. This confirms the hypothesis that despite a structured intervention, a variety of assessment methods is used. When analysing the majority of the teacher teams in this study, we see that for the characteristics of number of measurements, relation to the learning process and goal, assessment methods are evolving in the right direction, namely to the right side of the continuum, as shown in Figure 4.2. For the other characteristics, some innovations need to come through. But as every innovation, it should be implemented incrementally (Shepard, 2000). So, after a few years of implementation of the iSTEM curriculum, the assessment methods might have changed a lot, because teacher teams need time to hone the knowledge, skill and understanding, in order to construct assessment materials (R. E. Bennett, 2011).

Also, we see that none of the teacher teams puts full responsibility to the students, which is completely understandable. Teachers still have the responsibility of assessment, the experience and the overview of control of competencies, so they should stay involved. Though, most teacher teams shift to a shared responsibility between them and the students.

A final conclusion about the characteristics of the theoretical framework can be drawn when comparing all continua. Although some teacher teams make an attempt to shift to an assessment culture, none of the teacher teams shows a shift on all characteristics. This can be explained by the fact that not only the teacher team is responsible for an assessment culture, but also the school environment is (National Research Council, 2001). Unfortunately, not all schools are ready yet to shift to an assessment culture.

Applicability

Since teachers could prove their statements with assessment instruments and their sayings were in line with those of the students, it seems that teacher teams answered the questions fairly and did not fall into social desirable answers, as it has been the case in other studies (van Petegem & Vanhoof, 2002). Teachers did not report an assessment culture, when it was not the case. This makes the findings of this study interesting. Several explanations could be given for having these fair interviews. First of all, the interviewer already had a connection with the teachers. She has cooperated with them for the past three years and had several discussions with them. This made the interviewees were more comfortable than a regular interview with a stranger. Secondly, the teachers were ensured that their names would not be published, so their anonymity is granted (Emans, 2002). Thirdly, the teachers only had some guidelines and

examples for the assessment, so it was clear to them that they were free to chose the assessment method of their choice. As a consequence, no 'wrong answers' could be given. Lastly, the interviewer took a neutral attitude against the answers of the interviewee (Emans, 2002). This is incorporated in the interview guideline by first asking about the teachers' assessment practices and only asking about the proposed assessment instruments in the end.

Conclusion

Teacher teams struggle with constructively aligning objectives, instruction and assessment, but for teacher teams that try to establish constructive alignment, higher order thinking skills are assessed and students report a match between instruction and assessment.

When considering all dimensions of assessment in iSTEM, where assessment for learning is an integrated part of constructivist learning and instruction, a shift toward an assessment culture is noticed by almost every teacher team. Though, not one teacher team has shifted completely to the side of alternative assessment, as shown in Figure 4.2. Though, this shift will help the teachers to obtain constructive alignment in the iSTEM course.

Teacher teams realise it is necessary to conduct a broad assessment and most teacher teams also try to do so. This broad assessment mostly includes only formal assessment, based on tests, tasks and reports, while a broad assessment should also tests for skills and competencies.

Time-investment is the biggest barrier for teachers to integrate an assessment culture. On the other hand, teachers and students find the time invested in feedback very rewarding. Students appreciate the it, because they can go to work with the feedback and improve their skills. Teachers find it useful, because they notice an effect of their feedback in students' work and perceive this as a catalyst to keep on doing it.

This study provided some insights into the pedagogic-didactic reasoning related to assessment in integrated STEM education. Though, it is difficult to make generalizable conclusions about assessment in iSTEM courses, since every classroom context is nested in its constraints and as such forms a unique environment (S. Barab & Squire, 2004). Teachers are aware a change in their assessment strategy is necessary, but not all of them have found a way towards the change. The study also provided a lot of freedom in assessment for the teachers. Although the learning materials and goals were the same for all teachers, a variety of assessment instruments were used in different classrooms.

The choice for the assessment is influenced by the school environment, curriculum guidelines and teacher experiences.

Suggestions for further research

In the beginning of the chapter, we argued that research is necessary to explore how forms of assessment matching iSTEM can be made feasible in classrooms and how they affect student learning, teaching practices and educational decision making of secondary school teachers (National Research Council, 2001). After this project, this chapter provided some qualitative answers about feasibility in classrooms, effects on students learning and teaching practices. Though, this study is too short-term to make general educational recommendations, further research is needed.

This research should examine the vision of the school management about assessment and compare it to the assessment in classrooms. Probably, a link will appear, since the school board sets the environment in which the teachers work. When this link is made clear, the school board should be coached to create an environment to facilitate an assessment culture, in which teacher teams can operate. This follow-up study study will have big implications for assessment practices.

Another track to explore is about the influence of constructive alignment on student approaches to learning. Since students report to be aware of the constructive alignment, it would be helpful to have an in-dept interview with the students about their learning gains when they report constructive alignment (Miedijensky & Tal, 2009; Leslie & Gorman, 2017). These insights about the relationship between the goals, instruction and assessment can help teachers to redesign their assessment practices in order to enhance deep approaches to learning (Segers et al., 2008).

Table 4.6: Rubric on draft planning

	Insufficient	**Sufficient**	**Good**	**Excellent**
Realistic planning	The sequence of the planning is not right.	The presented planning is not feasible within the proposed time frame, but the sequence is correct.	The major part of the planning is realistic, although some steps are miscalculated for time.	The presented planning is realistic in time and sequence.
Completeness planning	The presented planning contains no or irrelevant intermediate steps.	The planning contains some well-thought and some irrelevant intermediate steps.	The planning contains most of the necessary intermediate steps to reach the goal.	The planning contains all necessary intermediate steps to reach the goal.

Table 4.7: Rubric on adjustment planning

	Insufficient	**Sufficient**	**Good**	**Excellent**
View on own planning	Students have trouble to estimate where they are according to their planning.	Students are able to situate some aspects of their work in their planning.	Students are able to situate most aspects of their work in their planning.	Students can perfectly situate their work in their planning.
Modify planning	Students don't have a clue how and when the planning needed to be adjusted.	Students can say when they have adapted the planning, but have trouble explaining why and how.	Students can explain how, when and where the planning is adjusted, but not why.	Students can explain when, where, how and why they adjusted the planning.
Improvements	Students don't suggest any improvements.	Students suggest some improvements, but they won't improve the process.	Students suggest some good improvements, but forget about some aspects.	Students suggest good improvements.
Critical view	Students don't reflect on the process or intermediate result.	Students reflect on the intermediate results, but not on the process.	Students reflect on the process, but not on the intermediate result.	Students reflect on the process and the intermediate result.

Table 4.8: Rubric on collaboration

	Insufficient	**Sufficient**	**Good**	**Excellent**
Collaboration	There are no debates in the group. Either by to much disagreement, or by one leader not open for debate.	Because of disagreements in the group, the group decides to give everyone an individual tasks.	Sometimes hard debates rise in the group, but in the end the group can go through.	Collaboration is smoothly and debates are held peacefully.
Handle problems	The group doesn't think thoroughly about a solution for raising problems. The teacher is consulted for the smallest problems or the first thought-of solution is implemented.	The group thinks thoroughly about solutions for raising problems, but wants confirmation from the teacher about the thought-of solution.	The group thinks thoroughly about solutions for raising problems. When no solution raises, the groups waits for too lang before consulting the teacher.	The group thinks thoroughly about solutions for raising problems. If no solution raises, they consult the teacher in time.
Remarks	The group ignores critical remarks from others.	The groups goes to work with easy-solvable critical remarks from others, without reflection.	The group opens-up for critical remarks from others, reflects about them, but only works with easy-solvable remarks.	The group opens-up for critical remarks from others, reflects about them and goes to work with them.

Table 4.9: Rubric on result

	Insufficient	**Sufficient**	**Good**	**Excellent**
Went well/ Went wrong	Students don't have a clue what went well and wrong during the project. Or they only see what went well.	Students only see what went wrong and forget about what went well.	Students can tell what went well and wrong, but forget about some aspects.	Students can tell what went well and wrong during the whole project.
Improvements	Students don't suggest any improvements.	Students suggest some improvements, but they won't improve the process.	Students suggest some good improvements, but forget about some aspects.	Students suggest good improvements.
Critical view	Students don't have a critical view towards themselves, nor their own group, nor other groups.	Students only have a critical view towards other groups.	Students have a critical view towards their own and other groups, but not towards themselves.	Students have a critical view towards other groups, their own group and themselves.
Integration	Students can't tell which concepts of science, mathematics, engineering and technology were necessary to work on the project.	Students can tell which concepts of science, mathematics, engineering and technology were necessary to work on the project, but are not able to make links between these concepts.	Students are able to make a few links between the seen concepts of science, mathematics, engineering and technology.	Students can perfectly describe the link between scientific, mathematical, engineering and technological concepts.

Table 4.10: Part of the data analysing matrix

		School A K9 - K10	School B K9 - K10
Format and content of assessment	Based on tasks and tests	+	+
	An examination of STEM takes place	-	-
	Based on practica	+	+
	Based on attitudes	-	+
	Based on competencies		+
	Based on planning		+
	Based on project report	+	
	Based on presentation		+
	Linked to the other courses	+	+
	Content of other courses is assessed the courses theirselves	-	
	Used a rubric		+
	Used performance lists	+	
	Used a checklist	+	
	Pupils are assessed in group		+

Table 4.11: Assessment strategies used in iSTEM classes (x is when teacher teams still use this assessment strategy, (x) means that they have used it in the past)

	Proposed assessment			Own assessment										
	Checklists	Performance lists with continua	Rubrics	Tests and tasks about knowlegde	Tests and tasks about higher order thinking skills	Experiment reports	Attitude	Competency	Planning	Project report	Presentation	Rubrics	Performance lists with continua	Checklists
A (K9-K10)		(x)		x	x	x				x				x
B (K9-K10)			x		x	x	x	x	x		x	x		
C (K9)							x	x		x				x
D (K9)		x						x	x	x	x			
D (K10)		x							x	x				
D (K11)														
E (K9)			(x)				x			x	x			x
E (K10)				x						x				
F (K10)				x		x								
F (K11)				x		x								
G (K9)				x						x	x			
G (K10)							x			x				
H (K9)								x						
H (K10)								x						
H (K11)				x		x								
I (K9-K10)				x			x							
J (K9-K10)								x		x				x
K (K9)							x							x
L (K9)								x						
L (K11)				x				x						

Table 4.12: Relationships between inductive themes in the rows and theoretical dimensions of assessment by Segers et al. (2006) in the colums

References are given to	**Authenticity**	**Number of measurements**	**Levels of comprehension**	**Dimensions of intelligence**	**Relation to the learning process**	**Responsibility**	**Goal**
Goals & objectives							x
Format & content of assessment	x		x	x	x		
Feedback					x		x
Adjustment of the students					x	x	x
Transparancy						x	
Frequency		x					
Self- and peer-assessment				x		x	
Grading							
Previous experience							
Assessors						x	

Chapter 5

Conclusion

This chapter first retakes the research questions and conclusions from the individual chapters. After that, a meta-conclusion is made of all the chapters, followed by implications for teaching and theoretical frameworks, and suggestions for further research.

5.1 Design of an iSTEM curriculum

Chapter 2 consists of a description and implementation of the developed learning modules in the framework of STEM@school. Since the theoretical framework for iSTEM was conceived as part of the project, this part qualifies as design-based research (S. Barab & Squire, 2004). As a result, the research questions in this chapter are:

1. Is it possible to design learning modules based on the iSTEM framework of STEM@school?
2. How do teachers implement the learning modules in their classroom practices?
3. What barriers do teachers face while implementing the modules in todays secondary education?

This chapter describes the modules developed by the author together with teacher teams. It clarifies that is it possible to design iSTEM learning modules with inclusion of the five key characteristics, namely integration of different

STEM disciplines, problem-centered and cooperative learning, with explicit attention to research and design. Moreover, results of discipline-specific educational research are taken into account.

The structure of the learning modules is described and explained in detail. It is clear that the learning modules contain another degree of freedom for students of different age: a learning progression is built in. Learning modules for K9 education are more restricted and more guided than the ones for K11 education. This gradual construction is necessary in order to engage students in problem-based learning, make them familiar with the teaching approach and train them for solving more complex problems (Dooley, 1997; Merrill, 2002; Gulikers, 2006). Still, some guidance for the students is provided in every learning module. Otherwise, they do not succeed in linking the to-be-learned material to their previous gained knowledge (Mayer, 2004). Moreover, this guidance also facilitates transfer of the learned concepts for the students (Mayer, 2004; D. J. Harrison et al., 2016), as also shown in the chapter about transfer. Furthermore, also the complexity of the modules promotes transfer (Mayer, 2004; D. J. Harrison et al., 2016).

After implementation of the learning modules in the classroom, it seemed impossible to achieve all learning objectives pointed out in advance. Teachers in this study mostly see the time restriction and curriculum goals as a barrier to integrate all learning objectives and engineering design (Gresnigt et al., 2014; McCrum, 2016; Roehrig et al., 2012). This can only be changed by a serious curriculum reform and reviewing school organizational structures (Singer et al., 2000; Roehrig et al., 2012).

Besides time restrictions and curriculum goals teachers' confidence in teaching the newly designed learning material, unfamiliarity with the teaching approach, and resistance to change were challenging for teachers in this study. These barriers are also mentioned in previous research (Gresnigt et al., 2014; Tandogan & Orhan, 2007; Gero, 2017; Christou et al., 2004; Shernoff et al., 2017). As a result, not all curriculum materials are used as they were intended by the developers (J. Bennett & Lubben, 2006). In order to overcome this, teacher teams should be given more time to get familiar with the innovative teaching approach and master the learning materials and as such take a greater ownership (Ríordáin et al., 2016).

It is difficult to make general conclusions about the implementation of these modules, since every classroom context is nested in its constraints and as such form a unique environment (S. Barab & Squire, 2004).

5.2 Transfer of concepts

Chapter 3 describes the transfer abilities of students, both in an iSTEM curriculum and in a traditional curriculum. This chapter addresses the following research questions:

1. To what extent are students able to transfer the concepts of slope, programming loop, area under the curve, and series and parallel circuits from one familiar context, encountered in class, to another familiar context, not encountered in class?
2. To what extent do students refer to one context in order to solve a problem in another context?
3. Which difficulties arise when solving problems concerning the concepts of slope, programming loop, area under the curve and which of these are persistent in an attempt to transfer them? Which scaffolding hints can help to overcome those difficulties?
4. Do students who are involved in an integrated STEM curriculum transfer the use of concepts to another context more easily than students who are involved in a regular science curriculum? Do the former students connect concepts more flexibly across contexts than the latter?

We found it challenging to formulate conclusions about students' transfer ability of a whole concept. Students barely succeed in transferring a whole concept to a new context. But, when looking in more detail at different steps and strategies, we can make some conclusions about students' transfer ability. Some students are able to transfer some steps and strategies to another context. However, often they use a different solution strategy in a familiar context not encountered in class, than in the familiar context encountered in class. Our findings are in line with the research findings of Ivanjek et al. (2016), who showed that students use different problem solving strategies in different contexts. Furthermore, as Planinic et al. (2013); Ivanjek et al. (2016) found before, whether or not transfer will happen, depends on a lot of different factors, so it is hard to tell why the transfer did not occur. Unfortunately, no difference in transfer ability could be found between non-iSTEM and iSTEM students in the present study.

Secondly, we asked whether students refer to one context in order to solve a problem in the other context. It seemed that students were referring to the reference test when doing the concept transfer test to justify why they use a certain problem solving strategy. This happened 15 times, 10 of which were correct references. Students did not often refer to the class context. However,

when they were struggling, referring to the abstract context in which they learned the concepts, sometimes helped them out. So, we have the impression that the teaching strategy in classrooms is still too abstract for students, or that the link between the abstract concepts and the applications is not clear enough for them.

Thirdly, we looked for difficulties while solving the test and looked which of these are persistent in the transfer test. Moreover, we are interested in which hints can help to overcome those difficulties. Most of these difficulties are not new, and have been mentioned in literature, as explained in chapter 3. These difficulties seem quite persistent from the test items in a familiar context encountered in class (RT) to the test items in a familiar context not encountered in class (CTrT) and arise even more often in the CTrT, indicating that they are not 'overcome' but show up again in contexts not encountered in class. It is remarkable that few iSTEM students face these difficulties in the RT, but more of them in the CTrT. So it seems to be that the interpretation of concepts and difficulties is still linked to the context.

In some cases, these difficulties could be overcome during the interviews by pointing students to specific parts of the assignment, in the graph or the formula, or by making abstraction of the concept and asking how they did it in class and as such explicitly linking to known situations. Our findings again show that transfer does not occur spontaneously or easily, so explicit attention is needed. This requires that enough different contexts are provided to the students, so they are prompted to apply the concept. Moreover, our results indicate that small focused questions support scaffolding for students to transfer ideas to new contexts.

5.3 Design and implementation of an assessment strategy

The assessment strategies used by the teachers is the subject of chapter 4. An assessment strategy matching the iSTEM goals was designed and offered to teacher teams as plausible tools for assessment in the iSTEM course. Furthermore, the assessment strategies of the teachers in iSTEM classes are examined by interviewing the teachers. We compared their assessment strategies to each other and the proposed assessment strategy. Additionally, we linked the used assessment strategies to the perceptions of the students. We want to examine how students, enrolled in the iSTEM course, are assessed, whereby we take into account the perceptions of students and teachers. The overall question is: How do teacher teams align goals, instruction and assessment, and make

sure this triangle is constructive for the students? More precisely, the following research questions are posed:

1. Which assessment method do teachers choose in the iSTEM course?
2. Which theoretical grounding do they use to justify their choice for the assessment method?
3. What are the catalysts and barriers that teacher teams experience to implement a new assessment method?
4. How do students experience the assessment method related to the iSTEM classes?

It can be concluded that teacher teams struggle with completing constructive alignment of goals, instruction and assessment, but when they eventually succeed in aligning, higher order thinking skills are assessed and students report a match between instruction and assessment.

When considering all dimensions of alternative assessment (authenticity, number of measurements, levels of comprehension, dimensions of intelligence, relation to the learning process, responsibility, goal), a shift toward alternative assessment is noticed by almost every teacher team. Remarkably, not one teacher team has shifted completely to the side of alternative assessment, as shown in Figure 4.2. Though, this shift will help the teachers to obtain constructive alignment in the iSTEM course.

Teacher teams realise it is necessary to conduct a broad assessment and most teacher teams also try to do so. Though, this broad assessment mostly includes only formal assessment, based on knowledge tests, tasks and reports, while a broad assessment should also test for skills and competencies.

Time-investment is the biggest barrier for teachers to integrate new forms of assessment. On the other hand, teachers and students find the time invested in feedback very rewarding: students because they can go to work with the feedback and improve their skills; teachers because they notice an effect of their feedback in students' work and perceive this as a catalyst to structurally embed this in their classroom practice.

This study provided some insights into the pedagogic-didactic reasoning related to assessment in integrated STEM education. Though, it is challenging to make generalizable conclusions about assessment in iSTEM courses, since every classroom context is nested in its constrains and as such forms a unique environment (S. Barab & Squire, 2004). Teachers are aware a change in their assessment strategy is necessary, but not all of them have found a way to

implement the change. The study also provided a lot of freedom in assessment for the teachers. Although the learning materials and goals were the same for all teachers, a variety of assessment instruments were used in different classrooms. The choice for the assessment is influenced by the school environment, curriculum guidelines and teacher experience. We think it is better to choose for multiple, contextualized, integrated assessments with a high level of comprehension and more responsibility for the students, based on literature and the perceptions of the students.

5.4 Overall conclusions

This PhD intended to examine the effect of an iSTEM teaching approach on student transfer abilities. Furthermore, the used assessment strategies in iSTEM classrooms are examined. In order to examine these effects, first an iSTEM teaching approach needed to be developed in order to create an iSTEM learning environment.

The development of iSTEM learning modules evolved to a fruitful collaboration between researchers and secondary school teachers. This collaboration challenged us to integrate project- and problem-based learning in the rigid structure of Flemish secondary schools. We all wanted to establish a challenging environment for students to integrate and apply their STEM knowledge. The collaboration established a professional learning community. These kind of communities are important for teachers in order to develop and discuss learning materials and assessment methods (R. E. Bennett, 2011). So, these professional learning communities should be enhanced, in order to develop new materials and facilitate a structured distribution (Schleicher, 2015). On top of that, the learning communities can facilitate collaboration between teachers from different study trajectories, and as such provide opportunities to gain insights from each others teaching experiences (*Advies STEM-studiekeuze [Advice STEM choice of study]*, 2014; Guzey, Moore, & Harwell, 2016).

Time-restrictions are a recurring phenomenon teachers are struggling with. They mention a lack of time to develop learning materials, professional development, collaboration, teaching concepts and integrating unfamiliar assessment methods in classes. This claim of the teachers is supported by literature findings (Prawat & Floden, 1994; Stohlmann et al., 2012; Frykholm & Glasson, 2005; Shernoff et al., 2017; Verentinnicoff & Vandewalle, 2015; Gentile et al., 2012). This literature indicates teachers are overloaded with their work to teach, that there is almost no time left for development of learning materials and collaboration.

Concurrently, the lesson plans for each course are overloaded with content. Thus almost no time is left to experiment with different assessment methods.

Another possible consequence of this time-restriction is the limited difference in transfer abilities between iSTEM students and students from the regular curriculum. Due to the shortness of time, students do not transfer concepts out of the challenge into new contexts. Students do learn a certain concept in a science or math class and apply it in the iSTEM course, but the concept is not further transfered into other contexts, also because the standards of the individual disciplines remain separate (Czerniak et al., 1999). As a consequence, students following the iSTEM course are able to use the concept in the context of the challenge, but struggle to transfer the concept to another context. This lack of transfer ability can have some other reasons. Firstly, students are not confronted with the complexity of every concept in different new contexts, meaning they only used the concept in one real world challenge and for the remainder of the time they made standard exercises about the concept. Though, complexity in context would facilitate transfer (Pedersen & Liu, 2002). Secondly, the assessment of most teachers is not focused on transfer of knowledge, as a consequence, students will not acquire this competence (Segers, 1997; Segers & Dochy, 2001; Segers et al., 2006; Meyers & Nulty, 2009). Thirdly, transfer is facilitated when students receive feedback about the conditions under which it is appropriate to apply certain concepts (National Research Council, 2001; Pellegrino & Chudowsky, 2003). Unfortunately, not one teacher in this study integrated transfer in the assessment, not in the process evaluation nor in the knowledge evaluation. As a consequence, feedback on it is also not received.

Since this research is nested in the Flemish secondary school context, it is hard to make general conclusions about the different topics, because the unique environment of every school has an influence on the teaching and learning in that school (S. Barab & Squire, 2004). However, our personal opinion is that with the development of the iSTEM learning modules, we started a curriculum innovation and a collaboration between teachers which is unstoppable. Giving this innovation the chance to grow, will enhance students transfer abilities. We also notice a shift to a better constructive alignment between goals, instruction and assessment. This, however, needs more time to be fully implemented.

5.5 Implications for teaching and learning

The iSTEM teaching approach aims to train students for 21st century skills and is based on constructivist grounds. This implies the student is an active learner. This active involvement of the students is not only about gaining knowledge, but

also involvement in assessment (Tandogan & Orhan, 2007). As a consequence, more responsibility of learning and assessing should be given to the student.

One of these 21st century skills is transfer. In Chapter 3, the teaching strategies which can support transfer are discussed. These are: making exercises in completely different contexts and linking concepts to real world examples, using different representations, rehearse previous gained knowledge, provide scaffolding and sometimes teaching a concept in a decontextualized manner. These teaching strategies are integrated in the iSTEM teaching approach. As a consequence, the iSTEM teaching approach will have a positive influence on students' transfer abilities on the long term.

The developed module in this work points teachers to results of discipline-specific research results. Teachers have indicated they use these results when provided. As a consequence, professional development courses and pre-service teacher training should incorporate results from discipline-specific educational research (Cox et al., 2016). This focus is important because research has shown that teacher's feedback and confidence to teach depends on their (pedagogical) content knowledge (Aschbacher & Alonzo, 2006; Eckman et al., 2016). So, it is important to increase student learning gains.

5.6 Further research

Further research should examine the vision of the management of the school regarding assessment and iSTEM. This vision can be compared to the implementation of the curriculum and the assessment in classrooms (Thibaut, Knipprath, Dehaene, & Depaepe, 2018; LaForce et al., 2016). A link will probably appear, since the school board sets the environment in which the teachers work. When this link is made clear, the school board should be coached to create an environment to facilitate iSTEM teaching approaches and an assessment culture, in which teacher teams can operate. The proposed study will have big implications for teaching and assessment practices.

Once the influence of the management of the school on the teaching and assessment practices is studied, it is interesting to study the influence of the teaching approach on student learning. Since students report to be aware of the constructive alignment of goals, instruction and assessment, it would be helpful to have an in-dept interview study with the students about their learning gains when they report constructive alignment (Miedijensky & Tal, 2009; Leslie & Gorman, 2017). These insights about the relationship between the goals, instruction and assessment can help teachers to redesign their teaching and

assessment practices in order to enhance deep approaches to learning (Segers et al., 2008).

Student learning can also be influenced by the learning modules. In this project we started developing based on the learning objectives, in order to cover them all. Literature suggests to start with designing the assessment, because it is central and the first thing students look at (Meyers & Nulty, 2009). Taking off this way ensures assessment is ready to use when implementing and matched with the instruction and goals. Starting with the assessment also has an impact on the design process of the learning modules. It ensures transfer is a part of the assessment and curriculum. This approach incorporates the risk that teaching to the test will take place. Ideally, the assessment strategy is developed early in the design process, but after the goals and teaching approach are set.

In order to embed transfer as part of the assessment, research on a broader scale is necessary. The study described in Chapter 3 can be a preface for other, quantitative, studies. The difficulties and categorizations presented in this study can serve as a starting point for developing other tests, which can result in a quantitative analysis (Prince et al., 2012). The exposed difficulties, for instance, can serve as suitable distracters for multiple-choice questions in a research environment, focusing on quantitative results, not in a classroom (Shernoff et al., 2017). These distracters can provide a clear insight in the way students think about or apply a concept. The triangulation of qualitative and quantitative evidence is important in educational research because of the many parameters to deal with (Christie & de Graaff, 2017).

As mentioned before, student learning is influenced by the used assessment strategy. It would be interesting to study how the developed assessment instruments affect student learning. Maybe some differences on student learning can be discovered between the different instruments. Also the feedback of the teachers on the developed assessment instruments would be an added value for this research.

5.7 Recommondations

The school board can increase the quality of their education by encouraging teachers to cooperate. This cooperation can be established by creating multidisciplinary teacher design teams, clear teachers' schedules at the same time and encourage them to debate.

The assessment research in this work has shown that teachers do not always have the opportunities to choose an appropriate assessment strategy, due to the

regulations of the school. School can give more freedom to the teachers to select a suitable assessment strategy. Therefore, teachers have to take assessment into account when designing their course.

Also the government can encourage teachers to take matters in their own hands concerning their class. If the government decreases the obligated curriculum guidelines, more freedom is given to the teachers in order to design their own lessons and their own curriculum guidelines.

Research results will serve to facilitate an iSTEM curriculum reform (Van den Berghe & De Martelaere, 2012; Verentinnicoff & Vandewalle, 2015) for teachers, teaching approaches, professional development and restrictions. This curriculum reform is necessary in order to educate the 21st century students and give more responsibility to teachers. The iSTEM teaching approach presented in this work provides a starter for this curriculum reform.

Appendix A

Appendix

A.1 Questionnaire about the module of the passive house

General information

Please select your school from the list below.

We regularly align our course together with...

- teachers of engineering
- teachers of physics
- teachers of mathematics
- teachers of engineering and physics
- teachers of engineering and mathematics
- teachers of physics and mathematics
- teachers of engineering, physics and mathematics

Did all students create a passive house and a sun boiler?

- Yes.

- No, the class was split in two groups. One group created a passive house and the other group a sun boiler.
- No, the students only created a sun boiler.
- No, the students only created a passive house.
- No, the students did not create anything.

Introduction and building energy level

Did the student looked into their own in-house energy system and did you discussed it afterwards?

- Yes.
- No. The students did looked into their own in-house energy system, but we did not discuss it.
- No, the students dit not looked into their own in-house energy system.

Did the students discuss some statements about renewable energy?

- Yes.
- No.

Did the students spend some time in class about renewable energy?

- Yes.
- No.

Did the students calculate the payback period of a renewable energy source?

- Yes, the students have calculated the payback period themselves for a renewable energy source.
- Yes, we have calculated the payback period for one renewable energy source in class.
- No.

Did the students do some research about the regulations of the building energy level?

- Yes, the students have looked up several definitions.
- No, these definitions are taught.
- No, these definitions are not brought under attention.

Did you refer back to the pupils' in-house energy system and definitions when they had finished the whole module?

- Yes, I referred back to several physics concepts
- Yes, I referred back to their in-house energy system
- No.

Sun boiler

Did the students et up and carried out the experiments of the sun boiler by themselves?

- Yes.
- No, the students only carried out the experiments.
- No, the experiments were carried out in front of the class.
- No, the experiments are not carried out.

How did students react when they were given more freedom during inquiry? (Multiple answers possible)

- They demonstrated a bigger learning gain.
- I did not give them more freedom.
- They found it difficult.

Did the students formulated the equations for the thermal equilibrium themselves during inquiry?

- Yes.
- No, it was formulated with the whole class.
- No, the equations for the thermal equilibrium were given to them.
- No, the students did not perform these experiments.

Did the students build their own sun boiler based on the results of their experiments?

- Yes, the students have drawn their own conclusions and have built their sun boiler based on those conclusions.
- Yes, the results of the experiments are discussed in class and the sun boilers are built based on this discussion.
- No, the students have built a sun boiler without taking into account the results of the experiments.
- No, the students have not built a sun boiler.

Did the students calculate the efficiency of their sun boiler?

- Yes, the students have done this themselves.
- Yes, the efficiency is calculated in class.
- No, the efficiency is not calculated.

Did you make adjustments to the module of the sun boiler? If yes, which adjustments and why?

The passive house

Did the students build a house themselves?

- Yes, they built a house completely on their own, with their own creativity.
- Yes, they built a house according to a manual.
- No, we used an existing model of a house.

Did the students use a circular support during building the roof?

- Yes, and they made the necessary calculations themselves.
- Yes, but the necessary calculations are made in class.
- No.

Did the students insulate their house in order to make it more passive?

- Yes, the students have chosen an appropriation insulation material, based on their calculations of the heat conduction.
- Yes, the students have insulated their house, without taking into account heat conduction.
- No.

Which misconception(s) did you bring under attention during your class? (Multiple answers possible)

- All objects in the same room, have the same temperature.
- All materials can be placed on a continuum ranging from heat insulator to heat conductor.
- The difference in heat conduction between an insulator and conductor when touch it.

Which analogies did you use in class in order to facilitate transfer or to clarify certain concepts? (Multiple answers possible)

- Electrical currents as analogy for heat current.
- Electrical conduction as analogy for heat conduction.
- Electrical resistor as analogy for heat resistor.
- Ohm's law as analogy for the formula of heat conduction.
- The reservoir as analogy for heat conduction.

Did the students perform some experiments themselves in order to determine the heat conduction coefficients of some materials?

- Yes, they have done the experiments, analyzed the graphs, made the necessary calculations and determined the heat conduction coefficients as such.

- Yes, they have done the experiments, but the graphs and calculations are discussed in class.
- No, the experiments and calculations are done in class.
- No, the experiments were not executed.

Did the students completed the exercises about misconceptions of thermal concepts?

- Yes, they did it by peer instruction.
- Yes, they did it on their own.
- Yes, the exercises are completed in class.
- No.

Did you make adjustments to the modules of the passive house and heat conduction? If yes, which adjustments and why?

Temperature control

Did the students controlled the temperature in their house?

- Yes, with floor heating and the hot water from the sun boiler.
- Yes, with a power resistor.
- No.

If the students did not control the temperature in their hous, why is that?

- We had no time left
- It is too difficult for them.

Did the students program the on/off control loop themselves?

- Yes.
- No, we did it in class.

- No, the program is given to the students.

Did the students predict the behavior of the heating system in the house? (Multiple answers possible)

- Yes, based on the 3 assumptions (no loss, constant loss, reality).
- Yes, but only the realistic situation.
- Yes, but only qualitative.
- Yes, but only quantitative.
- Yes, but only discussed.
- Yes, but only in class.
- No.

Did you make distinction between an open loop and a closed loop?

- Yes.
- No.

Did you make adjustments to the module of control engineering? If yes, which adjustments and why?

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Biography

Leen Goovaerts was born in 1990 in Turnhout, Belgium. In 2012, she graduated as an industrial engineer at Thomas More. That same year she finished her teacher education at KU Leuven. After teaching one year, she started her PhD in the STEM@school project.



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