Educating engaged and competent students for **STEM**

Effects of integrated STEM education

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Educating engaged and competent students for STEM

Effects of integrated STEM education

De vorming van gemotiveerde en competente studenten in STEM

Effecten van geïntegreerd STEM-onderwijs

Dissertation to obtain the degree of doctor in Educational Sciences

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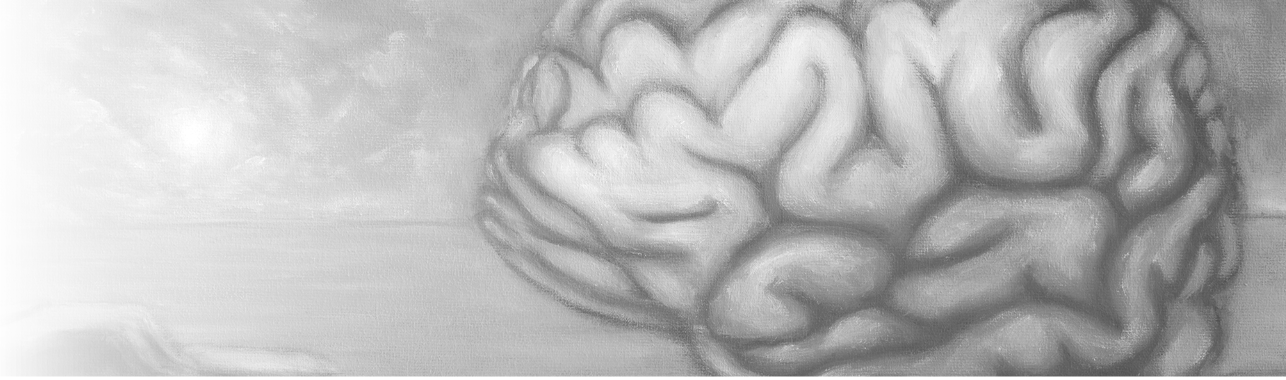

Dankwoord

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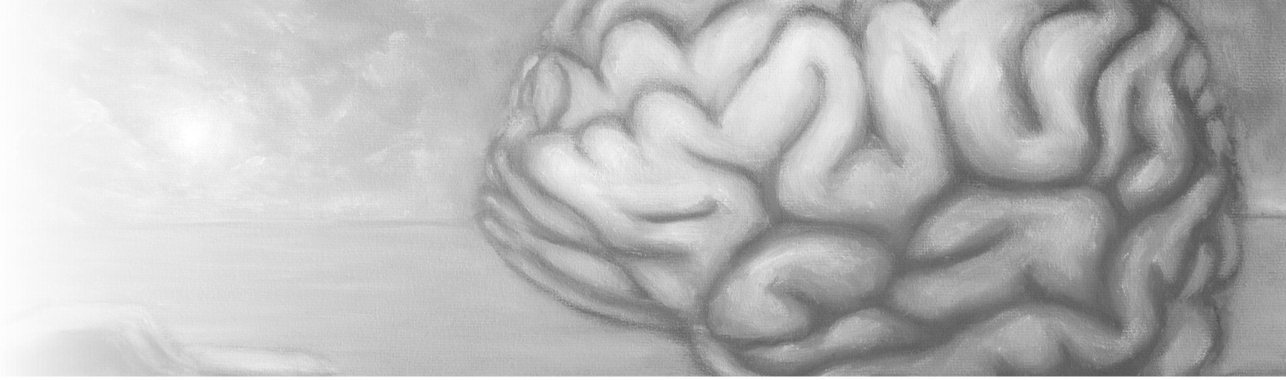
CHAPTER 1



Introduction

Nothing in life is to be feared, it is only to be understood.
Now is the time to understand more, so that we may fear less.

- Marie Curie -

The need for STEM professionals

Over the past few decades, growing concern has been reported about young people's reluctance to participate in science, technology, engineering, and mathematics (STEM). Especially in highly developed countries, students disengage from STEM subjects (Organisation for Economic Co-operation and Development (OECD), 2008; Sjøberg & Schreiner, 2010; Bøe, Henriksen, Lyons, & Schreiner, 2011; Keith, 2018). Multiple reports have argued that the number of students with a STEM degree is not keeping pace with the demand for STEM talent (e.g. President's Council of Advisors on Science and Technology, 2012; National Science and Technology Council, 2013; National Science Board, 2015; STEMconnector, 2018). Women, in particular, remain under-represented when it comes to participation in STEM (Huyer, 2015; OECD, 2018). The problem of students disengaging from STEM emerged in the early 1990s, and has been a growing problem to date (Bøe et al., 2011; Moore & Smith, 2014; Keith, 2018).

Students' lack of interest in pursuing a STEM study or career is problematic because society faces complex challenges for which STEM professionals are needed (Bøe et al., 2011). Countries need a sound economy and innovation capacity, and the world needs to find solutions for societal and environmental problems. Shrinking resources, climate change, traffic problems, epidemics, and an aging society are examples of worldwide problems for which STEM innovations and applications will provide part of the solution. Also, people's demand for technology in daily life (e.g. smartphones) requires a qualitative and well-considered development of technology (Wang, Moore, Roehrig, & Park, 2011; Kjærnsli & Lie, 2011; Bøe et al., 2011). As societies need to find solutions for these problems, there is a pressing need for a large number of students to graduate from STEM-related fields (Keith, 2018). The World Economic Forum (2016) has predicted an increased demand for specialists in the STEM field for years to come.

Besides the need for qualified STEM professionals, the general public, especially young people, also need to be STEM literate. Understanding and applying concepts from the different STEM domains is necessary to construct a substantiated opinion about complex problems and to be a smart consumer of available technologies (Honey, Pearson, & Schweingruber, 2014). All citizens, including non-STEM professionals, are faced with dilemmas, or asked to take a stance on democratic decisions, such as referenda on nuclear energy or traffic arteries (Schreiner & Sjøberg, 2004). For example, in Flanders (the Dutch-speaking part of Belgium), a referendum has been held to determine whether there should be a green roof over the Antwerp traffic ring-road (Gazet Van Antwerpen, 2016). In this case, STEM literacy is a competency for engaged citizenship in participatory democracy.

Despite these needs, and the positive prospects in the labor market for people with a STEM background, insufficient numbers of students actually choose a STEM profession or career (Bøe, Henriksen, Lyons, & Schreiner, 2011; Moore & Smith, 2014; Keith, 2018). Although young children are generally intrinsically motivated to learn about science and have a favorable attitude towards STEM, their interest and attitudes towards it begin to decline from the point of entry to secondary school (Ardies, De Maeyer, & Gijbels, 2015; Osborne, Simons, & Collins, 2003). At the level of secondary education, there is still a sufficient number of students present in STEM-oriented programs, but in higher education STEM study is far less popular (Hernandez et al., 2014). Students gradually leave STEM throughout their educational trajectory, with drop-out at various points along their educational careers. In the literature, this phenomenon has been described in terms of a 'leaky pipeline' (Watt et al., 2012).

In Flanders, the phenomenon of the 'leaky pipeline' can be observed. In secondary education, a large percentage of students are enrolled in study with a strong focus on science, mathematics, or technology (36% in 8th grade and 45% in 10th grade). The study track named 'Science and Mathematics' is even the most popular choice throughout the course of secondary education. When leaving secondary education, 45% of students have a diploma from a STEM-oriented study track (STEM monitor, 2018). However, in the transition from secondary to tertiary education students drop out of the STEM pipeline. Only 45% of those choosing STEM in secondary education continue in the STEM-track in higher education. The drop-out rate is even higher for girls, as only 39% of females choosing STEM in secondary education enter STEM-oriented study in higher education (STEM monitor, 2018). While these numbers are slightly more positive than the percentages of earlier years, the need for STEM professionals in Flanders is still substantial; a considerable number of in-demand jobs require applicants to have a STEM background (Vlaamse Dienst voor Arbeidsbemiddeling en Beroepsopleiding (VDAB), 2018). For instance, for each engineering vacancy, the number of candidates is four times lower than the overall number of candidates per vacancy (VDAB, 2018). Another example is the shortage of ICT students. The number of ICT students cannot meet the demands from the industry, which obliges enterprises to engage foreign developers, or to move application projects to offshore corporations (VDAB, 2018).

The 'leaky pipeline' has given rise to the development of educational approaches all over the globe that aim to motivate students to choose a STEM study or profession. These have the potential to improve students' learning. One of the potential promising approaches that could be employed to prevent the problem is integrated STEM (iSTEM), which forms the core of the STEM@School project in Flanders.

The STEM@School project

From 2014 to 2018, a large-scale collaborative project was undertaken between the University of Leuven and the University of Antwerp: STEM@School. Besides the collaboration between the Flemish universities, two educational umbrella organizations were also involved, covering approximately 70% of all secondary schools in Flanders: Catholic Education Flanders and Education of the Flemish Community (GO!). The aim of STEM@School was to develop learning modules for integrated STEM education in secondary schools (9th to 12th grade), and to carry out a thorough evaluation of the effectiveness of this integrated approach. Four PhD researchers from the University of Leuven developed iSTEM learning materials in collaboration with teacher design teams, and two PhD researchers from the University of Antwerp evaluated the project. The role of the two umbrella organizations was to support the participating schools in their implementation, and to monitor the content of the materials developed to ensure that they covered all the learning objectives and curricular guidelines.

The STEM@School project had four main objectives:

1. Develop a curriculum in which iSTEM plays a central role,
2. Design challenging iSTEM learning materials and the design of a teaching method,
3. Implement and evaluate the iSTEM educational approach, and
4. Make recommendations for policy and practice.

The development and implementation of the STEM@School project was built upon key principles based on educational research literature. This evidence-based approach aims to attract more qualified and better motived students to STEM fields by improving students' interest and learning.

Key principles for STEM education

In the educational research literature, some promising instructional practices have been identified, which could potentially increase students' interest in STEM while simultaneously ensuring the attainment of STEM learning outcomes (Thibaut et al., 2018). These practices are inspired by the learning theory of social constructivism. This theoretical framework is based on the ideas of Vygotsky (1980) that learning is a socially situated process, and that knowledge is therefore constructed through interaction with others. The student is seen as an active participant in the learning process, rather than only a receiver of knowledge (Ertmer & Newby, 1993). The use of this framework as an inspiration for STEM education has several implications for instructional practice. Five distinctive but related key principles were identified that are considered most essential for effective STEM teaching (Thibaut et al., 2018):

1. problem-centered learning,
2. cooperative learning,
3. inquiry-based learning,
4. design-based learning, and
5. integration between STEM disciplines.

Problem-centered learning entails the use of authentic real-world problems to create a challenging, motivating, and enjoyable way to learn (Colliver, 2000). Problem-centered learning focuses on applying and transferring knowledge to realistic contexts that resemble challenges encountered by STEM professionals in the workplace (Ashgar, Ellington, Rice, Johnson, & Prime , 2012). The problematic situation thus serves as the organizing center and the context for meaningful learning (Ashgar et al., 2012) and demonstrates the relevance of the learning content (Thibaut et al., 2018). Typically, these challenges are open-ended and allow for multiple solution paths. While there exists mixed evidence about its effectiveness on cognitive outcomes (Colliver, 2000), Norman and Schmidt (2000) argue that the more challenging, motivating, and enjoyable an approach to education may be is a sufficient reason for existing. Furthermore, problem-centered learning might also have non-cognitive effects, such as increased self-efficacy with regard to performance in a future profession (Dunlap, 2005). The study of Merrill and Gilbert (2008) demonstrates that problem-centered learning is most effective when combined with appropriate peer interaction. This also constitutes the second key principle for effective STEM teaching: cooperative learning.

Cooperative learning involves the promotion of teamwork and collaboration with others (Thibaut et al., 2018). Students are encouraged to communicate science concepts and mathematical and engineering thinking in small groups. The meta-analysis of Springer, Stanne and Donovan (1999) demonstrates that cooperative learning in small groups is effective with regard to academic achievement, positive attitudes towards learning, and persistence through STEM courses. An important factor in the effectiveness of cooperative learning is the concept of positive interdependence (Johnson & Johnson, 2009). This exists when students perceive that they can attain their goals only if the other individuals in the group attain their goals. This results in students encouraging and facilitating each other's efforts (Johnson & Johnson, 2009).

Inquiry-based learning requires students to question their current knowledge about a certain topic, and to identify which additional knowledge they require to proceed. Students use their already acquired knowledge to actively design and conduct investigations and experiments (Thibaut et al., 2018). Inquiry-based learning allows students to improve their understanding of both science content and scientific practices and is grounded in the recognition that science is essentially a question-driven open-ended process (Edelson, Gordin, & Pea, 1999). Inquiry-based learning enhances students' science literacy and research skills (Gormally, Brickman, Hallar, & Armstrong, 2009; Ergül et al., 2011).

Design-based learning entails the use of technological or engineering design. Analogous to inquiry-based learning, students do not only learn about the core ideas of engineering, but also deepen their understanding of the engineering design process itself (Guzey, Moore, & Harwell, 2016). Engineering design activities can strengthen students' knowledge of STEM-related content, because they fill the gap between knowledge and the application of the studies' concepts (Thibaut et al., 2018). Indeed, Riskowksi, Todd, Wee, Dark, and Harbor (2009) found design-based learning to be effective as students who were involved in design-based learning displayed higher levels of thinking and greater content knowledge than students who followed a more traditional learning approach.

The integration of STEM content is the last key principle for STEM education. Integrated STEM (iSTEM) aims to merge the fields of the different STEM areas into a single curricular project that emphasizes concepts and their application across the four disciplines (Roehrig, Moore, Wang, & Park, 2012). Removing barriers between disciplines is intended to increase students' conceptual understanding and achievements regarding STEM topics and increase recognition of the relevance of the subjects in relation to each other and to the context of real-world problems (Honey et al., 2014). This way, learning could become more meaningful and prolonged (Becker & Park, 2011). Integrated STEM education is a promising effort to attract more qualified and motivated students in STEM fields by improving students' interest and learning in STEM. It has received increasing attention from educators and researchers over the past decade (Honey et al., 2014; Kelley & Knowles, 2016). Becker and Park (2011) synthesized the effects of iSTEM on students' learning in a meta-analysis. They concluded that integrative approaches among STEM subjects have positive effects on students' learning. Besides cognitive advantages, iSTEM could also positively impact affective outcomes. Judson and Sawada (2000), for instance, reported that the integration of mathematics into a science course led to significantly higher positive attitudes towards mathematics. In a meta-analysis, Yildirim (2016) found integrated STEM to positively impact students' attitudes towards individual STEM disciplines.

In the literature, different levels of increased forms of integration are described. A multidisciplinary approach begins with subject-based content and skills, and students are expected to form connections between the subjects that they have been taught in different classes. Each sub-domain maintains its identity without a direct mixture in the totality of the integration (Wang et al., 2011). An interdisciplinary approach, on the other hand, starts with a problem that requires an understanding of the content and skills of multiple subjects. The boundaries between the subjects are blurry (Wang et al., 2011). The highest level of integration is the transdisciplinary approach (Vasquez, Sneider, & Comer, 2013), where knowledge and skills from multiple disciplines are applied to solve real-world problems. Hence, transdisciplinary is, in fact, interdisciplinary applied to relevant and authentic problems.

As opposed to the previous principles (i.e. problem-centered learning, cooperative learning, inquiry-based learning, and design-based learning), the principle of integration of STEM content can only be applied when the different STEM domains are involved in the learning content. For instance, in physics lessons the principle of problem-centered learning could be applied without making the connection with other disciplines. But, it is by definition impossible to work in an integrated way in physics lessons without introducing concepts from other STEM disciplines. When it comes to effective STEM teaching, it is important that all principles are incorporated in the didactical approach (Thibaut et al., 2018; Kelley & Knowles, 2016). What is more, in educational practice the principles cannot be seen as separate from one another. In the STEM@School project, integration of STEM content is considered as the core, and the connecting principle for the other principles. The integration of STEM contents facilitates the application of the other four key principles. Indeed, in an iSTEM challenge, the lesson is problem-based, students are encouraged to collaborate, and students apply inquiry-based learning and design-based learning to understand and apply STEM concepts.

This dissertation focuses on an educational approach as the combination of all STEM principles, with the integration principle as key facilitator: the iSTEM educational approach. In this approach, the key principles are translated into learning materials.

The STEM@School iSTEM learning modules

As STEM is in secondary education traditionally solely taught in separate courses (e.g. physics and mathematics), new, challenging learning materials should be developed in which these components come together. With regard to the design of the educational approach, the learning materials must comply with the five key principles (problem-centered learning, cooperative learning, inquiry-based learning, design-based learning, and integration of STEM content) and must introduce real-world problems to the students (such as safety issues, mobility issues, and energy problems). An example of an integrated learning module is the energy-neutral house.

The ***energy-neutral house*** is a learning module in which students are challenged to build a house that is heated by solar water heaters and underfloor heating. They learn how to construct a strong roof, and how to reach a certain indoor temperature. To succeed in this challenge, students have to use knowledge and skills from all STEM disciplines, such as pressure, gas laws, thermal energy and phase transitions (science), building the solar collectors with the appropriate materials (technology), programming the control loops with Arduino (engineering), and trigonometry, elementary mathematical functions, and sequences (mathematics).

Figure 1. Example of an iSTEM learning module: the energy-neutral house.

The learning module is a transdisciplinary problem (Vasquez, 2013), because it consists of a challenge that is relevant in terms of societal and ecological problems. Students address these challenges by working in small groups and applying knowledge and skills across disciplines, thereby making connections between principles and concepts. Students are active participants in their learning, as they search for answers to their own questions (e.g. "what is the optimal design for a stable roof?"), and reflect on their learning (Buckner & Kim, 2014). This inquiry-based learning requires the development of problem-solving skills and engineering design competences (Moore & Smith, 2014; Thibaut et al., 2018). These characteristics are the foundation of all learning modules.

Evaluation of the iSTEM educational approach

While previous research has suggested that an iSTEM educational approach constituted around the five principles might be effective (Becker & Park, 2011; Yildirim, 2016; Kelley & Knowles, 2016), and various programs for iSTEM education have consequently been developed, assessing the general effectiveness of these approaches still needs empirical research. It is important to gain insight into both the cognitive and the affective effects of an iSTEM educational approach. Indeed, both components are involved in students' decisions to choose to study STEM (Dweck, 2002), and both components should be taken into account when investigating whether iSTEM education could prevent the STEM pipeline from leaking. Research has shown that students' cognitive STEM performances in secondary education both predict their study choice (Parker et al., 2012) and predict their academic achievement in higher education (Benbow & Arjmand, 1990). Affective outcomes are also very decisive for students' future job or study choices.

Research has extensively shown the importance of attitudes, motivation, and self-efficacy. Students with more positive attitudes towards a certain field are more likely to make a study choice in that field (Armitage & Conner, 2001; Taylor, 2015). Students who express more positive forms of motivation also exhibit better learning results and engagement (Ryan & Deci, 2000b; Kusurkar, Cate, Vos, Westers, & Croiset, 2013), which can in turn lead to more persistence and less drop-out in the educational trajectory (Vallerand & Bissonnette, 1992; Vallerand, Fortier, & Guay, 1997; Ntoumanis, 2005). Besides attitudes and motivation, self-efficacy is also an important factor that predicts willingness to participate in STEM and study choice behavior. Lau and Roeser (2002), for instance, found that students with high levels of self-efficacy with regard to science in secondary education are more inclined to choose to study science in higher education. Also, with regard to these cognitive and affective variables, there could be a differential impact of iSTEM for students with different characteristics such as sex, abstract reasoning ability, and socioeconomic status (Halpern et al., 2007; Deary, Strand, Smith, & Fernandes, 2007; Yerdelen-Damar & Peşman, 2013; PeWang & Degol, 2017; Shin et al., 2015; DeWitt & Archer, 2015). Hence, if the goal is to attract more competent and engaged students in STEM fields, all these variables should be included in the evaluation of an iSTEM educational approach.

Current challenges

To date, several gaps exist in the literature that aims to evaluate the effectiveness of iSTEM (Becker & Park, 2011; English, 2016). A first gap in the current body of knowledge is the number of studies that have integrated all components of STEM. Most studies concern interventions with the integration of only two or three components (e.g. Apedoe, Reynolds, Ellefson, & Shunn, 2008). Second, not all relevant outcomes of iSTEM education have been investigated. Few studies reported on more than two associated cognitive outcomes (Becker & Park, 2011). Also, most research has focused on cognitive outcomes rather than on affective outcomes (Becker & Park, 2011; Yildirim, 2016; English, 2016). A third concern is the small scale of the interventions and the predominantly short time period in which they are evaluated. To conclude, long-term empirical research with the integration of all STEM components is very rare and, as a result, the effects of an iSTEM approach on relevant cognitive and affective outcomes is a crucial gap in the field. This dissertation aims to contribute to the field of iSTEM evaluation by addressing these issues.

Positioning of the studies

Since students are currently disengaging from STEM, and given the need for a thorough evaluation of an iSTEM educational approach, the aim of this dissertation was twofold: (1) we wanted to provide more insight into students' perspectives on STEM, and (2) we wanted to evaluate the effectiveness of an integrated STEM educational approach, in terms of cognitive and affective outcomes. Hence, the current dissertation combines the project goals of STEM@School with regard to an iSTEM effectiveness assessment with broader challenges in the field of STEM research. Five studies are included in this dissertation, which are schematically represented in Figure 2.

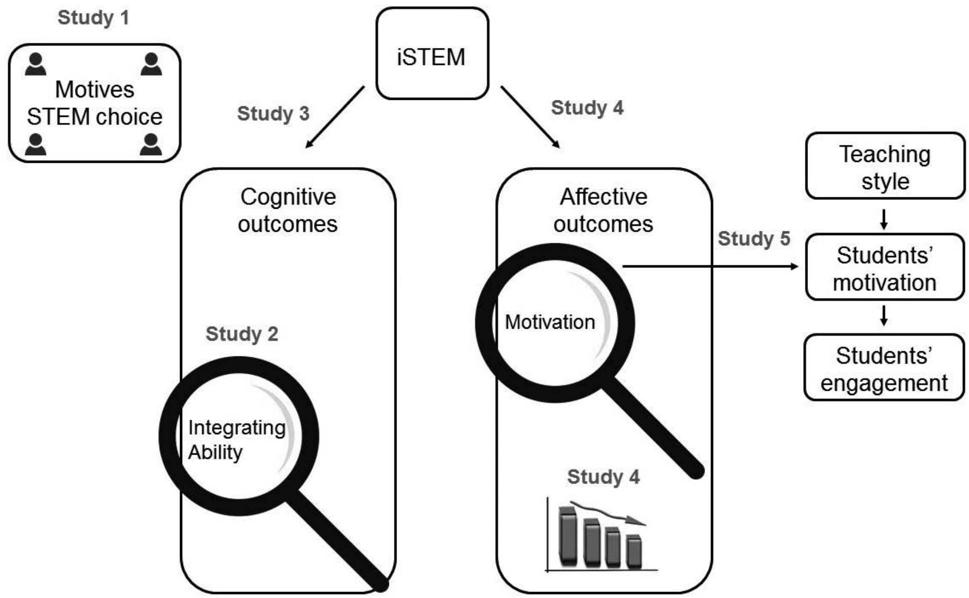


Figure 2. Schematic overview of the studies included in the dissertation.

All the studies provided pieces of information that help researchers and practitioners to fully grasp the problem of disengagement with STEM and provide guidance in decision-making about interventions that may prevent this evolution. First, we aimed to contribute to the domain of STEM study choice. Previous research has shown that students become less engaged in STEM over time (e.g. George, 2006; Ardies, et al., 2015). Nevertheless, there was a group of students who were considering STEM study who could provide us with valuable information about the factors that convince students to pursue a STEM career. Hence, we explored the motives of students who were currently considering whether to choose a STEM profession. This way, we gained insight into what students found important for their STEM study choice, and we consequently decided which components could possibly be emphasized in the learning modules. This also revealed which motives and which groups of students were still missing within the STEM choosers. Hence, *study 1* functioned as an analysis of the state of affairs, and as an exploration of the prevailing challenges with regard to the choice of studying STEM.

After the establishment of the project goals and the desired scientific contributions, we defined a set of relevant outcome variables which would provide information about the effectiveness of iSTEM education. Both cognitive and affective outcome variables were included, as both components are crucial with respect to study choice (Dweck, 2002). The assessed cognitive outcomes in this dissertation were outcomes regarding physics, mathematics, technological concepts, and integrated physics and mathematics. The affective outcomes investigated were attitudes, motivation, and self-efficacy. Before conducting the studies, there should be conceptual clarity about the constructs measured, and validated test instruments should be available. *Study 2* elaborated on the conceptualization of the construct of one of the outcomes of interest, namely, integrating ability. This is the ability to purposefully combine recently acquired knowledge and skills from two or more distinct STEM disciplines to solve a problem in a familiar context that necessitates this very combination to solve it. Besides the construction of the theoretical framework, this study also describes the development and the validation of an instrument to assess integrating ability.

After defining the concepts of interest and developing and validating all necessary instruments, we assessed the effectiveness of iSTEM education on cognitive (*study 3*) and affective outcomes (*study 4*). In these two effectiveness studies we investigated the general and differential effects of iSTEM on student outcomes. Besides the effect of iSTEM on affective outcomes, *study 4* also assessed the development of students' attitudes, motivation, and self-efficacy with regard to STEM in the general population. Together with *study 1*, this part of the dissertation contributes to a better understanding of why students do (or do not) engage in STEM.

The evaluation of an iSTEM intervention provided insight into which outcomes benefited from this educational approach and revealed for which outcomes this approach was less beneficial or had mixed effects. In the literature regarding engagement in the school context, it has been suggested that the teacher might play an important role, too (Tessier, Sarrazin & Ntoumainis, 2010). The teacher could have a facilitating or impeding impact especially with regard to motivation. In *study 5* we investigated the impact of teachers' motivating style on students' motivation and engagement. This knowledge could be applied to optimize the application of an iSTEM approach and adds to the theoretical framework regarding the relationship between teachers' motivating style, students' motivation, and students' engagement.

To conclude, in order to provide more insight into the problem of students' disengagement in STEM, we conducted several studies that investigated students' (changing) relationships with STEM. Thereby, we investigated the effect of iSTEM as a possible intervention.

Research questions of the this dissertation

We adopted a quantitative approach to advance our understanding of students' relationships with STEM, and of the effectiveness of an iSTEM educational approach to change this relationship. We started on the basis of the problem that STEM professionals are needed, but that a decline in interest in pursuing a STEM career has been observed during recent decades. Thus, insight into the mechanisms of this problem and the evaluation of possible solutions was crucial. Therefore, we answered the following research questions in this dissertation:

Study 1: To what motives do students attach importance when considering studying STEM, and which profiles regarding STEM motives can be identified?

While previous research has focused on the prevalence of relevant study choice motives, little is known about how much importance students attach to various motives when making their study choice in STEM. Hence, the first aim was to gain a better insight into the study choice motives of students. Besides uncovering the importance of various STEM motives, this study also adopted a person-centered approach, which provided a complementary insight into the relative importance of clustered motives for different subgroups of students. The first study was based on cross-sectional self-report questionnaires with regard to study motives.

Study 2: How can we conceptualize integrating ability, and how can this construct be measured?

The second study provided a definition of 'integrating ability' and established a framework for understanding its components. Based on this definition and framework, a multiple-choice instrument for testing integrated physics and mathematics in the ninth grade (IPM9) was developed and validated through Item Response Theory (IRT) research.

Study 3: What is the effect of an iSTEM intervention on students' cognitive performance, and what is the differential effectiveness with regard to student characteristics?

In the third study, we aimed to evaluate the effectiveness of a large-scale two-year intervention in which students had to respond to relevant challenges by making use of knowledge and skills from different STEM domains. We incorporated all four domains in the intervention and investigated the cognitive effects on physics knowledge, physics application, mathematics knowledge, mathematics application, technological concepts, and integrating ability. In a longitudinal study, we investigated the effect on these cognitive outcomes and the differential effect of sex, socioeconomic status (SES), and abstract reasoning.

Study 4: How do affective outcomes regarding science and mathematics evolve over time, and what is the general and differential effectiveness of iSTEM with regard to these affective outcomes?

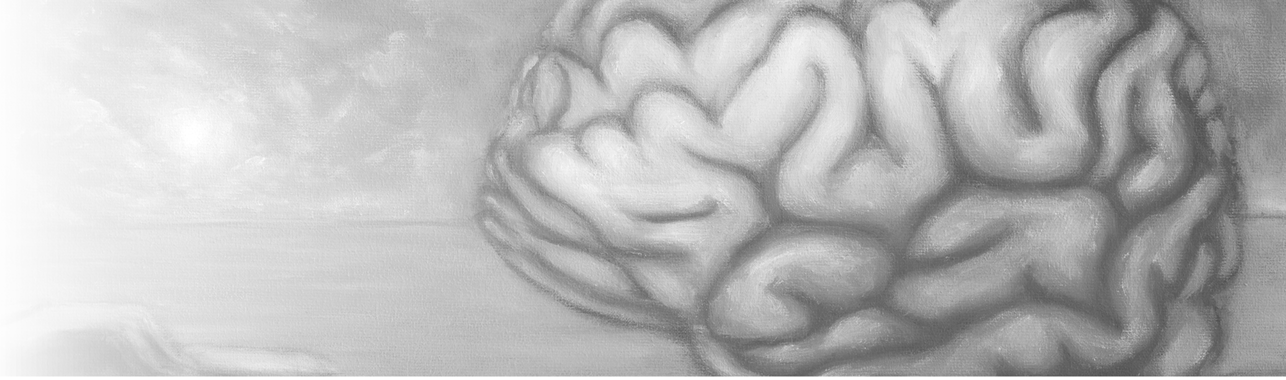
We examined the impact of a two-year iSTEM intervention on students' affective outcomes regarding STEM. In this study, we focused on science and mathematics affective outcomes, and investigated (1) the evolution of affective outcomes regarding science and mathematics over time in traditional education, (2) the impact of an iSTEM curriculum on affective outcomes with regard to science and mathematics, and (3) the differential effectiveness of the iSTEM curriculum regarding sex and SES.

Study 5: What is the relationship between STEM teachers' motivating style, students' motivation towards STEM, and students' engagement?

The fifth study used the framework of self-determination theory (SDT) to investigate the relationship between teachers' motivating style (autonomy support, provision of structure, and involvement), students' motivation (controlled vs. autonomous), and students' engagement with STEM. In the literature, no direct links have been investigated between these three concepts, and the topics of motivation and engagement in the STEM context have been insufficiently researched. Classroom observations for teachers' motivating style and students' engagement were connected to students' self-reported motivation to study several STEM-related subjects.

The five studies are described in separate chapters. Although all five chapters contribute to the understanding of students' relationships with STEM, or the effectiveness of iSTEM education, each chapter can also be read on its own. Therefore, repetition or overlap across the chapters is inevitable. The final chapter gives an outline of the main findings of this dissertation. Furthermore, we discuss implications for researchers and practitioners, and address key challenges for future research.

CHAPTER 2



Study 1:

Understanding the choice for a study in STEM. Motives and STEM-profiles among students.

This chapter is based on:
De Loof, H., Boeve-de Pauw, J., & Van Petegem, P. (Submitted).
Understanding the choice for a study in STEM.
Motives and STEM-profiles among students.

Abstract

At the moment societies around the globe are facing a shortage of STEM professionals. Insight into the motives for the study choice of students is crucial to understanding why they do choose such a study or decide on a profession in STEM. While previous research has focused on the prevalence of relevant STEM motives, little is known about how much importance students attach to various motives when making their study choice. The aim of the present paper is to gain a better insight into the study choice motives of students. Besides uncovering the importance of various STEM motives, this study also adopts a person-centered approach which provides a complementary insight in the relative importance of clustered motives for different subgroups of students. To achieve these research goals, 25 diverse motives for choosing a field of study in higher education were presented to 991 students aspiring to be STEM-professionals (mean age = 13.84 years). This study revealed that there are six underlying dimensions in the motives: external motives, self-efficacy and interest, career status, social motives, future perspectives, and intellectual status. A cluster analysis of the dimensions provided evidence for four distinct STEM-profiles: motivated choosers, non-motivated choosers, typical choosers, and external choosers. These insights can be valuable for study counseling and career choice programs in order to attract more motivated students into the STEM field.

1. Introduction

Recently, a lot of attention has been paid to the shortage of STEM-schooled professionals on the labor market. STEM is an acronym for Science, Technology, Engineering and Mathematics. The STEM field has been growing rapidly in recent years, and therefore the demand for STEM-schooled professionals has been increasing globally (Marginson, Tytler, Freeman, & Roberts, 2013). Despite the sufficient presence of students in STEM-oriented study programs in secondary education, few students are choosing STEM in higher education (Hernandez et al., 2014). A crucial furcation point therefore seems to be the moment the students make a choice with regard to their proposed field of study in higher education. The shortage of professionals in the hard sciences (e.g. physics, technology, engineering, and mathematics) is even higher than in the case of the soft sciences (e.g. biology and health issues) (Bøe et al., 2011; OECD, 2008). Given the challenges of the 21st Century (e.g. global warming, traffic problems, shrinking resources, etc.) and the need for creative innovation, STEM-schooled professionals are essential to safeguarding and developing human well-being, economic growth and sustainability (Kjærnsli & Lie, 2011). If we want to face these challenges, it is important that a sufficient number of students make a motivated choice in terms of study or a career in STEM. As the teenage years are of the outmost importance when it comes to identity development and career exploration (Super, 1980), research on STEM career intentions has mainly focused on students in secondary education (e.g. Wang, 2013). Gaining a better insight into the motives of students who are making decisions about their professional future is crucial in order to contribute to solving the shortage of STEM professionals. As previous research has mainly focused on understanding disengagement in STEM (e.g. Watt et al., 2012), little is known about the study choice motives of students who decide to pursue a STEM career. This paper focusses on the latter group of students, in order to contribute to the domain of STEM study choice. Several theoretical frameworks have provided perspectives to identify the main motives for choosing a field of study, of which the social cognitive career theory (Lent, Brown, & Hackett, 1994), expectancy-value theory (Eccles, 1994), and theories regarding personal interest (Hidi & Renninger, 2006) are the most influential.

1.1. Frameworks of motives

Social cognitive career theory (SCCT; Lent et al., 1994) is a theoretical framework that can shed light on the reasons why students choose a STEM career or study. SCCT posits that choice aspirations are influenced due to beliefs about the performance capacity of the individual (self-efficacy), the outcomes to which efforts could lead (expected outcomes) and goal mechanisms. These personal variables may interact with contextual factors such as social supports and barriers, or socio-demographic, material, and/or financial factors (Lent, Paixão, Silva, & Leitão, 2010). According to SCCT, students' interest is developed largely on the beliefs about their self-efficacy and outcome expectations (Lent et al., 2010).

Consequently, SCCT distinguishes five main underlying reasons for choosing a STEM career:

1. *Self-efficacy*, i.e. believing that one will perform well in this field,

2. *Outcome expectancies*, i.e. believing that choosing a certain field of study will help one attain social prestige,

3. *Goal mechanisms*, i.e. having a clear career goal related to STEM,

4. *Contextual factors*, i.e. benefiting from parental support for a particular area of study, and

5. *Interest*, i.e. having STEM-related interests.

Another widely applied framework that is used to explore and explain educational and occupational choice behavior is *expectancy-value theory* (EVT; Eccles et al. 1983; Eccles, 1994). Using the modern EVT, five key underlying factors influencing STEM choice can be detected (Eccles & Wigfield, 2002; Boeve-de Pauw, Van Petegem, & Lauwers, 2014):

1. *Interest* – enjoyment value (or intrinsic value) e.g. choosing to study biology because one is fascinated by living organisms

2. *Self-efficacy* – expectation of success, e.g. choosing biotechnology because one believes one will succeed in this area of study

3. *Attainment value* – the importance of performing well in a subject, which is related to the degree to which the study matches with a student's identity, e.g. choosing to become a scientist because one has the feeling that this profession suits one

4. *Utility value*, e.g. the qualification leads to many options on the labor market, and

5. *Relative cost* – negative implications, e.g. the number of years of study.

Where SCCT considers interest as a mediating factor for the role of self-efficacy and outcome expectations on choice consideration (Lent, Brown, Nota, & Soresi, 2003; Lent et al., 2010), and EVT regards interest as one component of a multifaceted model, other studies have concentrated on interest as the main reason why people choose a particular area of study or career (e.g. Morgan, Isaac, & Sansone, 2001). Indeed, the literature regarding interest development, describes a four-phase model that could predict students' study choice (Hidi & Renninger, 2006). Within the four-phase model of interest development, triggered situational interest, maintained situational interest, emerging individual interest, and well-developed individual interest are distinguished. The four phases are considered to be sequential, and in cases where interest is supported and sustained, the individual will develop progressively. Further interest development corresponds with greater chances to choose and persist in a study in the respective domain (Fink, 1998, Harackiewicz, Barron, Tauer, & Elliot, 2002, Renninger, Ewen, & Lasher, 2002). From this perspective, the low enrollment numbers in terms of STEM studies could be caused by a limited interest in STEM-related topics. Consistent with this assertion, Sjøberg and Schreiner (2010) reported that the level of interest on the part of students from European countries and from other developed countries outside Europe was quite low. A possible explanation may be that students in wealthy countries are more selective in their interests than students in less wealthy countries, because they perceive school more as an obligation than as a privilege (Sjøberg & Schreiner, 2010).

1.2. Motives and motivation

SCCT, EVT and interest-based models provide insight into the reasons why students choose a STEM-related field of study or a career in STEM. Summarizing, motives regarding self-efficacy, outcome expectations or value, and perceived barriers, were highlighted across different approaches, and all approaches stressed the importance of interest. Several studies rely on these motive constructs to predict choice considerations with regard to STEM studies and careers (e.g. Lent et al., 2003; Wang, 2013). Other studies (e.g. Shin, Rachmatullah, Roshayanti, Ha, & Lee, 2018) use these constructs to develop a compound measure to assess willingness to choose a STEM career, and investigate the role of other factors (such as country, gender, and education level) with regard to this choice. Although considerable research has been devoted to the role of different predictors for study choice (Lent et al., 1994), less attention has been paid to the role of students' self-perceived importance when it comes to STEM study motives. Yet, the degree to which students attach importance to a certain motive is important, because some motives might be more adaptive than others in terms of psychological and academic outcomes. For instance, we might expect different study results from a student who has chosen a certain area of study predominantly for the amount of teaching hours than from a student who has chosen this study because of interest. For that reason, it is relevant to be aware of the interplay between study choice motives and study choice motivation.

The concept of a motives, not to be confused with motivation, refers (within the current article) to a reason for choosing a certain area of study without making a statement about the quality of that reason. Motivation on the other hand, is viewed as the quality of a reason and concerns the type of reason that underlies the study choice. Motivation has been studied extensively through, for example, the lens of self-determination theory (SDT; Ryan & Deci, 2000c). According to SDT, behavior can be controlled (associated with the experience of being pressured or coerced) or it can be autonomously motivated (accompanied by the experience of volition and choice) (Ryan & Deci, 2000c; Vansteenkiste, Lens, & Deci, 2006). With regard to controlled motivation, two regulation types can be distinguished: *external regulation* (the behavior is urged by external factors such as rewards or punishments) and *introjected regulation* (the behavior is induced by internal pressure such as feelings of guilt and shame). A more autonomous form of motivation is that of *identified regulation* (doing an activity because of the value of the activity, such as personal relevance). At the end of the autonomous motivation continuum, intrinsic motivation can be placed. Behavior that is an expression of intrinsic motivation does not have to be regulated: the activity is carried out because one enjoys the nature of the activity (Ryan & Deci, 2000c; Vansteenkiste, Lens, & Deci, 2006).

Autonomous motivation has been linked to adaptive career decision making (Guay, Ratelle, Sene´cal, Larose, & Deschenes, 2006), whereas controlled motivation is associated with negative outcomes such as less career satisfaction (Vansteenkiste et al., 2007). Besides the quality of a reason for a choice, SDT approaches choices also in terms of the content of the goals choosers value. Intrinsic goals, such as contributing to society, are distinguished from extrinsic goals, such as wealth and image (Vansteenkiste et al., 2006). The pursuit of extrinsic goals are typically negatively related to wellbeing, whereas the pursuit of intrinsic goals is related to more positive outcomes (Vansteenkiste, Simons, Lens, Sheldon, & Deci, 2004).

Although study choice motives and study choice motivation are different concepts, we can connect each study to underlying motivation. It is worth noting that one motive is not necessarily restricted to a single possible underlying motivation. For instance, students can indicate that the main reason for choosing a particular STEM study, is that they believe they are capable of mastering the related subjects. However, for one student, this motive may stem from the fear of others' negative judgements (controlled motivation), whereas another student may look forward to the enjoyment of having the feeling of mastering a subject (autonomous motivation). For other motives, the relationship with the underlying motivation is much clearer: the motive of having interest is obviously related to intrinsic motivation, which is par excellence an autonomous form of motivation. Hence, study choice motives and study choice motivation are different concepts, but could not be seen separately from each other. As the underlying motivation for a motive has implications for the psychological and academic outcomes of the study choice, it is of great importance to investigate the importance that students attach to various study choice motives.

In summary, it is not sufficient to make an inventory of relevant motives that are provided by theoretical frameworks. It is also essential to know how much importance students attach to various motives when making their study choice. Additionally, study choice might be multi-determined. Multiple reasons or motives might be important when it comes to study choice, such as interest in the course material, the prestige of the field of study, or the possibilities of employment. Yet, we might assume that some motives are of great importance to some students, whereas other motives might be more important for others. Furthermore, we can hypothesize that some different subgroups of students exist, being made up of students who combine some motives in a particular way. The assumption that students can attach great importance to more than one motive may reflect a truer representation of students' motive configuration, such as, for instance, choosing a STEM subject both because it leads to a well-paid job and because others recommended this field of study. Hence, distinct groups of student types might exist that can be identified in terms of different motive profiles.

1.3. Motive profiles

In the light of the above, we must adopt a person-centered approach in order to identify different motive profiles. This approach complements the approach involving the investigation of the presence of study choice motives and their effects on the likelihood of pursuing a STEM career (e.g. Boeve-de Pauw et al., 2014; Morgan et al., 2001; Lent, Lopez, Lopez, & Sheu, 2008; Lent et al., 2010), which is generally used in motive research. Indeed, research on study choice motives with regard to STEM has typically adopted a variable-centered approach, and has examined the effects of STEM motives through structural equation modeling (e.g. Lent, Sheu, Gloster, & Wilkins, 2010; Wang, 2013). Research examining the effects of STEM motives entails the hypothesis that each additional motive will increase the chance that someone will chose a STEM study (e.g. Lent et al., 2003), or uses motives as a compound measure to assess STEM career motivation (e.g. Shin et al., 2018). The assumption that the addition of motives will lead to an increased probability of choosing a STEM study, and better study outcomes, might not be optimal, as it is possible that fewer motives lead to equivalent or even more positive outcomes. For example, it might be possible that a mixed motive profile with regard to an area of study involving high importance in terms of interest and low importance in terms of social status, might yield more positive outcomes than a profile characterized by both high importance of interest and high importance of social status. Hence, it would appear necessary to better understand the different clusters that exist in STEM study choice motives.

In this study, we have adopted a person-centered approach, since this yields multiple advantages (Gillet, Vallerand, & Rosnet, 2009): (1) it allows us to consider study choice as being multi-determined, (2) it provides opportunities to classify students in terms of meaningful subgroups, and provides information on motive profiles as they actually exist in a study choice context, and not simply as theoretically proposed by SCCT, EVT and interest-based models, (3) it abandons the idea of motives as additional constructs, but presents motives as part of a more complex interplay, and (4) it allows researchers to determine the number of students characterized by distinct motive profiles, which is not possible with correlation or regression analyses.

Besides the advantages from a theoretical viewpoint, a person-centered approach has also benefits at the practical level (Vansteenkiste, Sierens, Soenens, Luyckx, & Lens, 2009). Such an approach highlights the relationships between the constructs at the level of the individual, and allows students to be allocated to subgroups which are characterized by an optimal or a suboptimal motive profile. The division of students in these subgroups is advantageous both from a diagnostic and an intervention point of view (Vansteenkiste et al., 2009). First, the combination of important motives that is typical of a certain motive profile offers more diagnostic information about what drives a student to choose a particular study. Second, intervention efforts aiming to attract more students to STEM, can accommodate the needs of particular groups of students (Hayenga & Corpus, 2010; Roeser, Eccles, & Sameroff, 1998). Third, in the context of study choice, support and advice is given at the level of the individual. Knowing and understanding different student profiles can lead to students feeling seen and understood, which can enhance their motivation (Larkin-Hein & Budny, 2000). Fourth, the insights arising from a person-centered approach make it possible to investigate whether or not new teaching programs for STEM are altering the distribution of students between different STEM-profiles, possibly in favor of more adaptive profiles linked with autonomous forms of motivation or intrinsic goals.

1.4. Aim and research questions

The aim of the present paper is to gain a better insight into students' motives for study choice in terms of STEM. This will add to the body of knowledge by focusing on students' self-attached importance to these motives. Furthermore, this study aims to explore these motives through a person-centered approach. The current study, therefore addresses two central research questions:

1. To what underlying motives do students attach importance when considering studying a particular area of STEM?

2. Which student profiles regarding STEM-motives can be identified?

2. Method

We explored the underlying motives for making a study choice in STEM and the importance of these motives in study 1, and further examined the presence of student profiles in study 2.

2.1. Participants

To answer these research questions, we made use of a convenience sample: the schools participated in a large-scale study in which the effectiveness of integrated STEM was investigated. Participants were students attending 37 different secondary schools in Flanders (the Dutch speaking part of Belgium) who had stated that they would like to have a career in STEM. In general, the emphasis in their chosen curriculum was on science and mathematics or industrial sciences. The average age of the participants was 13.84 years and 96% were born in Belgium. Participants indicated the country of birth for both their parents: 89% of their fathers and also 89% of their mothers were born in Belgium. With regard to parents' level of education, participants' answers revealed that 67% of their fathers and 76% of their mothers had obtained a degree in higher education.

We made use of two groups of participants, as described in Table 1. Both groups participated in the study at the beginning of grade 9, but the second group participated one year after the first group. The first sample comprised 989 students (63% boys, 37% girls), from which 537 indicated that they were considering a STEM-career (81% boys, 19% girls). The second sample was similar to the first, and consisted of 1,247 students (39% girls, 61% boys), of whom 454 were considering a STEM-career (21% girls, 79% boys).

Table 1. Description of two samples of participants

Sample	1	2
Total *N* respondents	989	1247
→ *N* STEM choosers	537	454
% boys; % girls	81%; 19%	79%; 21%
***M* Age**	13.86 (*SD* = .56)	13.83 (*SD* = .54)

2.2. Procedure and instruments

All students completed an online questionnaire including demographic information, along with measures for study and career choice consideration, and study choice motives. Using an open-ended question, students were asked which profession they would like to practice in the future. By drawing on the approach of Morgan et al. (2001)the desire for interesting work was cited by most students in the sample (89% White, 6% Asian, 5% other, students' responses to this question were coded independently by two researchers into the following categories: (1) not math- or science-related, (2) related to a traditional math or science field, or (3) related to an application of math or science in medical or health services. Decisions regarding the classification of a profession were based upon the study categorization of the Flemish Ministry of Education (Onderwijskiezer, 2016). The students included in the analysis of the present study (n_1 = 537 and n_2 = 454) were all found to be part of category 2 (considered to be hard science), which implies that they had indicated a desire to aspire to a (non-medical) STEM-profession.

In the first study, we validated a study choice motive questionnaire which consists of a variety of study choice motives that have been demonstrated to play a role in the study choice process (e.g. interest, self-efficacy, contextual factors, outcome expectancies, relative cost, etc.). The instrument consisted of 25 motives (presented in appendix A) which were primarily based on the shared and unique motive components of SCCT (Lent et al., 1994) and EVT (Eccles & Wigfield, 2002). Also, previous study choice literature was consulted to detect additional motives that were not covered by SCCT or EVT (e.g. Scarbecz & Ross, 2002). The definite questionnaire was also used in the study of Boeve-de Pauw et al. (2014), who investigated a similar population to the one in the current study. Participants indicated on a five-point Likert scale, ranging from 1= *No influence* to 5= *Strong influence* how much influence these 25 motives have on their intention to choose a STEM study in higher education. After validation, the instrument was used in the second study. The students voluntarily completed the questionnaire in their schools during normal school hours, after permission was obtained from the institutional ethical committee and the students' parents, in line with Belgian legislation.

2.3. Plan of analyses

Table 2. Overview of analyses

Study	1		2
Research question	1		2
Analysis	EFA	CFA	CA
Sample	1	2	2

Study 1. Exploratory factor analysis (EFA) was used to explore the data and find a smaller set of meaningful underlying dimensions. The EFA was performed on the first sample of participants (see Table 2). As the instrument was not based on one theoretical model, but consisted of items from different models and scales, an explorative approach was chosen. Maximum-likelihood extraction followed by varimax rotation was employed (Costello & Osborne, 2005). The number of factors was reduced by a visual inspection of the scree plot (Cattell, 1966), and based on the Kaiser criterion (eigenvalues >1; Cohen, Manion, & Morrison, 2002; Raîche, Walls, Magis, Riopel, & Blais, 2013). We only withheld items with a factor loading >.35 (Cohen et al., 2002). Items with factor loadings on two or more factors were removed, after which replicate analyses were performed. Consequently, a label was assigned to each dimension based on the content of the item groups. Information on scale reliability was obtained using Cronbach's α internal consistency estimates.

The results of the EFA, measured in the first group of participants, regarding the underlying motives in the instrument, were validated with a second group of participants (see Table 2). Confirmatory factor analysis (CFA) was thus carried out on the second sample to examine the factor structure of the motive questionnaire. The fit of the factor structure was evaluated using the comparative fit index (CFI), the root mean square error of approximation (RMSEA) and its 90% confidence interval (CI), due to the tendency of the chi-square statistic to reject well-specified models with relatively large sample sizes (Hair, Anderson, Tatham, & Black, 1998). A good factor structure is achieved when the CFI is close to .95, the RMSEA is close to .06 (Hu & Bentler, 1999), and the lower boundary of the 90% CI of the RMSEA includes the value of .05 (Browne & Cudeck, 1993). The participants' scores with regard to the motive factors were examined in order to determine which motives they find most important when making a study choice (first research question).

Study 2. In order to answer the second research question, we used cluster analysis (CA) on the second sample (see Table 2) to generate STEM study choice motive profiles, based on the motive scores. CA is a technique that is used to detect groups of students with similar patterns of variation across sets of variables (Mooi & Sarstedt, 2011). It maximizes between-group heterogeneity and within-group homogeneity. A two-stage CA procedure was used, where hierarchical cluster analysis was performed to determine the optimal number of clusters, and non-hierarchical *k*-means CA was used to further fine-tune the cluster solution through an iterative process (Gore, 2000; Hair et al., 1998). Because hierarchical cluster analyses are sensitive to outliers in the data, we began our analyses by removing multivariate outliers (Mahalanobis distance values, $p<.0001$) and univariate outliers (z value >3.29). As a first step, we used Ward's method to execute a hierarchical CA based on squared Euclidian distances. Statistical criteria were used to determine the most suitable number of clusters; each separate cluster should not contain fewer than 5% of the total number of respondents, and a multivariate test should indicate that the cluster solution explains at least 50% of the total variance (Milligan & Cooper, 1985; Tinsley & Brown, 2000). In the second step, a non-hierarchical *k*-means clustering procedure was performed with the initial cluster seeds of the results of the hierarchical cluster analyses. A maximum of 20 iterations was allowed. We assessed whether or not clusters differed significantly on the underlying variable through post-hoc analysis. The final cluster centers were investigated in order to interpret the cluster solution (Mooi & Sarstedt, 2011).

3. Results of Study 1

3.1. Validation of an instrument to assess the importance of STEM study choice motives

In the first study, EFA was conducted to distinguish the underlying motives students report when considering a study in STEM. EFA revealed six underlying dimensions of motives for study choice. Factor scoring coefficients, and the labels assigned to these factors, can be found in Table 1, including Cronbach's α internal consistency estimates, which are all in the acceptable range ($\alpha > .60$; Cohen et al., 2002), with the exception of 'social motives', which had a Cronbach's α of .58. The dimensions in Table 3 are reported in order of the amount of explained variance. The cumulative explained variance of all six factors was 55%.

The first scale was labelled 'External Motives' because all motives are associated with the external context, and not with the study in essence. The second scale, 'Self-Efficacy and Interest', groups items that tap the importance that students attach to their belief in their ability to master the subject and their interest in it. The third scale was labelled 'Career Status', and groups items that either refer to materialistic benefits or to the social status associated with a particular career. The fourth scale, 'Social Motives', consists of motives regarding commitment to society and social contact. The fifth scale, 'Future Perspectives', concerns motives, with the focus on flexible pathways which keep opportunities open. The sixth and last scale was called "Intellectual Status' because the motives refer to status, without mentioning career or materialistic benefits.

Table 3. Factor structure of motives for study choice and Cronbach's α

Item *Why do you choose this study? Indicate for each statement how much influence this reason has when it comes to making a study choice.*	**Factor** 1	2	3	4	5	6	**Scale**	**α**	**Explained variance**
The number of study years.	.647						External Motives	.70	24%
The number of teaching hours in the curriculum.	.630								
My friends have chosen this study as well.	.549								
My parents recommend this study.	.460								
I do not know what to choose otherwise.	.454								
Student coaches have recommended this study.	.367								
I think my chances of succeeding are rather high with regard to this study.		.643					Self-Efficacy and Interest	.70	11%
I am interested in the courses of this study.		.630							
I think I am capable of mastering the subjects in this study.		.607							
I can perform well in the courses of this field.		.529							
This study leads to an interesting job.		.395							
This study will allow me to acquire a high social status.			.626				Career Status	.73	6%
This study will allow me to achieve my great visions.			.590						
This study offers a lot of opportunities to have a career.			.518						
Later in life, I want to live in high prosperity.			.494						
I want a profession with a lot of human contact.				.623			Social Motives	.58	5%
I want to make an effort for others.				.534					
This study offers a lot of development opportunities.					.696		Future Perspectives	.65	5%
In this study, various directions are possible.					.578				
This study is good for my general development.						.622	Intellectual Status	.63	4%
This study is prestigious.						.578			

CFA validation of the prior EFA data did not result in an acceptable fit, as CFI = .86, RMSEA = .07 (90% CI = .06; .07). We inspected modification indices (MI) to determine if the model could be improved. The MI of item 13 ("This study will allow me to achieve my great visions", part of the 'Career Status' scale) exceeded a value of 23, and the alteration was suggested to add a loading on the 'Self-Efficacy and Interest' scale. As we didn't allow double loadings, item 13 was removed from the model. The adapted model was tested, which eventually resulted in an acceptable fit, as CFI = .89, RMSEA = .06 (90% CI = .05; .07). Standardized factor loadings are displayed in Figure 1 and were uniformly significant. Given the acceptable fit, we proceeded with this model and calculated the participants' mean scores on these six scales to examine which motive factors they find most important when making a study choice.

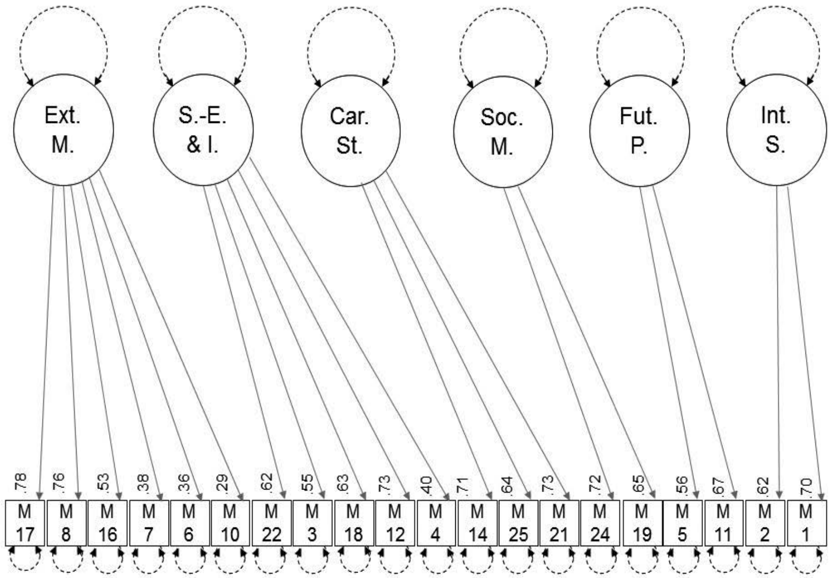


Figure 1. Six factor CFA solution with standardized factor loadings.

3.2. Importance of underlying motives for studying STEM

We investigated the importance of these underlying motives in order to answer the first research question. Descriptive statistics for the six scales are shown in Table 4. On average, 'Self-Efficacy and Interest' appears to be the most important STEM study choice motives, which indicates that students place great emphasis on aspects that are related to the topic of the study itself. External motives appear to be the least important.

Table 4. Scale descriptive statistics

Scale	*N* items	*M*	*SD*
Self-Efficacy and Interest	5	3.96	.51
Future Perspectives	2	3.83	.77
Career Status	3	3.51	.84
Intellectual Status	2	3.18	.90
Social Motives	2	2.76	.94
External Motives	6	1.97	.62

4. Results of Study 2

4.1. Clusters of STEM-motives

To answer the second research question, CA was used. Prior to conducting CA, we removed 1 univariate and 5 multivariate outliers, resulting in a sample of 448 students. Hierarchical CA was used to determine the number of profiles regarding STEM-motives. Solutions ranging from two up to seven clusters were explored. A model with four clusters was considered most suitable, given the statistical criteria (Milligan & Cooper, 1985; Mooi & Sarstedt, 2011; Tinsley & Brown, 2000). The number of respondents belonging to each of the clusters ranged from 79 to 140, which is more that 5% of the total number of respondents for every cluster. A multivariate test indicated that this cluster solution explained 50% of the total variance (Partial Eta Squared = .50), thereby respecting the 50% threshold. The solution with four clusters was preferred to solutions with more clusters since the latter explained below 50% of the total variance, and was chosen over solutions with fewer clusters because the significant differences between the clusters explained fewer variance. The cluster solution explains 44% of the variance in External Motives, 33% of the variance in Self-Efficacy and Interest, 34% of the variance in Career Status, 40% of the variance in Social Motives, 31% of the variance in Future Perspectives, and 29% of the variance in Intellectual Status.

In the second stage, the cluster centers resulting from the hierarchical seed points were used as non-random starting points in the iterative k-means CA. The number of respondents belonging to each of the clusters ranged from 86 to 148 (see Table 5). The final cluster solution explained 52% of the total variance (Partial Eta Squared = .52). This cluster solution explained 48% of the variance in External Motives, 36% of the variance in Self-Efficacy and Interest, 46% of the variance in Career Status, 36% of the variance in Social Motives, 38% of the variance in Future Perspectives, and 43% of the variance in Intellectual Status. All these effects are significant, as shown in Table 6. Note that a Partial Eta Squared <.01 is considered as no effect, .01-.05 as a small effect, .06-.14 as a medium effect, and >.14 as a large effect (Cohen, 1988), which indicates that we can consider all cluster effects on motive scales as large effects.

Table 5. Number of cases in each cluster

Cluster	*N*	%
1	86	19
2	148	34
3	109	25
4	96	22

Table 6. Amount of explained variance by a solution of four clusters

	Motives for studying STEM	Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Cluster	External Motives	203.79	3	67,93	132.46	0.00	.48
	Self-Efficacy & Interest	156.42	3	52.14	81.45	0.00	.36
	Career Status	200.13	3	66.71	123.10	0.00	.46
	Social Motives	153.74	3	51.25	79.72	0.00	.36
	Future Perspectives	166.10	3	55.37	89.00	0.00	.38
	Intellectual status	187.72	3	62.57	110.11	0.00	.43

4.2. Interpretation of STEM-profiles

The mean scores for each cluster with regard to the underlying study choice motives for STEM were used to label and interpret the four clusters. A visual representation of the raw cluster scores on the underlying dimensions is presented in Figure 2; the factor cluster scores are visualized in Figure 3. The raw scores allow for an understanding of the absolute importance of the different motives for the different clusters. The factor scores on the underlying factors are useful when it comes to interpreting the four clusters, as they indicate the relative importance of the motives for the different clusters. For all clusters Figure 2 shows a similar pattern in the importance of study choice motives for STEM, which corresponds with the results in Table 2. Nevertheless, meaningful differences can be observed between the four clusters, as Figure 2 shows distinct patterns in terms of factor scores. The *y*-axis in Figure 2 represents the *SD* or *z* scores, which can be interpreted as effect sizes. An *SD* of .2 can be considered to be a small effect, .5 *SD* a medium effect, and .8 *SD* a large effect (Cohen, 1988).

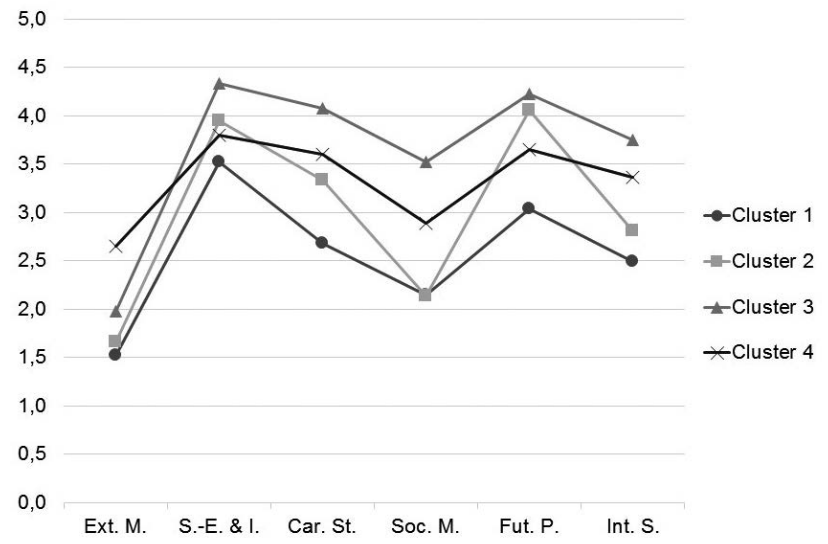


Figure 2. Raw cluster scores on underlying dimensions.

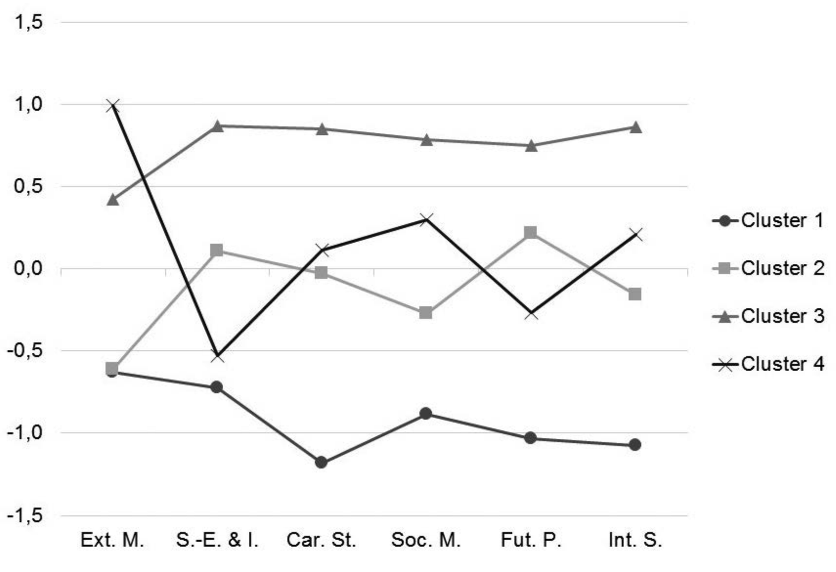


Figure 3. Factor cluster scores on underlying dimensions.

As can be noted, the four clusters were characterized by *z* scores that mostly reflected a medium to strong deviation from the mean. Post hoc tests revealed that all clusters differed significantly on the motive subscales, except for External Motives, where clusters 1 and 2 did not significantly differ, on Self-Efficacy and Interest, where clusters 1 and 4 did not significantly differ, and on Career Status, where clusters 2 and 4 were not significantly different. Hence, the four clusters differed considerably in terms of their profiles regarding the importance of motives for studying STEM. The following groups emerged: (a) cluster 1 or the *non-motivated choosers*, with relatively low scores on all STEM motives; (b) cluster 2 or the *typical choosers* with relatively high scores on Self-efficacy and Interest and Future Perspectives but low scores on External Motives, which follows a rather standard or average pattern; (c) cluster 3 or the *motivated choosers* with high scores on all motive scales; and (d) cluster 4 or the *external choosers* with relatively high scores on External Motives and low scores on Self-efficacy and Interest.

5. Discussion

The present research aimed to examine students' motives for choosing to study STEM, both by investigating the importance of different motives, and by clustering students in meaningful STEM profiles. Therefore, we first validated an instrument to assess the importance of STEM study choice motives. Subsequently, we examined which motives students considered to be most important, and finally we adopted a person-centered approach by determining STEM profiles.

5.1. Validation of an instrument to assess the importance of STEM study choice motives

The first aim was to examine to what underlying motives students attach importance when considering studying in the STEM field. For this purpose, an instrument with 25 study choice motives was analyzed to explore the underlying motives with regard to STEM study choice. The instrument items covered the main motives put forward by SCCT (i.e. self-efficacy, outcome expectancies, goal mechanisms, contextual factors, and interest; Lent et al., 1994), EVT (i.e. interest, self-efficacy, attainment value, utility value, and relative cost; Eccles & Wigfield, 2002) and interest theories. EFA in the first study sample indicated that six underlying dimensions can be found regarding study choice motives for STEM: *External Motives, Self-Efficacy and Interest, Career Status, Social Motives, Future Perspectives,* and *Intellectual Status*. CFA in the second study sample confirmed this result, which provides evidence of the internal validity of the instrument. Nevertheless, some reliability scores were relatively low (e.g. social motives), which could possibly indicate that more items are needed to measure these motives.

In both SCCT and EVT, interest and self-efficacy are central concepts in explaining the choice behavior of students. In our current results, interest and self-efficacy were part of the same dimension or scale. This might be in part explained by the assertion of SCCT that students' interest is developed largely on beliefs about their self-efficacy, thus playing the role of a mediating factor (Lent, Brown, Nota, & Soresi, 2003; Lent et al., 2010).

Another explanation might be that the instrument consisted of only one item that explicitly mentions the inherent interest of a study, hereby reducing the chances of finding a separate interest dimension.

The concepts of outcome expectations (SCCT) and utility (EVT) are similar and compromise one dimension, while in the current study they are distributed among several motive scales (i.e. Career Status, Intellectual Status, Social Motives and Future Perspectives). The context concept of SCCT (which includes barriers) or the costs of EVT can, on certain dimensions, be compared to the external motives that were used in our study. They have in common that the motives do not emerge from ideas or expectations about the study in essence. Instead, external factors such as advice from others or characteristics of the study organization play a more important role.

Some of the subscales of the instruments that were used in our study are unique and add to the STEM motive literature, as they have not been described in earlier research. For instance, no theoretical approach has considered social motives as a separate motive category, neither has the previous literature reported different types of status motives. Our study has made the distinction between career status (i.e. status that emerges from a successful career) and intellectual status (i.e. status that emerges from a prestigious study that benefits the general development). Given that such motives might be at play in the process of study choice, they can have implications for study counselors who might benefit from a comprehensive overview of possible STEM study choice motives.

5.2. Importance of underlying motives for studying STEM

This study was designed to reveal the importance of underlying motives for studying STEM (research question 1). 'Self-efficacy and Interest' appeared to be the most important motives. Thus, the emphasis on Interest as the most crucial factor for pursuing a study or career as highlighted by interest-based research in terms of study choice motives (e.g. Morgan et al., 2001), can be supported by our current results. Because Interest as a motive is closely linked to the concept of intrinsic motivation, it is plausible to argue that students who are considering a STEM-career are intrinsically motivated when making a study choice. This assumption would have positive implications for the wellbeing and performance of the students, as autonomous motivation can be linked with higher psychological wellbeing, better use of meta-cognitive strategies, more determination and perseverance, less procrastination, better cognitive processing, and higher grades (Vansteenkiste et al., 2009).

Besides Interest, this study also highlights the importance of Future Perspectives in terms of STEM study. It indicates that students do actively contemplate the possibilities of their study choice. The status that is associated with a particular STEM study or career is also of substantial influence, though Career Status is seen as more important than Intellectual Status. This finding is highly relevant as research shows that goal content matters for psychological wellbeing (Vansteenkiste et al., 2004).

Students who opt for a STEM study because of the financial benefits and the social status that is involved with it, might be at risk of being predominantly extrinsically motivated, which is linked with negative outcomes (Vansteenkiste et al., 2007).

Surprisingly, relatively low values were found for the importance of social motives when choosing a STEM study. These results might indicate that the social component of STEM-professions is insufficiently clear for students. This finding is in line with research by Struyf, Boeve-de Pauw and Van Petegem (2017) on students' perceptions about the social and societal orientation of hard science careers. They found that stereotypical views of 'isolated' science careers still remain among the student population, although most students had more nuanced perceptions about the social and societal orientation of science careers. The hypothesis that the social component of STEM careers is insufficiently clear, might explain the relative low presence of girls in the sample of our study. Of all students who indicated that they wanted to have a STEM career, only 21% was female. Earlier research (Diekman, Clark, Johnston, Brown, & Steinberg, 2011) found that women tend not to prefer STEM careers because they value altruistic behavior or interpersonal relationships more than men. The low scores on the importance of social motives is not only associated with an underrepresentation of girls in the group of STEM choosers, but it might also be problematic for learning and psychological outcomes. Social motives are classified as intrinsic goals which are linked with more autonomous forms of motivation, which are consequently linked with more positive outcomes (Vansteenkiste et al., 2004). Hence, in future educational initiatives regarding STEM, it might be beneficial to additionally highlight the possibility of contributing to society and working in close contact with others, in order to attract more students (especially girls) with social study choice motives.

The results indicated that the external contextual factors were of least importance when considering STEM as a study choice. This implies that students' motives in general are not driven by controlled motivation, which is a form of motivation that is linked with negative outcomes (Vansteenkiste et al., 2007). However, the mere presence of external motives is not necessarily problematic; some external motives might even be helpful (e.g. student coaches have recommended this study), although caution is advised when a student experiences too much external or internal pressure.

After examining the importance of Self-Efficacy and Interest, Future Perspectives, Career Status, Intellectual Status, Social Motives and External Motives, we extended the STEM motive research by adopting a person-centered approach.

5.3. STEM-profiles

This study adopted a person-centered approach in order to detect profiles regarding STEM-motives (research question 2) and provides complementary insight in the relative importance of the study choice motives of different subgroups as they exist in a real-life study choice context. We found a four-cluster solution that described the variance in importance of students' STEM motives. Two clusters were characterized by either relatively high scores on all motives or relatively low scores on all motives, and were consequently labeled as *motivated choosers* and *non-motivated choosers*. One cluster had a motive profile that matches the group average that was found regarding the importance of motives in the first part of the study, which corresponds with higher scores on Self-efficacy and Interest, and Future Perspectives, but lower scores in terms of External Motives. Accordingly, this group was labeled as *typical choosers*. A last motive profile was characterized by a relative high importance of External Motives, but low scores on Self-efficacy and Interest, and was labeled as *external choosers*.

The study choice motives of the motivated choosers are an expression of intrinsic motivation, as the essence of the study itself prompts the students to pursue a STEM career or study. This profile is highly adaptive, given the high importance of Self-efficacy and Interest (Deci & Ryan, 2000; Fransson, 1977). A less adaptive profile is that of the non-motivated choosers, as they displayed not only lower scores on Self-efficacy and Interest, but also on all other STEM motives. Given the low importance of all motives, one could hypothesize that the non-motivated choosers might be less likely to actually choose a STEM study or career. Bearing in mind that the group of non-motivated choosers represents a substantial percentage of students (19%), this might partially explain why students who wanted to become a STEM professional at the beginning of secondary education are reluctant to choose a STEM study at the end of secondary education.

As STEM motives in a person-centered approach are not merely considered as additional constructs, students with high scores with regard to several STEM motives are not automatically expected to be better adapted to study STEM. The finding that the external choosers are attaching at least as much importance to different STEM motives as the typical choosers, is an illustration of this matter. The external choosers' motives consist of external factors which are mainly based on external regulation (Deci & Ryan, 2000). Given the lack of intrinsic motivation for STEM study, external choosers are possibly more likely to drop out than the typical choosers (Alivernini & Lucidi, 2011). Also, external choosers are hypothetically more susceptible to advertising and trends, since external influence is an important reason to choose STEM. However, not all external motives might be negative. It is possible that some students in this cluster are motivated to choose STEM, but also need affirmation from others regarding their study choice.

Contrary to the finding that external motives seem not to be of high importance in general, but still receives higher importance scores in a subgroup of external choosers, we did not find such a pattern for social motives. Students did not only attach less importance to social motives when considering a STEM study in general, but there was also no cluster that was characterized by higher scores on the importance of social motives. The absence of 'social choosers' might again be an indication that the social component of a STEM career is not sufficiently clear to students.

The findings of this study have implications for practice. First, intervention efforts could be tailored to the needs as revealed by these four profiles. It is, for example, possible to emphasize the challenging nature or relevance of STEM in order to arouse interest, or to highlight the various possibilities of a STEM-study. On the other hand, not all possible interventions might be advantageous, since they might also attract less adaptive profiles. For instance, an intervention that highlights the materialistic benefits of a STEM-career might potentially attract more students, but could eventually lead to an increase in the number of students who are less intrinsically motivated, who may be at higher risk of dropping out (Alivernini & Lucidi, 2011). Second, the person-centered approach might - owing to better insight based on the STEM-profiles - facilitate interventions which aim to attract more students in adaptive profiles. It is, for example, possible to support self-efficacy in students, so that students who believe that a STEM-study is reserved for exceptional students, are less reluctant to choose a STEM-profession. In the same way, insight in STEM-profiles makes it possible to investigate whether or not new STEM teaching programs are altering the distribution of students between the different STEM-profiles. Given the absence of social motives, it might even be desirable to develop an intervention that creates a new STEM-profile, consisting of people who chose STEM partly because of its opportunities to work with others and for the benefit of society. Currently, this is a possible adaptive but under-represented motive. As mentioned earlier, not all profiles might be considered adaptive, and interventions might alter the distribution in a negative way. For instance, a meta-analytic review of Deci, Koestner and Ryan (1999) revealed that extrinsic rewards undermine free-choice intrinsic motivation and self-reported interest. Students who were initially intrinsically motivated to perform a task, became more extrinsically motivated when given a reward. We must bear in mind that if we want to attract more adaptive profiles (such as the motivated choosers), or if we want to alter the distribution between the clusters, we are inevitably choosing a normative approach.

5.4. Limitations and future research directions

The limitations of our study need to be acknowledged, such as the use of a sample of students between 13 and 15 years of age. Although career aspirations are already formed at a young age (Super, 1980), further investigations are desirable to see whether these underlying dimensions for choosing STEM still remain when other age groups are taken into consideration. In other words, it remains an open question as to whether or not motives differ between age groups. For instance, it would be interesting to examine 18 years-old students' motives for choosing STEM, since they are on the verge of making a decision regarding their future study or career. Another limitation concerns the cross-sectional nature of the study. Longitudinal research is needed to investigate whether some students might change to a different cluster over time as a result of psychological maturation processes or exposure to a particular learning environment. Furthermore, the research yields the assumption that study choice is a fully rational and deliberate process. Students might have other motives of which they are not (yet) aware, and which they consequently cannot report. Furthermore, the meaning of the underlying factors and clusters is, to a certain extent, open for interpretation.

The results of our study indicate several exciting paths for future research. First, STEM profiles might be linked with several outcomes such as actual study choice later in life, learning outcomes, and career satisfaction. The hypotheses about the adaptability of the clusters put forward in this study should be empirically tested in order to predict future study and career outcomes. Not only could this elucidate the implications of belonging to a certain STEM motive cluster, it could also be a suitable approach for testing the external validity of the clusters. Furthermore, connecting a person-centered approach with study and career outcomes might make these profiles employable in study counseling and career choice programs. Second, additional research is needed involving other countries and cultures to investigate if the same STEM-profiles are found around the world. It cannot be ruled out that regional, international and cross-cultural differences have an influence on the importance of motives for choosing STEM (e.g. Sjøberg & Schreiner, 2010).

6. Conclusions

The current research originated from the finding that little was known about the importance attached to motives with regard to a study choice in STEM. Besides a study of the importance of STEM motives, a person-centered approach also provides a complementary insight into the relative importance of the study choice motives of different subgroups. This study has established that six dimensions of motives for choosing STEM exist: External Motives, Self-Efficacy and Interest, Career Status, Social Motives, Future Perspectives, and Intellectual Status. Self-efficacy and Interest seem to be of the highest importance, while External Motives generally are least important. The results of the cluster analysis on the dimensions provided evidence for, and insight into, four different STEM-profiles: motivated choosers, non-motivated choosers, typical choosers and external choosers. From a theoretical standpoint, the current research extends research on STEM motives by focusing on the importance of study choice motives by linking motives to underlying motivation and by generating meaningful STEM profiles. From an applied perspective, insight into STEM profiles might be of value for study counseling and career choice programs in order to attract more motivated students to the STEM field. In sum, the present findings represent what would appear to be the first attempt to uncover the importance of STEM study choice motives, and the prevalence of different STEM profiles.

CHAPTER 3

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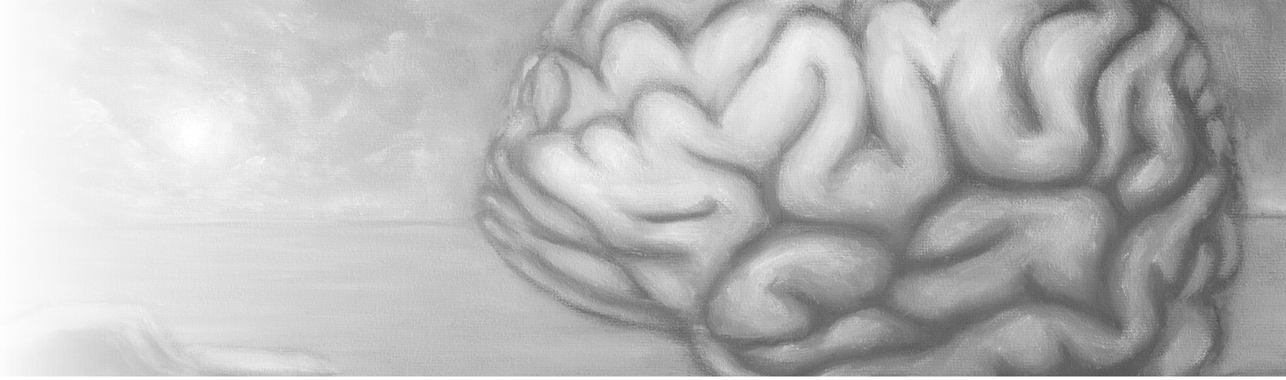


Study 2:

Toward a framework of integrating ability: conceptualization and design of an integrated physics and mathematics test.

This chapter is based on:
De Loof, H., Ceuppens, S., De Meester, J., Goovaerts, L., Thibaut, L., De Cock, M., Dehaene, W., Depaepe, F., Knipprath, H., Boeve-de Pauw, J., & Van Petegem, P. (Submitted). Toward a framework of integrating ability: conceptualization and design of an integrated physics and mathematics test.

Abstract

The awareness that many problems in our society are interdisciplinary in nature, and require the integration of multiple STEM concepts to solve them, has given rise to a new instructional approach, called 'integrated STEM education'. Integrated STEM education aims to remove the barriers from the STEM fields, and has the potential to increase students' interest and motivation for learning, as well as to lead to improved achievement. It is important to assess the effectiveness of educational STEM initiatives in terms of students' integrating ability, but to date, no such instruments are available. This study provides a definition of 'integrating ability' and establishes a framework for understanding its components. Based on this definition and framework, a multiple-choice instrument for testing integrated physics and mathematics in the ninth grade (IPM9) was developed and validated. The definition and framework for integrating ability, and the construction guidelines for an integrated test, can be used by researchers and practitioners to develop new instruments regarding the ability to integrate STEM subjects.

1. Introduction

Growing concerns about students' achievement in and motivation for science, technology, engineering and mathematics (STEM) has led to much attention being paid to STEM education. To face the challenges of the current knowledge-based society in a growing global economy, high-quality educational STEM programs are necessary (National Academies of Science, 2007). The awareness that many problems in our ever-changing society are interdisciplinary in nature, and require the integration of multiple STEM concepts to solve them, has given rise to a new instructional approach, called 'integrated STEM education' (Wang, Moore, Roehrig, & Park, 2011).

Integrated STEM education aims to merge the content fields of the different STEM areas into a single curricular project that emphasizes concepts and their application from across the four disciplines (Roehrig, Moore, Wang, & Park, 2012). The removal of the barriers between these disciplines demands an educational approach in which students participate in engineering design and research. By integrating science, technology, engineering and mathematics, students gain a deeper conceptual understanding and learn to recognize the relevance of the subjects in relation to each other and to real-world problems. Thus, integrated STEM education has the potential to increase students' interest and motivation for learning, as well as to lead to improved achievement (Thibaut et al., 2018).

1.1. Evaluating integrated STEM education

While various programs for integrated STEM education have been developed, assessing the general effectiveness of these approaches is not straightforward (Becker & Park, 2011). To our current knowledge, no validated assessment instruments for the ability to integrate are available, and research on integrated STEM evaluation is scarce, especially when it comes to evaluating students' ability to make connections between the different STEM subjects (National Academy of Engineering and National Research Council, 2014). Existing studies of students' ability to integrate STEM (e.g., Depelteau, Joplin, Govett, Miller, & Seier, 2010; Kiray & Kaptan, 2012) often fail to provide a clear definition of the measured construct. Moreover, often no explanation of the integrated nature of the test questions is given.

To make claims about the effectiveness of integrated STEM approaches, students' ability to make connections between the different STEM subjects should be tested with integrated questions. Effectiveness studies regarding integrated STEM education have focused mainly on students' achievement in separate subjects (e.g., Turpin, 2000), but research into the impact on students' ability to make connections between disciplines is scarce (National Academy of Engineering and National Research Council, 2014). One of the main challenges is the design of an assessment instrument that covers the integration of the numerous concepts and skills inherent to STEM. Furthermore, the ability to integrate across STEM disciplines has not yet been captured by a clear definition. Some researchers do report the use of integrated questions in their studies, but do not include a definition of integrating ability. Depelteau et al. (2010), for example, examined the effects of 'SYMBIOSIS', a biology-math integrated curriculum. They developed a concept test, consisting of 33 items that were identified as either 'predominantly math', 'predominantly biology', or as 'truly integrated conceptually'. However, no information was given about what exactly constitutes a 'truly integrated' question. Kiray and Kaptan (2012) investigated the effects of an integrated science and mathematics program on the achievement of eighth-grade students. A multiple-choice test consisting of 30 questions in three categories ('only science', 'integrated science/math' and 'overall') was created. In this study as well, no details about the nature of the integrated questions were provided. The lack of conceptual clarity in previous studies indicates the need for a thorough definition and conceptualization of students' ability to integrate.

The current study aims at developing a theoretically supported and empirically validated instrument to measure students' ability to solve integrated physics and mathematics problems, thus providing a first step towards fully assessing the effectiveness of integrated STEM instructional approaches (i.e., not only assessing separate STEM contents, but also assessing the ability to integrate STEM contents). To do so, we provide a definition and a framework for integrating ability. Based on this conceptualization, we then present the development and validation of an instrument to contribute to both research and practice in STEM education. The developed framework can be used for constructing similar test instruments for integrating ability in all STEM disciplines.

1.2. 'Integrating ability': definition and framework

We define *integrating ability* as the ability to purposefully combine recently acquired knowledge and skills from two or more distinct STEM disciplines to solve a problem in a familiar context that necessitates this very combination to solve it. In this study, 'recently' covers the time frame of the ongoing school year, and refers to the integration of new learning content (and not already-acquired knowledge and skills) through its application in other disciplines. A 'familiar context' is a context that has been addressed during classroom activities. The knowledge and skills mentioned in the definition are those that are typically attributed to discipline-specific curricula, but that concern underlying concepts that can be related cross-disciplinarily.

The ability to solve integrated problems, however, cannot merely be defined as finding the correct solution to integrated problems. To illustrate this issue, we use a metaphor of constructing a wall with building blocks. There are two types of building blocks: high-quality ones which are perfectly rectangular, and ill-shaped ones. Besides the quality of the building blocks, the skill of the builder is also crucial to constructing a stable wall: expert builders can arrange the bricks perfectly, while incompetent builders cannot. Giving the builders access to the two types of building blocks can result in four different possible outcomes for the wall, as represented in Figure 1: (1) a well-structured wall with good-quality bricks, (2) a well-structured wall with ill-shaped bricks, (3) a badly-structured wall with good-quality bricks, and (4) a badly-structured wall with ill-shaped bricks.

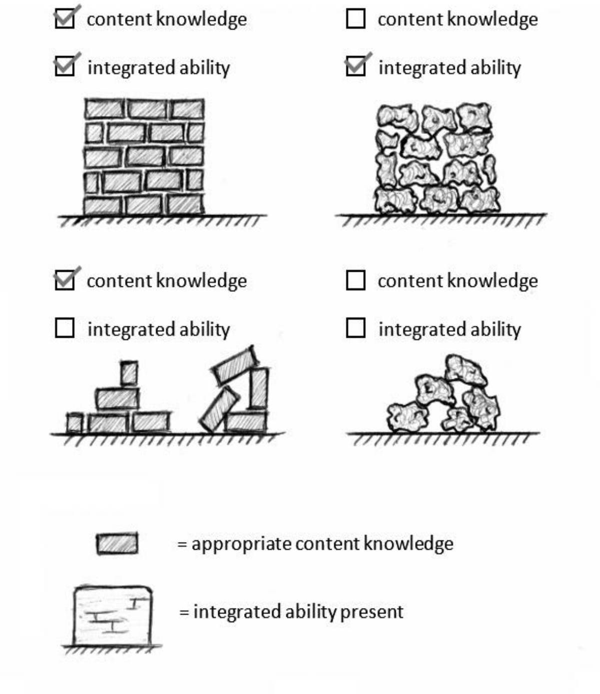


Figure 1. Constructing a wall with building blocks as a metaphor for integrating ability: four situations.

The ability to build a well-structured wall represents **integrated ability** (i.e. the ability to select and combine STEM concepts) and the good-quality building blocks represent the **appropriate content knowledge**. **Integrating ability** combines these two notions in order to correctly solve an integrated problem. Note that integrated ability is different from general reasoning ability, as its successful application can depend on the required content knowledge. It is for instance possible that integrated ability in the context of chemistry and biology is present, but that it is not sufficient in the context of mathematics and physics.

In Table 1, the four possible situations are displayed. The presence of **integrated ability** (Table 1, Situation 2) is a condition for **integrating ability** (Table 1, Situation 1), i.e., employing the present integrated ability by making use of the appropriate content knowledge. Theoretically, it is possible for the integrated ability to be present, but the appropriate content knowledge not to be, which would lead to an incorrect answer. We assume that all participants who answer the question correctly find themselves in Situation 1, except where a fortunate guess was made. If we wanted to measure integrated ability separately from content knowledge, (a) additional discipline-specific questions that evaluate the presence of the appropriate content knowledge would need to precede the integrated questions, and (b) with the integrated questions, the appropriate content knowledge would need to be provided. Thus, the present instrument only measures integrating ability without making separate statements about integrated ability.

Table 1. Combinations of integrated-ability presence and content-knowledge appropriateness

	Appropriate content knowledge	Inappropriate content knowledge
Integrated ability present	Situation 1	Situation 2
Integrated ability absent	Situation 3	Situation 4

Blank cases result in a correct answer, grey cases result in an incorrect answer (except where a fortunate guess is made).

In this study, we focus on students' integrating ability for physics and mathematics. In appendix B, an example can be found of an integrated physics-math problem, applied to the four possible situations.

Given the importance of integrated STEM education, and given the need to assess educational initiatives regarding this integrated approach, good instruments to evaluate the effectiveness of these initiatives are necessary. Students' ability to integrate STEM concepts is one important outcome in the evaluation of educational initiatives regarding integrated STEM. However, to date, no theoretical frameworks and no instruments for integrating ability are available. This section has provided a definition and a framework for integrating ability. In the next section, based on this definition and framework, the development of a multiple-choice instrument for integrated physics and mathematics for the ninth grade will be presented.

2. Method

2.1. Developing the instrument

The goal of the study presented here is to capture students' integrating ability. The developed multiple-choice test targets students in Grade 9. Consequently, the test is referred to as the Integrated Physics and Mathematics Test for Grade 9, abbreviated 'IPM9'. Based on our definition of integrating ability, the integrated content test was developed following the standards for educational and psychological testing (Eignor, 2013). The development process had six different steps, which were based on the standards for educational and psychological testing of the American Psychological Association (APA; Eignor, 2013):

1. establishing the test format,
2. listing the physics and mathematics concepts that have been introduced in the ongoing school year,
3. identifying cross-disciplinary links between these concepts,
4. developing draft items that cover these links,
5. having experts review these draft items, and
6. implementing the experts' feedback.

The IPM9 was developed by a multidisciplinary team consisting of engineers, physicists, educational researchers, and pedagogical advisors. Step (1) was performed by a researcher with a background in educational research, who also executed the validation of the instrument, and Steps (2), (3), (4) and (6) were performed by four researchers with backgrounds in engineering or physics. Step (5) was performed by experts in content and test design. As a first step, the choice for a multiple-choice format was made, in response to the large number of participants. The second step involved listing all the new learning content in physics and mathematics covered during the targeted grade, as can be seen in Table 2.

Table 2. List of new concepts regarding physics and mathematics

Physics	Mathematics
I. Position (uniformly accelerated linear motion)	I. First-order function/equation
II. Velocity (uniformly accelerated linear motion)	II. Slope
III. Average velocity	III. Surface trapezoid
IV. Acceleration	IV. System of equations
V. Average acceleration	V. Vector
VI. Force	VI. Sine, cosine, tangent
VII. Torque	VII. Pythagoras
VIII. Reflection of light	
IX. Refraction of light	

Once the concepts were listed, the third step was to identify links between these concepts in order to construct integrated items. In the fourth step, 17 questions that combined a physics concept (left column in Table 2) with a mathematical concept (right column in Table 2) were developed. During the fifth step, the drafted items were handed to experts (engineers, physicists and educational advisors). These experts verified the formulation of the items as well as the content validity. The items had to be formulated in an unambiguous way to prevent any misunderstandings or misinterpretations. The difficulty level of the items was also monitored by the experts. The feedback of the experts was implemented in a new version of the items, which was the sixth and final step in the development of the item battery and resulted in an item battery of 16 questions.

In Figure 2, an example of an integrated physics and mathematics item can be found. This item is situated in the domain of motion, a context that is familiar to students, since it has been regularly addressed in classroom problems throughout the ongoing school year. To solve the problem, students should determine when the moving persons cross each other, taking into account their velocity. They therefore have to apply mathematical ideas concerning linear functions and equitations. As illustrated by this solving strategy, students need to combine concepts from both physics and mathematics in an effective manner, hence giving evidence of integrating ability. An example of a physics item and a mathematics item – as opposed to the integrated physics-mathematics item – can also be found in Figure 2.

Integrated physics-mathematics

A jogger leaves for a run at 9 km/h. Ten minutes later, a cyclist leaves from the same starting point as the jogger, riding his bike at 24 km/h. After how many minutes does the cyclist cross the jogger?

A) 16 minutes
B) 12 minutes
C) 20 minutes
D) 10 minutes

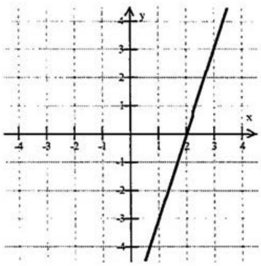
Physics

Which statement is correct at all times?

A) Two objects that have the same velocity at a given moment, do not necessarily have the same position.
B) Two objects that have the same velocity at a given moment, also have the same acceleration.
C) Two objects that have the same position at a given moment, do not have the same velocity.
D) Two objects that have the same position at a given moment, also have the same acceleration.

Mathematics

Which function corresponds to the graph?



A) f(x) = 2x - 5
B) f(x) = 3x + 2
C) f(x) = 3x - 6
D) f(x) = -5x + 2

Figure 2. Example of an integrated physics-mathematics item, a physics item, and a mathematics item.

2.2. Validation of the instrument

Participants. To validate the developed IPM9 items, a study was conducted among 988 Flemish students (age: M = 13.85, SD = .55; sex ratio: boys:girls = 1.56). All participants were in a curriculum with an emphasis on science, technology and mathematics, and attended classes in 42 different schools. All were part of the STEM@School project (Knipprath et al., 2018).

Procedure. Before the actual administration, a pilot study was conducted with a smaller group of 372 students, in order to investigate the psychometric qualities of the 16 developed items, which resulted in an item battery of 14 remaining questions. Two items were excluded due to insufficient discrimination capability (discrimination value <0.15). The pilot study was also necessary to ensure the online test functioned well technically, and the questions were understandable.

In the current study, the 14 items of the IPM9 were administered to 988 ninth graders between the beginning and the end of May 2016 (= one month before the end of the ninth grade). The items of the IPM9 were part of an overarching STEM test, concerning several STEM fields. In this overarching test, all taught physics, mathematics, technology and research competences were addressed.

Students completed the online tests in their schools during normal school hours. Eight out of the 14 multiple choice questions were randomly presented to each student, as the IPM9 had to fit into the provided time frame of the overarching STEM test. Students were informed that only one out of the four alternatives was correct. A paper copy with a list of formulae was provided to the students. The list contained the basic formulae that were needed to solve some of the questions (e.g., the formula to calculate the circumference of a circle) but not relevant to the assessed integrating ability. Students and their parents were provided with information about the aim of the study, and with a passive informed consent procedure, approved by an institutional ethical committee, which accorded with the Belgian law on clinical trials.

Analysis of instrument validity. Item response theory (IRT) was used to investigate the psychometric qualities of the IPM9, using latent trait models under IRT. The ltm-package of R (open source software for statistical computing) was used, which is fit for an analysis of multivariate dichotomous data (Rizopoulos, 2006). Item characteristics (i.e., difficulty and discrimination) were analysed using IRT, with the probability of item responses being regressed on the latent trait 'integrated ability'. Items with a discrimination value below 0.15 were removed from the item battery, and IRT was reperformed with the remaining items. After IRT analysis, the reduced version of the item battery was evaluated by the item developers, to guarantee the content validity of the scale.

IRT-based models are widely used in psychometric research for the assessment of educational abilities (Crocker & Algina, 1991). In IRT, the underlying trait is often referred to as the Greek letter theta (θ), with a mean of zero and a standard deviation of one. In the current validation study, θ is conceptualised as 'integrating ability'. The difficulty of an item is the ability required to guarantee a 50% probability of answering the item correctly. Only participants with a high degree of 'integrating ability' will be able to answer the difficult items, which implies they will only be answered correctly by a few individuals. Conversely, items with lower difficulty values are likely to be answered correctly by participants with lower ability as well, and thus answered correctly by many participants. Item discrimination, on the other hand, is an index of an item's capability to differentiate between students in different positions on the latent 'integrating ability'. This implies that persons with low ability have a smaller chance of correctly responding than persons of higher ability and vice versa. Items with a high discrimination value are better indicators of 'integrated ability' than items with a smaller discrimination value.

Various IRT models exist with different assumptions and parameters. The Rasch model is the most parsimonious IRT model for dichotomous items, and assumes all items have a discrimination index of 1 logit, which is the slope of the item characteristic curve (ICC). A less strict IRT model is the one-parameter logistic model (1-PL model), where the discrimination index can have a value other than 1, and where all items have equivalent discriminations. Within the two-parameter logistic model (2-PL model), all items that fit the model can have different discrimination indices. The model with the best fit for the data was identified by analysis of variance (ANOVA). Once the most suitable model had been selected, the precision of each integrated item was calculated, and the test information function (which presents the degree of precision at different values of 'integrated ability') was requested.

With regard to external validity, convergent validity and discriminant validity were investigated with theoretically related concepts (i.e. physics application and mathematics application) and theoretically unrelated concepts (i.e. technological concepts) respectively.

3. Results

In this study, analysis of variance (ANOVA) showed that the 2-PL model had the best fit for the data. Estimators of the relative quality of the different measurement models can be found in Table 3. After inspection of the infit values (which were close to zero) and outfit values (which were close to one), we concluded that all items fitted well in the chosen model. In Table 4, the discrimination value (α) and difficulty (β) of each item is presented. Five items were omitted due to low discrimination values.

Table 3. Akaike Information Criterion (AIC), Bayesian Information Criterion (BIC), and Log-Likelihood values for the Rasch model, 1-PL model, and 2-PL model

	AIC	BIC	Log-Likelihood
Rasch model	5269	5315	-2625
1-PL model	5202	5253	-2591
2-PL model	5193	5285	-2579

Table 4. IRT item parameter estimates for the IPM9: remaining item battery

Items	α	β
I1	0.42	-0.92
I3	17.91	0.06
I4	0.38	0.69
I5	0.57	0.96
I7	0.18	2.09
I9	0.33	2.20
I10	0.24	3.47
I11	0.39	4.08
I13	0.31	5.60

The discrimination values for all the nine remaining items were above 0.15 (*min*. = 0.18, *max*. = 17.91), which indicated that all items were able to differentiate between students with divergent integrated ability. The discrimination value of Item 3 (α = 17.91) was remarkably high, which positively affected the mean discrimination index of the nine integrating ability items (M = 2.30, SD = 5.52). Difficulty varied between β = -0.92 and β = 5.60, with Item 1 as least difficult and Item 13 as most difficult respectively.

The precision of the IPM9 can be evaluated by the item information functions that are calculated from the parameters, displayed in Table 3. The test information function is the sum of the item information functions, and can be found in Figure 3.

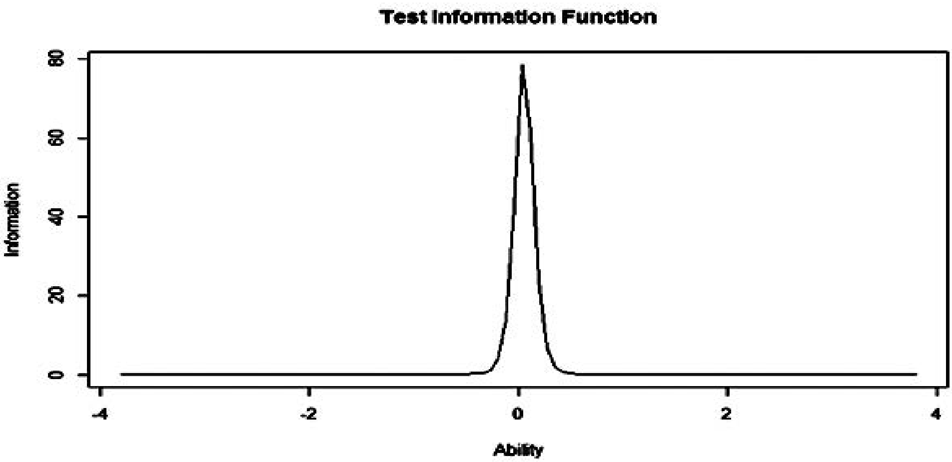


Figure 3. Test information function by level of integrated ability (θ).

The test information function shows a sharp peak around θ = 0, due to the high discrimination value of Item 3, which has a difficulty of 0.06. This means that the IPM9 is very informative for students with a medium integrating ability.

The content validity of the remaining nine items was assessed by the developers who had constructed the initial items of the IPM9. More specifically, the items needed to cover all the new mathematics and physics learning content of the last school year. The remaining items were still able to cover the definition and the aim of the integrated physics and mathematics test. These results indicate that the IPM9 is a valid test of integrating ability with discriminating items of varying difficulty.

External validity was investigated by comparing the IPM scores of students with scores on physics, mathematics, and technological concepts. As physics and mathematics concepts are necessary to solve integrated questions (i.e. the presence of the appropriate content knowledge), but are not sufficient to correctly answer an integrated question we would expect a weak positive correlation between these outcomes. The ability to answer questions with regard to technological concepts on the other hand, should be unrelated to integrating ability. Hence, we expect no significant correlation between those constructs. As Table 5 shows, a significant but negligible convergence between the IPM on the one hand and physics application and mathematics application on the other hand was found. This illustrates that integrating ability is a qualitative different construct than the application of physics or mathematics. No significant correlation with technological concepts was present. Thus, we can conclude that the IPM exhibits satisfactory external validity.

Table 5. Correlations between IPM, physics application, mathematics application and technological concepts

Variables	1.	2.	3.	4.
1. IPM				
2. Physics application	.12**			
3. Mathematics application	.19***	.27***		
4. Technological concepts	-.05	-.07**	-.10***	

Note. The scores on the variables are scores over time.*$p< .05$. **$p<.01$. ***$p<.001$.

4. Discussion

With the increased interest in integrated STEM education, the need has arisen to evaluate students' abilities relating to integration. This paper provides a first step towards evaluating students' integrating ability. To accommodate the lack of a definition in the literature, we formulated *integrating ability* as the ability to purposefully combine recently acquired knowledge and skills from two or more distinct STEM disciplines to correctly solve a problem in a familiar context that necessitates this very combination to solve it. A framework for understanding integrating ability and its components (i.e., integrated ability and content knowledge) was also established. As integrated ability is difficult to grasp without explicitly providing the necessary content knowledge, we focused on the assessment of integrating ability.

Based on this definition and framework, we developed and validated an evaluation instrument for ninth-grade students. After several steps in the development process, this resulted in the IPM9: an instrument of nine multiple choice items with satisfactory psychometric properties (all items had a satisfactory discrimination value).

4.1. Applications

The definition and framework can be used by researchers and practitioners to develop new instruments regarding the ability to integrate STEM subjects. Since the differences between concepts such as integrating ability, integrated ability, and content knowledge are clarified, this framework can be beneficial when it comes to making considered conceptual choices. In addition, this conceptual separation reveals which components should be incorporated into a test. For instance, where a researcher aims to capture all the separate components of integrating ability, the test should include discipline-specific content knowledge questions, as well as integrated ability questions (which are integrated questions where the appropriate content knowledge is provided). The definition and framework of integrating ability in STEM provide clarity in making decisions regarding the assessment of educational STEM initiatives. Moreover, this definition and framework has the potential to be applicable in a wider context than that of STEM. This approach to integrating ability could also be useful in relation to other subjects.

As for the integration of STEM content, our results indicate that this approach can be used to develop an instrument to test integrating ability regarding physics and mathematics. In this study, this approach resulted in the IPM9, which is a valid and reliable instrument for assessing integrated physics and mathematics for students in the ninth grade. The IPM9 could be particularly of interest in a research context, to evaluate educational initiatives regarding integrated STEM. For instance, this test instrument could benefit research that aims to examine whether there is a noticeable difference between students who are following different STEM learning programs . In the context of evaluating integrated STEM approaches, this instrument could be harnessed to investigate the difference between students taught through the traditional, disciplinary curriculum approach and those immersed in a cross-disciplinary, integrated curriculum approach. It should be noted that this specific instrument is designed to be used as a research instrument, not as an instrument to be adopted in an assessment context in class. Where the theoretical approach and the development process of this test are universally applicable, the specific learning goals which are incorporated into the IPM9 are determined by context-dependent STEM curricula.

4.2. Limitations and directions for future research

An important characteristic of the IPM9 is its potential to assess integrating ability. We focused on integrating ability (which is the combination of integrated ability and content knowledge) since the assessment of integrated ability alone is difficult without providing the necessary content knowledge. As a result, in this study, no statements about integrated ability could be made. Future studies aiming to distinguish between the different components of integrating ability would need to incorporate separate content knowledge questions. It could be argued that it is difficult to guarantee the presence of integrating ability without explicitly testing content knowledge. However, no correct answer could be obtained without having the appropriate content knowledge (as content knowledge is part of integrating ability); consequently, a correct answer to a question regarding integrating ability implicitly indicates the presence of the appropriate content knowledge. The exception in a multiple-choice test is that of a fortunate guess.

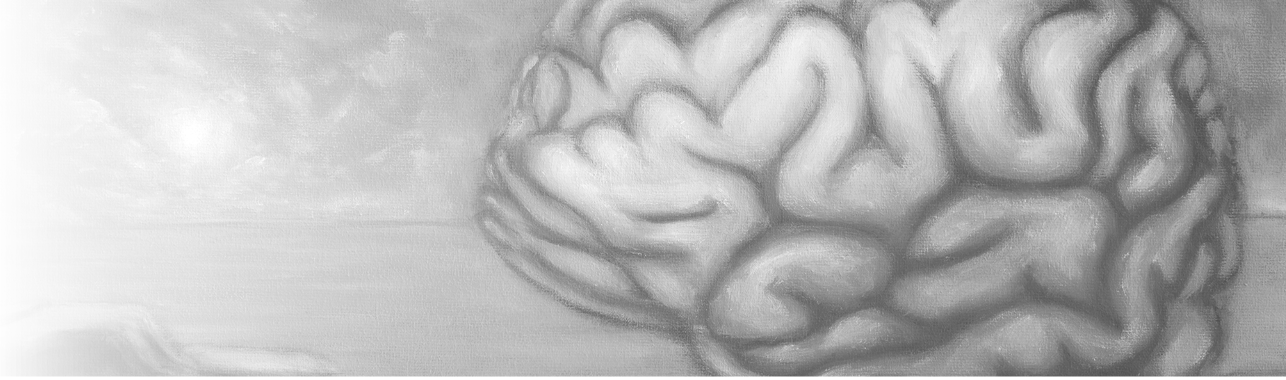
A second point of critique relates to the multiple-choice format of the test items, which can essentially only answer the questions "How many students pass or fail?" and "Which incorrect responses are chosen most?". It cannot easily answer the question "Why do students pass or fail?". Future research could therefore extend this test with student interviews, and request students to follow a 'think aloud' protocol, to gain further insight into how students solve integrated questions.

Finally, it should be apparent that the IPM9 is a suitable test to evaluate the ability to solve integrated physics and mathematics questions, but that it is only one possible instrument to test integrating ability, and not the gold standard for measuring integrating ability in all possible contexts. Researchers should bear in mind that the IPM9 was tested in a specific country, targeting concepts that were incorporated into the national curricula. In addition, the IPM9 only incorporates physics and mathematics, and does not include any other STEM subjects. Nonetheless, this study provides a definition, a framework and a test construction guideline on which researchers can rely when developing a test to evaluate the integrating ability of students.

5. Conclusion

This study has demonstrated the need for an instrument that can assess the integrating ability of students in STEM subjects. A definition of integrating ability was provided, as well as a theoretical framework. In addition, a test was constructed and validated to determine the integrating ability of students in the ninth grade regarding physics and mathematics. Despite some shortcomings, we believe that the contributions of this framework and instrument to theory and practice could benefit both future research and the evaluation of STEM education initiatives.

CHAPTER 4



Study 3:

Integrated STEM education: the effects of a long-term intervention on students' cognitive performance.

This chapter is based on:
De Loof, H., Boeve-de Pauw, J., & Van Petegem, P. (Submitted). Integrated STEM education: the effects of a long-term intervention on students' cognitive performance.

Abstract

Integrated Science, Technology, Engineering and Mathematics (iSTEM) education is a promising approach to attracting more qualified and better motivated students to STEM fields by improving student interest and learning. In this study, we respond to one of the salient challenges facing integrated STEM educational research, namely investigating its educational impact. We developed a large-scale intervention where all STEM components are integrated in the specially-developed learning modules, and examined the impact this integrated STEM curriculum has had on cognitive performances regarding physics, mathematics, technological concepts, and integrated physics and mathematics. In total, 859 grade 9 students, distributed across 39 different schools, participated in a long-term study. The results of multilevel analyses show that iSTEM education had positive effects on cognitive performance in terms of mathematics knowledge and application and technological concepts. Differential intervention effects were found with regard to student characteristics. Since the impact was not apparent after the first year of implementation, but only after two years, we stress the importance of a long-term integrated STEM educational approach. Furthermore, our results advocate the integration of STEM domains in educational initiatives.

1. Introduction

Generating a sufficient number of qualified professionals in science, technology, engineering and mathematic (STEM) areas is a matter of international concern (Hernandez et al., 2014; Bøe, Henriksen, Lyons, & Schreiner, 2011; Lam, Doverspike, Zhao, Zhe, & Menzemer, 2008). Awareness of the problem with regard to young people's increasing reluctance to participate in STEM emerged in the early 1990s, and this has been a growing problem to this day (Bøe et al., 2011; Moore & Smith, 2014, Keith, 2018), as national reports continue to identify shortages of STEM graduates. The World Economic Forum (2016) predicted an increased demand for specialists in the STEM field for the years to come. The current knowledge-based society demands a large number of students graduating from STEM-related fields (National Academies of Science, 2007), as countries need a sound economy and find solutions for societal and environmental matters, such as sustainable energy production in a world with shrinking resources, adequate healthcare in an aging society, and well-considered technology development (Wang, Moore, Roehrig, & Park, 2011; Kjærnsli & Lie, 2011; Bøe et al., 2011). Integrated STEM can can play a central role in motivating students to choose a STEM study or profession and has the potential to improve students' learning (Honey, Pearson, & Schweingruber, 2014; Becker & Park, 2011).

1.1. Integrated STEM

STEM is an integration of the four subjects: science, technology, engineering, and mathematics (Wang et al., 2011). However, as the term is widely used, there is no consensus about the nature and range of the concept. Some researchers and educators use the term STEM to refer to one or more of its components, others use it only in the integrated sense (Wang et al., 2011; English, 2016). As we are discussing the term in the integrated sense, we will use 'integrated STEM' (iSTEM) in this paper. Sanders (2009) defines iSTEM approaches as "Approaches that explore teaching and learning between/among any two or more of the STEM subject areas, and/or between a STEM subject and one or more other school subjects" (Sanders, 2009, p. 21). According to Honey et al. (2014), iSTEM education includes a range of different experiences that involve some degree of connection. "The experiences may occur in one or several class periods, throughout a curriculum, be reflected in the organization of a single course or an entire school, or be encompassed in an out-of-school activity" (Honey et al., 2014, p. 2). Consequently, they define integration as "…working in the context of complex phenomena or situations on tasks that require students to use knowledge and skills from multiple disciplines" (Honey et al., 2014, p. 52).

In the current study, we approach iSTEM in terms of the integration of all its components into a single curricular project that emphasizes concepts and their application from across the four disciplines (Roehrig, Moore, Wang, & Park, 2012). Within this approach, the literature differentiates between multidisciplinary and interdisciplinary integration (Wang et al., 2011). The metaphor of chicken noodle soup versus tomato soup provided by Lederman and Niess (1997), is often used to explain the differences between these two forms of integration. The chicken noodle soup represents multidisciplinary integration, where each ingredient maintains its identity without a direct mixture in the totality of the integration. Multidisciplinarity starts from subject-based content and skills, and students are expected to form connections between the subjects that they have been taught in different classes (Wang et al., 2011). Tomato soup, on the other hand, represents interdisciplinary integration, where the boundaries between subjects are blurry. Interdisciplinarity starts from a problem that requires an understanding of the content and skills of multiple subjects (Wang et al., 2011). Vasquez, Sneider, and Comer (2013) add an additional level of increased integration by introducing the concept of transdisciplinary integration. Knowledge and skills from multiple disciplines are hereby applied to solve real-world problems. In the current study, we approach education in iSTEM as a transdisciplinary concept.

1.2. Educational Research in Integrated STEM

Removing barriers between disciplines is meant to increase students' conceptual understanding and achievements regarding STEM topics, and increase recognition of the relevance of the subjects in relation to each other and to the context of real-world problems (Honey et al., 2014; Thibaut et al., 2018). Integrated STEM education is a promising approach to attracting more qualified and motivated students in STEM fields by improving students' interest and learning in STEM. It has received increasing attention from educators and researchers over the past decade (Honey et al., 2014). Besides the possible positive effects of iSTEM education on the general student population, it has also been argued that iSTEM might be particularly beneficial to certain student populations. Cantrell, Pekca, and Ahmad (2006) for instance, showed that an integrated engineering curriculum diminished achievement gaps in typically low-achieving ethnic minority student groups. Other studies demonstrate that gender differences in performance might reduce when students follow iSTEM courses linked with real-world activities (Standish, Christensen, Knezek, Kjellstorm, & Bredder, 2016). Hence, student characteristics that might have an effect on cognitive STEM outcomes might have a differential impact in an iSTEM educational approach. In the literature, such characteristics are well documented: previous research has indicated that sex, abstract reasoning ability and socioeconomic status (SES) might influence cognitive scores on STEM domains (e.g. Halpern et al., 2007; Deary, Strand, Smith, & Fernandes, 2007; Yerdelen-Damar & Peşman, 2013).

To conclude, an iSTEM educational approach is possibly promising for both the general student population and for a variety of students with different characteristics. In response, numerous new teaching materials, projects, and even complete study programs have been developed. Such a development entails the challenge to investigate empirical evidence to support the effective implementation of iSTEM education (Becker & Park, 2011). Indeed, the notion that learning becomes more meaningful and prolonged when students can make connections between STEM concepts has prompted research that aims to investigate the cognitive benefits of iSTEM education.

Becker and Park (2011) have synthesized research findings on the effects of integrated approaches among STEM subjects on students' cognitive performances. In their meta-analysis they described 28 studies reporting on effectiveness regarding students' learning in integrated STEM conditions. According to Becker and Park (2011), the small number of studies is due to the finding that many pieces of research are in the form of opinion papers without empirical data. Studies varied in the degree to which they addressed the integration of two or more STEM-subjects, the number of participants, and their age. A first gap in the current body of knowledge is the number of studies that integrated all components of STEM and reported on all associated cognitive outcomes. Only one study addressed the integration of all components, i.e. a study on the effect of integrated STEM on students with learning disabilities (Lam et al., 2008). Five studies discussed achievement scores after integration of S-T-E, and five studies reported on scores after the integration of S-T-M. Other studies integrated only two components. Regarding the measured achievement, only Lam et al. (2008), reported on the scores on all components, and just two studies measured the scores on S-T-E. No studies reported scores on questions addressing integrated STEM. A second concern is the low number of participants and the small scale of the interventions. Since the mean number of participants is 174.58 (min. = 21; max. = 1053), it is difficult to draw far-reaching conclusions. A third shortage is that studies are limited in terms of time perspective. No longitudinal studies could be included, which has the implication that little is known about the long-term effect of iSTEM education.

Studies published after Becker & Park's (2011) meta-analysis encounter the same problems (i.e. a skewed focus on science at the expense of mathematics, no integration of all subjects, limited numbers of participants, and no studies from a long-term perspective) (English, 2016; Yildirim, 2016), and continue to be small in number. To conclude, long-term research with all STEM components integrated is very rare and, as a result, the effects of an iSTEM approach on cognitive performances is a crucial gap in the field. More empirical research on the educational effects of (integrated) STEM education is therefore needed (Honey et al., 2014). With our current long-term study, we respond to this challenge and to the need to fill the gaps in integrated STEM educational research. We focus explicitly on the effect of a large-scale intervention where all STEM components are integrated in the developed learning modules.

1.3. Design of the Intervention

The intervention, called STEM@School is a collaborative project between two universities (KU Leuven, and University of Antwerp) and two educational umbrella organizations (GO!, and Catholic Education Flanders) covering approximately 70% of all schools in Flanders. The KU Leuven developed the learning materials in collaboration with teacher design teams, and the University of Antwerp evaluated the project. The role of the two umbrella organizations was to support the participating schools in their implementation, and to monitor the content of the developed materials so that they cover all learning objectives and curriculum guidelines.

Five iSTEM learning modules were developed. Schools incorporated three of these modules into the curriculum in grade 9, and two in grade 10. The participating schools introduced an integrated STEM subject in which the learning modules were addressed. To implement these learning modules, 4 to 5 teaching hours a week were required for the duration of each of two semesters. The schools taught the integrated STEM subject partly within the teaching hours of the regular mathematics, physics and engineering classes, and partly within additional hours in the form of optional classes. However, the integrated STEM subject did not replace the traditional subjects. Mathematics, physics and engineering classes continued to exist, but the content was aligned with the curriculum of the integrated STEM subject. More detailed information of the project and its implementation approach can be found in the project paper of STEM@School (Knipprath et al., 2018).

The learning modules consisted of challenges that were relevant in terms of societal and ecological problems, applying a transdisciplinary approach (Vasquez, 2013). Students address these challenges by applying knowledge and skills across disciplines, hereby making connections between principles and concepts. Problem-solving in an integrated STEM context also requires inquiry and design competences on the part of the students (Knipprath et al., 2018). These characteristics constituted the core of the iSTEM intervention, and were the foundation of all learning modules.

An example of one of the learning modules is the challenge of the optimization of traffic flow through a green wave (i.e. the coordination of traffic lights to allow continuous traffic flow). Students had to design and program a car in such a way that it could drive through a green wave without exceeding a safe speed limit. Also, they had to find different solutions, both with constant velocity and with acceleration. To succeed in this challenge they had to use knowledge and skills from all STEM disciplines, such as velocity and acceleration (science), building the car with appropriate materials (technology), programming the car (engineering), and functions (mathematics). Obviously, this division is to some extent artificial, as these domains are interdependent. For instance, mathematics is already embedded in the physical concept of acceleration (Becker & Park, 2011), and some authors consider engineering as a subset of technology (Williams, 2011). Nevertheless, all modules could be considered as challenges which incorporated themes from the different STEM domains.

1.4. Current Study

Given the need for long-term educational research regarding iSTEM education, we aimed to evaluate the effectiveness of a large-scale two-year intervention in which students had to respond to relevant challenges by making use of knowledge and skills from different STEM domains. To respond to challenges posed in previous integrated STEM educational research, we incorporated all four domains in the intervention, and investigated the cognitive effects on physics' knowledge, physics' application, mathematics' knowledge, mathematics' application, technological concepts, and integrated physics and mathematics. We put forward two research questions.

1. What is the impact of an iSTEM curriculum on cognitive performances regarding physics (both knowledge and application), mathematics (both knowledge and application), technological concepts, and integrated physics and mathematics after one and two years?

2. What is the differential effectiveness of the iSTEM curriculum regarding student characteristics (i.e. sex, SES and abstract reasoning)?

2. Method

2.1. Participants and Procedure

The schools in this study were part of STEM@School, and volunteered to take part in this longitudinal study. Thirty schools involving 612 grade 9 students implemented the experimental condition of the iSTEM education program. To assemble a representative control group, all Flemish schools (i.e. schools serving the Dutch-speaking community of Belgium) were listed, and an inventory of relevant characteristics was created, such as the number of students, study track options, and membership of educational umbrella organizations. Subsequently, for each experimental school, three matching schools were selected at random and invited to participate in the project. Control schools were invited through a letter, and if no response was received, school administrators were called by a researcher as a follow-up. Nine control schools took part in the project, involving 247 students in the control condition of a traditional education program, with separate physics, engineering, and mathematics courses.

The students in this study were taking classes in one of the following three study tracks: 1. Science and Mathematics, 2. Engineering, and 3. Latin and Mathematics. The total number of participants and the division over condition and study track can be found in Table 1.

Table 1. Number of participants (absolute and relative) divided over condition and study track

	Experimental condition	Control condition	Total	%
Science & Math.	396	169	565	66%
Engineering	201	47	248	29%
Latin & Math.	15	31	46	5%
Total	612	247	859	100%
%	71%	29%	100%	100%

The participants totalled 859 (66% boys and 34% girls) grade 9 students with a mean age of 13.86 years (*SD* =.54) at the start of the study. We followed a quasi-experimental longitudinal design over two years. Three measurement moments were undertaken in both the experimental and control conditions: (1) before the start of grade 9, (2) at the end of grade 9, and (3) at the end of grade 10 (Figure 1).

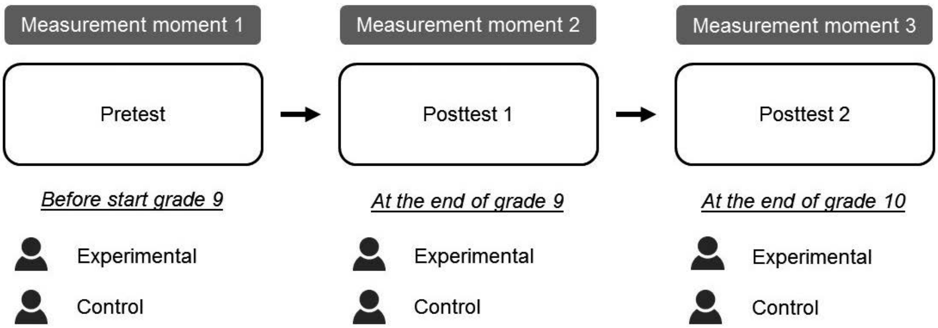


Figure 1. Measurement moments before the start of grade 9, after the end of grade 9, and after the end of grade 10.

While in total 859 unique participants were involved in the study, some of them were missing at different measurement moments. This could be due to schools dropping out of the project over time, or the failure of schools to administer surveys to students on a measurement moment, and because of the illness of individual students on a particular measurement moment. No selective attrition was observed, as Little's MCAR test showed that the data were missing completely at random. Table 2 provides an overview of the number of recorded responses of students over the three measurement moments.

Table 2. Number of recorded responses over measurement moments

	Time 1	Time 2	Time 3
Experimental	556	443	302
Control	238	208	138
Total	794	651	440

Students were allotted a unique code to guarantee their anonymity and to allow the researchers both to connect different questionnaires and tests within measurement moments, and to link questionnaires and tests across time. At the first measurement moment, students filled in an online questionnaire to provide demographic information, and completed a test measuring abstract reasoning ability. Online multiple-choice tests were administered, measuring cognitive outcomes with regard to STEM concepts. Cognitive outcomes were re-assessed at the second and third measurement moments, with tests that were adapted to the expected level at the end of grades 9 and 10 respectively. Students completed the online questionnaires and tests during normal school hours under supervision of the schools' contact person of STEM@School. Students and their parents were provided with information about the aim of the study, and with a passive informed consent procedure. This procedure was approved by an institutional ethical committee.

2.2. Instruments

Demographic information. Information regarding age, sex, and the SES of participants was obtained from the self-report of students on an online questionnaire. SES was determined by language spoken at home, country of birth of respondents and both parents (Tate, 1997), both parents' education, and both parents' occupational status[1] (Bornstein & Bradley, 2003). We performed exploratory factor analysis with varimax rotation on the above-mentioned variables, which led to two underlying variables: (1) origin, and (2) occupation and education. The weighted sum of the factor scores on these two variables led to a total SES score for each student.

Abstract reasoning ability. We gathered information on abstract reasoning ability as a proxy for general and non-verbal intelligence (Conway, Cowan, Bunting, Therriault, & Minkoff, 2002; Raven, Court, & Raven, 1977). The test consisted of 40 items and involved inductive reasoning about spatial features and relationships. Every item consisted of a series of figures with one inconsistent figure.

Cognitive outcomes regarding STEM concepts. Six instruments were developed to measure cognitive performance with regard to physics, mathematics and technological concepts: (1) physics knowledge, (2) physics application, (3) mathematics knowledge, (4) mathematics application, (5) technological concepts, and (6) integrated physics and mathematics (IPM). Adapted instruments for these outcomes were developed to respond to the expected level at each measurement moment, i.e. the start and end of the ninth grade, and the end of the tenth grade. Instruments were constructed based on the curriculum for physics, mathematics, and technological concepts of the ninth and tenth grades by pedagogical and subject-matter experts. In the case of integrated physics and mathematics, no items were developed for measurement moment 1, as students at the beginning of grade 9 were not yet familiar with curricular mathematics and physics concepts that lend themselves to be integrated in an overarching question. Information about the number of items per instrument, and an example item for each of the six measured outcomes, can be found in Appendix C. To reduce the burden on students and to make it possible to administer these tests during school hours, only eight items of each instrument were selected at random by the online software and presented to the students.

The psychometric qualities of the tests for physics knowledge, physics application, mathematics knowledge, mathematics application, technological concepts, and integrated physics and mathematics were investigated, using latent trait models under Item Response Theory (IRT). A detailed description of the IRT analyses can be found in Appendix D. After the psychometric qualities of the instrument were investigated, a factor score for each student was calculated. This procedure was repeated for every cognitive test instrument for each of the three measurement moments. Due to poor psychometric qualities of the physics knowledge test at measurement moment 3, no individual scores were available for that scale.

1 Typically, information about the family's economic situation is also used to calculate a measure for SES (Bornstein & Bradley, 2003). However, as we questioned students with an age range of 13-15, the current study did not include economic questions (Bradley & Corwyn, 2002).

2.3. Plan of Analysis

First, we investigated the intercorrelations among the dependent variables of the study which are shown in Table 3. Given that the correlations were between .01 (no linear relationship) and .42 (a small linear relationship), we conducted separate univariate analyses for all six cognitive outcomes.

Table 3. Intercorrelations among the dependent variables of the study

Variables	1.	2.	3.	4.	5.	6.
1. Physics knowledge						
2. Physics application	.11***					
3. Mathematics knowledge	.11***	.24***				
4. Mathematics application	.21***	.20***	.42***			
5. Technological concepts	-.03	-.01	.06*	.11***		
6. Integrated physics and mathematics	.10***	.06	.09**	.18**	.09***	

Note. The scores on the variables are aggregated IRT scores over time.*$p < .05$. **$p<.01$. ***$p<.001$.

Subsequently, we constructed mixed models which allowed us to investigate the general and differential effects of the iSTEM intervention. We conducted multilevel analysis employing JMP software (John's Macintosh Project) version JMP pro 13. Linear mixed models in JMP make use of all data (and not only complete cases), thereby also including information of cases with missing values.

This study used a three-level model where measurement moments at level 1 were nested within students at level 2, which were in turn were nested within schools at level 3. Multilevel modelling allows data to be clustered in groups, and to have a hierarchical structure. As students are measured three times, and their results are not independent. 'Student ID' was thus included as a random factor. Also, students learn together in a school, which could cause the outcomes of students within the same school to be more highly correlated than the outcomes of students between schools. Therefore, school was also included as a random factor. For all six investigated outcomes, we inspected whether a model with a fixed slope (random intercept model) fitted better to the data than a model with a random slope (random intercept and random slope model) (Raudenbush & Bryk, 2002). A multivariate likelihood-ratio test (2log (likelihood random slope) – 2 log (likelihood random intercept)) revealed that the random slope model fitted better than the restricted (i.e. fixed slope) model in the case of physics application and mathematics knowledge. To examine agreement among students and agreement among schools we computed intra-cluster correlation coefficients (ICC).

With regard to the fixed effects, we included six main effects to control for their direct influence on the cognitive outcomes. Besides condition (0 = control condition, 1 = experimental condition), and measurement moment (1 = time 1, 2 = time 2, 3 = time 3), we also controlled for sex (1= male, 2= female), abstract reasoning and SES, as previous research indicated that these variables might influence cognitive scores on STEM domains (Halpern et al., 2007; Deary, Strand, Smith, & Fernandes, 2007; Yerdelen-Damar, & Peşman, 2013).

Scores for abstract reasoning abilities and SES were standardized. It was also important to control for study (1= focus on science and mathematics, 2 = focus on engineering, 3 = focus on Latin and mathematics) as this variable was not homogenous in our sample.

To investigate the general intervention effects over time (see research question 1), we added the interaction between condition and measurement moment in the model. Differential intervention effects (see research question 2) for students with specific characteristics (i.e. sex, SES and abstract reasoning) were investigated by adding three-way interactions to the model.

3. Results

Mixed models were constructed for each cognitive outcome, containing the main effects of condition, time, study, sex, abstract reasoning ability, and SES, the interaction effect of condition x time, and three-way interactions of condition x time with the other predictors. The results, including intra-cluster correlation coefficients (ICC) of the two levels (students and school) are summarized in Table 4. Employing dummy coding, the last category was used as a reference category each time.

Inspection of the ICC indicated that the correlation between scores of the same student (that were not explained by the model) was 2% for physics knowledge, 13% for physics application, and 23% for mathematics knowledge. Correlation between schools was 2% for physics knowledge, 16% for mathematics knowledge, 7% for mathematics application, and 4% for integrated physics and mathematics. Note that 'student ID' is nested in 'school', so that the correlations of scores with regard to the same student entail correlations within the same school. For instance, no extra ICC for students was found for physics knowledge (2%), as the ICC of school was already 2%.

3.1. General Intervention Effects

We examined to what extent cognitive performances in terms of physics (knowledge and application), mathematics (knowledge and application), technological concepts, and integrated physics and mathematics questions are impacted by the iSTEM intervention (research question 1). More specifically, we investigated whether or not students in the experimental schools would perform better on STEM concepts than students in the control schools. Additionally, we also investigated whether or not students in the experimental condition would perform better after two years than after one year, in comparison to the control group, by examining the scores in the two different conditions over time.

The univariate analyses for the six cognitive outcomes are presented together in Table 4. The interaction between condition and time, indicating the effect of the iSTEM intervention, is displayed underneath the 'two-way interaction' header. This interaction was significant for mathematics (knowledge and application), and technological concepts. No significant interaction was found for physics (knowledge and application) and integrated physics and mathematics. This finding indicates that iSTEM education mainly has an effect on cognitive performances in terms of mathematics and technological concepts.

Table 4. Multilevel analysis of the effects of condition (0= control, 1= experimental), time (1= time 1, 2= time 2, 3= time 3, study track (1= science and mathematics, 2 = engineering, 3 = Latin and mathematics), sex (1= male, 2= female), abstract reasoning, and SES on cognitive outcomes

Fixed effects	**Phys. Know.**		**Phys. App.**		**Math. Know.**		**Math. App.**		**Techn.**		**IPM**	
	β	**SE**	**β**	**SE**	**β**	**SE**	**β**	**SE**	**β**	**SE**	**β**	**SE**
Intercept	-0.01	0.08	0.07	0.09	-0.20	0.13	0.03	0.12	-0.06	0.08	0.02	0.08
Main effects												
Condition [0]	-0.05	0.05	-0.06	0.06	-0.09	0.12	**-0.20***	**0.09**	**-0.15****	**0.05**	-0.10	0.05
Time [1]	0.02	0.03	-0.02	0.03	-0.01	0.04	-0.07	0.04	**-0.09****	**0.03**		
Time [2]			-0.05	0.04	-0.08	0.04	-0.06	0.04	-0.06	0.03	-0.03	0.03
Study track [1]	0.00	0.08	-0.15	0.09	0.17	0.11	0.07	0.11	**0.15***	**0.08**	0.03	0.08
Study track [2]	0.03	0.09	**-0.19***	**0.10**	0.27	0.15	0.19	0.13	0.12	0.08	0.15	0.09
Sex [1]	0.02	0.04	**0.18*****	**0.04**	0.09	0.05	-0.01	0.05	0.03	0.04	-0.02	0.04
Abstract reasoning	0.01	0.02	**0.09*****	**0.02**	**0.08****	**0.03**	**-0.00***	**0.03**	-0.03	0.02	0.03	0.02
SES	0.02	0.02	**0.04***	**0.02**	0.04	0.02	0.04	0.02	-0.00	0.02	0.00	0.02
Two-way interactions												
Condition [0] x time [1]	0.20	0.16	-0.11	0.15	**0.65*****	**0.19**	0.23	0.19	**0.30***	**0.14**		
Condition [0] x time [2]			-0.08	0.15	**0.64****	**0.19**	**0.74*****	**0.20**	**0.45****	**0.16**	0.21	0.13
Three-way interactions												
Con.[0] x time [1] x study track [1]	-0.31	0.18	0.31	0.17	**-0.65****	**0.21**	0.02	0.21	-0.10	0.16		
Con.[0] x time [2] x study track [1]			0.14	0.18	-0.29	0.22	**-0.57***	**0.23**	-0.30	0.19	**-0.29***	**0.15**
Con.[0] x time [1] x study track [2]	0.21	0.28	**0.78****	**0.24**	-0.56	0.31	0.05	0.31	-0.27	0.22		
Con.[0] x time [2] x study track [2]			0.29	0.25	**-0.97****	**0.32**	**-1.49*****	**0.34**	-0.13	0.26	**-0.43***	**0.20**
Con. [0] x time [1] x sex [1]	0.04	0.17	**-0.36***	**0.14**	-0.22	0.18	-0.06	0.18	0.12	0.13		
Con. [0] x time [2] x sex [1]			-0.11	0.16	0.02	0.20	0.13	0.21	-0.02	0.16	0.20	0.12
Con. [0] x time [1]x abs. reas.	0.08	0.08	-0.03	0.07	0.14	0.08	**0.22***	**0.08**	0.01	0.06		
Con. [0] x time [2]x abs. reas.			-0.03	0.08	**0.20***	**0.09**	0.09	0.09	0.03	0.07	0.01	0.06
Con. [0] x time [1] x SES	-0.06	0.06	**-0.13***	**0.06**	-0.09	0.08	-0.04	0.08	0.02	0.06		
Con. [0] x time [2] x SES			-0.06	0.08	0.09	0.10	-0.01	0.10	-0.02	0.08	0.01	0.06
Random effects												
ICC student	**.02***		**.13*****		**0.23****		0.09		.01		.11	
ICC school	**.02****		.02		**0.16*****		**0.07****		.01		**.04***	

Note. *$p < .05$. **$p<.01$. ***$p<.001$. Non-reference categories are specified between brackets.

A closer inspection of the interaction effect between condition and time for all cognitive outcomes can be found in Figure 2. The scores on the six outcomes are graphically displayed for control and experimental conditions across the three measurement moments. Note that these are IRT scores at a particular time-point, which means that this gives information about the relative scores of students on this time-point, but not about general progress over time.

In the case of physics knowledge, physics application and integrated physics and mathematics, no significant differences were found between the control and experimental condition over time. For mathematics knowledge, mathematics application and technological concepts, significant interactions were found. After two years, students in the experimental condition scored significantly higher on mathematics knowledge than did students in the control condition. The same result was found for technological concepts. However, both for mathematics knowledge and technological concepts, no significant difference between conditions could be found after one year. This finding indicates that the difference between the control and the experimental condition would become more pronounced after two years of iSTEM. For three of the six outcomes (mathematics knowledge, mathematics application and technological concepts), a difference was found between the scores after the first year compared to the scores after the second year. In addition, from this perspective, students in the experimental condition performed better than students in the control condition.

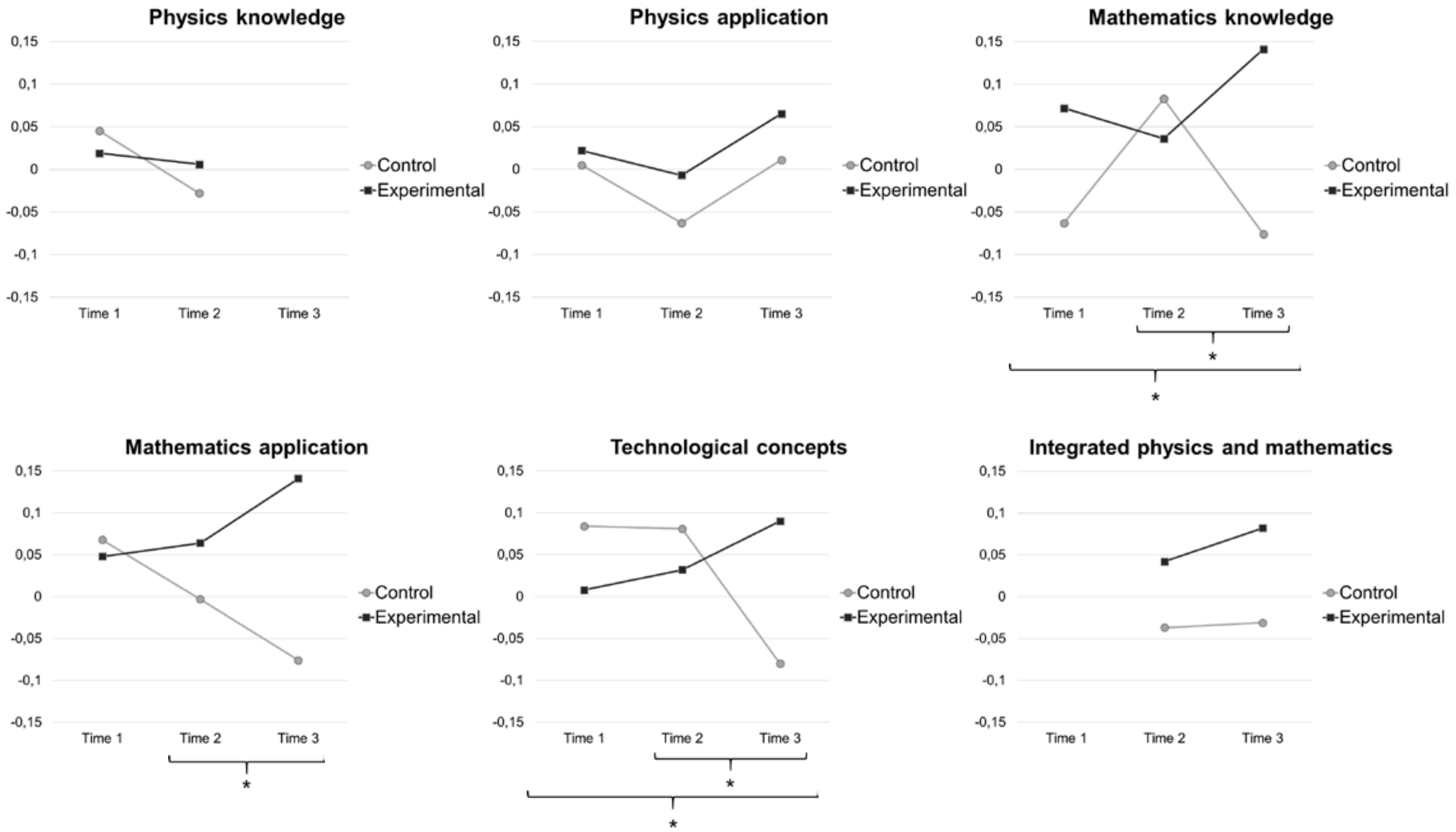


Figure 2. IRT scores on physics (knowledge and application), mathematics (knowledge and application), technological concepts and integrated physics and mathematics in control and experimental conditions on pretest (= Time 1), posttest 1 (= Time 2), and posttest 2 (= Time 3) .
Note. Significant interactions between condition and time are indicated with an asterisk.

3.2. Differential Intervention Effects

Besides the general intervention effects, we also examined the differential cognitive effects of an iSTEM curriculum with regard to students with specific characteristics (research question 2). More specifically, we investigated whether the effects of the iSTEM intervention differed for boys or girls, students with different SES, and students with different levels of abstract reasoning ability.

The interaction between condition, time, and specific student characteristics, indicating the differential effect of the iSTEM intervention, is displayed in Table 4 underneath the 'three-way interaction' header. The relationship between condition and time differed according to the study track for mathematics (knowledge and application) and technological concepts. We found a remarkable result for the effect of sex on the physics application scores. In general, male students performed better on this subject than did female students. However, females in the experimental condition performed significantly better after two years than females in the control condition, while no difference was observed for males. Abstract reasoning ability might to a certain extent positively determine the scores with regard to cognitive outcomes (i.e. for physics application and mathematics knowledge), but in the case of mathematics knowledge and application, the condition determines the impact of this relationship. For students in the experimental condition, the impact of abstract reasoning ability on mathematics (knowledge and application) was larger than for students in the control condition. With regard to the SES of students, a three-way interaction between condition and time was found for physics application. The relationship between SES and scores on physics application was stronger for students in the control condition. Otherwise stated, the impact of SES was lower for students in the experimental condition of integrated STEM.

4. Discussion

The aim of this study was to investigate the effect of an iSTEM curriculum on students' cognitive performances regarding physics (both knowledge and application), mathematics (both knowledge and application), technological concepts, and integrated physics and mathematics. We answered two research questions: (1) what is the impact of an iSTEM curriculum on cognitive performances after one and two years, and (2) what is the differential effectiveness of an iSTEM curriculum with regard to student characteristics?

4.1. General Intervention Effects

Aligned with previous research (e.g. Becker & Park, 2011), our study highlights the potential of an iSTEM education approach on diverse cognitive outcomes. However, some differences were found regarding the domains on which the intervention of an integrated approach had an impact. Becker and Park (2011), Honey et al. (2014), and English (2016) pointed out that the positive impact of iSTEM education differed for science (i.e. physics) and mathematics, with less evidence of a positive effect on mathematics' outcomes. Our results contrasted with these findings from previous research, as we found a positive impact of iSTEM on mathematics (both for knowledge and application), but not for physics.

Students in the experimental condition scored significantly better on mathematics than students in the control condition after two years of the intervention. For students in the experimental condition, the relevance of mathematics might have become clearer and less abstract throughout the learning modules, leading to an improved understanding of mathematical concepts and applications. While outcomes on both mathematics knowledge and mathematics application could be considered as medium effects according to Cohen (1988), the largest effect was found for mathematics application. An explanation for this finding might be that students in the iSTEM condition are more familiar with applying concepts of one subdomain to another. In this way, the ability to apply STEM concepts might be facilitated.

In this study, we did not find an intervention effect in terms of physics knowledge or application. That we did not these find these effects does not necessarily suggest that such an intervention could not have benefits regarding cognitive physics' outcomes. A possible explanation for the absence of positive effects with regard to physics knowledge might be that no data were collected on the third measurement moment due to the poor psychometric qualities of the test. Consequently, we could only analyze the difference between the first and the second measurement moment with regard to the two conditions. The fact that we did not find significant differences between the two conditions with regard to these two measurement moments might not be surprising, as no significant results were found for the other cognitive outcomes of this study either. Only when the third measurement moment (i.e. after two years of iSTEM education) was taken into account, were significant differences between experimental and control condition found. Presumably, this might also be the case for the outcomes regarding physics knowledge. However, this does not explain why we did not find an effect in terms of physics application. Given the larger effects with regard to mathematics application compared with mathematics knowledge, and given the findings from previous studies (e.g. Becker & Park, 2011), we might have expected an apparent effect on physics application as well.

The contrasting findings with those of previous research (i.e. effect on physics versus mathematics) might potentially be a consequence of differences in the operationalization of the intervention. The number and the degree of integration of the different components of STEM might, for example, be decisive factors. Also, interventions could differ in their emphasis on particular concepts or topics. It has been reported by English (2016) and Yildirim (2016) that a skewed focus on science at the expense of mathematics, and no integration of all subjects, is a common limitation within iSTEM education research. As little research exists involving the integration of all STEM components, further empirical research on the effects of iSTEM education needs to be conducted to extend the findings of the current study.

Analogous to the results with regard to mathematics knowledge, a positive effect of iSTEM education was found in terms of the results regarding technological concepts. Students in the experimental condition scored higher than students in the control condition after the third measurement moment (i.e. after two years of iSTEM education), both when compared to the first and the second measurement moments. The effect size of iSTEM on technological concepts was small (Cohen, 1988), in contrast to the effect sizes of mathematical outcomes, which were medium. This result indicates that further growth might be possible, by more explicitly addressing the technological concepts within the learning modules of the intervention. With regard to integrated physics and mathematics, no significant results were found. This result is remarkable, as the curriculum explicitly focused on the integration of the STEM domains. This finding demonstrates that it is not because connections between STEM domains are emphasized in the curriculum, students' own ability to integrate knowledge and skills necessarily improves. Thus far, the intervention of an integrated STEM curriculum appears to only effect cognitive outcomes regarding separate domains.

But the impact of an iSTEM educational approach might go beyond the cognitive outcomes measured in this study. Irrespective of the effects on the measured cognitive outcomes, the iSTEM approach could motivate students to see real-world applications and the relevance of the different STEM fields, even though students' performance did not increase in this study (Becker & Park, 2011).

To summarize, a positive impact of an iSTEM approach was found with regard to mathematics (knowledge and application) and technological concepts. Our findings indicate that the positive impact of iSTEM education is not limited to science, but could also positively influence cognitive scores in other domains. From this perspective, it is important for future initiatives to explicitly incorporate all STEM domains in teaching materials, and not only select two pragmatic combinations such as physics and technology. As already mentioned, no differences were found between conditions after one year of iSTEM. This stresses the importance of a long-term iSTEM approach, and has implications for the design of new integrated STEM programs. Long-term approaches with iSTEM incorporated in the standard curriculum are better suited to increase students' cognitive performance than short-term interventions.

4.2. Differential Intervention Effects

Our results showed an interesting positive impact on the performance of females with regard to 'physics application' (while no changes were found for the performances of males). As the lower physics scores of females is a well-known concern in the literature (Halpern et al., 2007), this might be an extra argument for the implementation of an integrated approach to STEM. Scores on physics application differed also for students with lower SES, when the integrated STEM condition was compared with the traditional approach. The negative impact of low SES (Yerdelen-Damar & Peşman, 2013) was smaller for students in the experimental condition of iSTEM. From this perspective, iSTEM education might create more equity.

For students in the experimental condition, the impact of abstract reasoning ability on mathematics (knowledge and application) was larger than for students in the control condition. This finding implies that, with regard to mathematics, an iSTEM approach favors those who already have more cognitive capabilities. The challenging nature of the learning modules might provide an explanation for this finding. When designing an integrated STEM intervention, educators should bear in mind that the impact of the intervention could vary with reasoning ability.

4.3. Limitations and Directions for Future Research

While our study has several strengths, such as its scale and longitudinal design, the explicit focus on iSTEM (the inclusion of all STEM domains), and the inclusion of multiple cognitive outcomes, limitations should also be acknowledged. First, we compared experimental schools with control schools, but it could not be guaranteed that the experimental schools implemented the iSTEM intervention in an impeccable way (O'Donnell, 2008), and that students in the control condition had no STEM initiatives whatsoever in their schools. It is more plausible that the experimental schools varied in the extent to which they implemented the intervention as intended, and that the control schools varied in the degree to which they did not implement (other) STEM initiatives. Nevertheless, we could ensure that all experimental schools were familiar with the integrated approach and that they implemented the learning modules in their classes. Also, intervisions with experimental schools and educational umbrellas were regularly organized so that schools were guided through the process and could optimize their iSTEM approach (Knipprath et al., 2018). The control schools, on the other hand, were queried about their ongoing STEM initiatives during the study. Most control schools did provide STEM projects for their students. However, they were only small-scale (e.g. extra programming exercises) and did not follow an integrated approach. In conclusion, we could presume that the critical component of the intervention (i.e. an iSTEM approach) was not present in the control condition. Future research could measure different characteristics (e.g. degree of integration, presence of a design challenge, etc.) of STEM initiatives in experimental and control settings, and determine the relationship with students' cognitive outcomes. In this way, a measure for implementation fidelity in the experimental setting could be provided, and a stricter oversight of the control condition could be attained.

A second limitation is that the role of the teacher was not included explicitly in this study. Variations in the implementation of the intervention could be mainly attributed to teacher characteristics and practices. Factors such as teachers' individual characteristics when accepting a new instructional approach, their attitudes towards an integrated approach with regard to STEM education, and their prior experiences could have an influence on the implementation of the learning modules (Thibaut, Knipprath, Dehaene, & Depaepe, 2018; Henderson & Dancy, 2007). Although teacher influence could be partially accounted for by controlling for the random effect of schools, we suggest that future research incorporates teacher characteristics when investigating the effect of iSTEM education. At the same time, further research is needed on ways of assisting teachers to implement iSTEM learning modules (Moore & Smith, 2014).

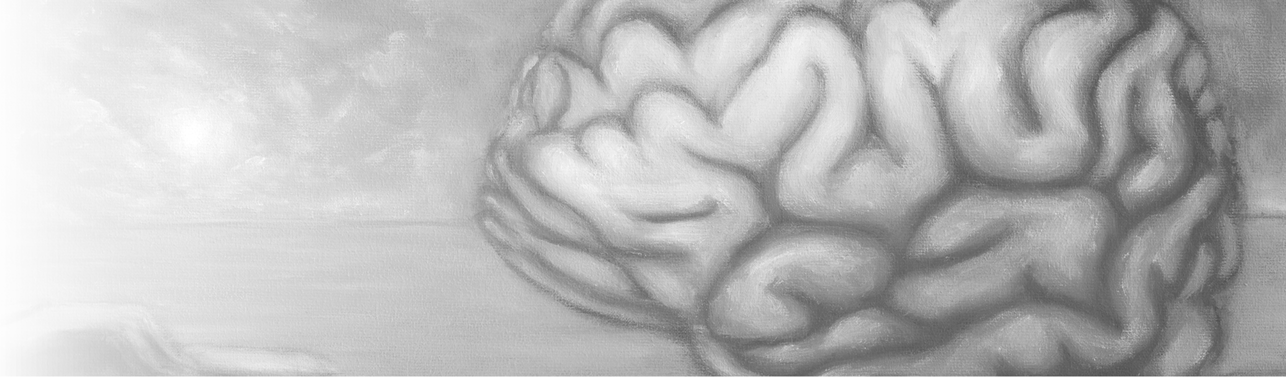
Summarizing, research regarding educational interventions is complex due to its multifaceted nature, such as the impact of implementation fidelity, teachers' characteristics, and complex settings. This exploratory study provided a first insight into the effects of iSTEM on a wide range of cognitive outcomes, and encourages future research to further investigate the crucial ingredients and the effective mechanisms associated with an iSTEM education.

5. Conclusion

This longitudinal study revealed that iSTEM education had positive effects on cognitive performance on mathematics knowledge and application, and technological concepts. Furthermore, the intervention had a positive impact on the performance of females on physics application, the negative impact of low SES was smaller in the case of physics application, and students with high abstract reasoning capabilities were favored when it came to mathematics knowledge and application. Our research shows the importance of a long-term integrated STEM educational approach, and advocates the integration of all STEM domains in educational initiatives.

CHAPTER 5

5



Study 4:

Engaging students with integrated STEM education: a happy marriage or a failed engagement?

This chapter is based on:
De Loof, H., Boeve-de Pauw, J., & Van Petegem, P. (Submitted). Engaging students with integrated STEM education: a happy marriage or a failed engagement?

Abstract

The 'leaky pipeline' with regard to students' engagement in Science, Technology, Engineering, and Mathematics (STEM) has triggered extensive research to understand and prevent students dropping out from STEM. To boost enrolment and interest in STEM fields, integrated STEM (iSTEM) education could be harnessed by providing students with relevant challenges. This study investigated (1) the evolution of affective outcomes regarding science and mathematics over time in traditional education, (2) the impact of an iSTEM curriculum on affective outcomes with regard to science and mathematics, and (3) the differential effectiveness of the iSTEM curriculum regarding student characteristics. Therefore, an iSTEM intervention was developed and evaluated over the course of two years. In total, 859 grade 9 students, distributed across 39 different schools, participated in the longitudinal study. The results of multilevel analyses show that students' attitudes, motivation, and self-efficacy towards science and mathematics becomes less positive over time. iSTEM education had positive effects on attitudes towards science and mathematics, but fewer positive results were observed for motivation and self-efficacy outcomes. Also, differential intervention effects were found with regard to student characteristics. Our results indicate that iSTEM has the potential to improve students' STEM attitudes, but that we should be careful with the implementation of this approach with regard to students' motivation and self-efficacy.

1. Introduction

There is international agreement about the importance of students' participation in science, technology, engineering, and mathematics (STEM) (DeWitt & Archer, 2015). The STEM career field is expanding at a rapid rate and a growing shortage of STEM professionals has been observed (Keith, 2018). However, especially in highly developed countries, students disengage from STEM subjects (OECD, 2008; Sjøberg & Schreiner, 2010; Bøe, Henriksen, Lyons, & Schreiner, 2011; Keith, 2018). Therefore, a great deal of attention has been given to the personal psychological factors that may influence students' engagement in STEM, or study or career choice.

1.1. Predictors of STEM engagement and study choice

Previous research has highlighted the importance of **attitudes** towards STEM. The Theory of Planned Behavior (TPB) put forward by Ajzen (1991) states that attitudes towards a behavior are the most important predictors of the behavior, together with subjective norms and perceived behavioural control. This theory is consistent with empirical research examining the role of attitudes in study choice (Armitage & Conner, 2001; Taylor, 2015). There is no general consensus about what is meant by attitudes towards STEM, as a range of components have been included in the concept (Osborne, Simons, & Collins, 2003). Some authors have attempted to provide some elaboration with regard to this topic, which resulted in certain recurring factors, such as the enjoyment of STEM learning experiences, the development of interest in STEM, and the development of interest in pursuing a STEM career (e.g. Klopfer, 1971). Interest in STEM and STEM career aspirations are two attitudinal components that have been proven to predict a STEM study choice (Wang, 2013; Morgan, Isaac, & Sansone, 2001; Schoon & Parsons, 2002).

Another crucial factor in understanding students' STEM participation is the concept of **motivation**. According to self-determination theory (SDT), motivation can be classified into intrinsic and extrinsic motivation (Deci & Ryan, 1985). When students are intrinsically motivated, they engage in the activity for the pleasure and satisfaction derived from participation itself, but when they are extrinsically motivated behavior has to be regulated (Deci, Vallerand, Pelletier, & Ryan, 1991). Research in the SDT tradition has established four regulation types that reflect a continuum from externally controlled to more autonomous forms of motivation: (1) *external regulation*, i.e. regulation with an external locus of initiation (e.g. punishment avoidance), (2) *introjected regulation*, i.e. regulation by internal pressure (e.g. guilt), (3) *identified regulation*, i.e. regulation by feelings of value (e.g. importance or usefulness), and (4) *integrated regulation*, i.e. regulation that is fully integrated with the individual's sense of self (e.g. assimilation with the other values, needs, and identities) (Deci et al., 1991). Intrinsic motivation, integrated regulation, and identified regulation can be considered as more autonomous forms of regulation, as the person does the activity more willingly. Introjected regulation and external regulation, on the other hand, are regarded as controlled motivation, as the behavior is controlled by external or internal pressure (Deci et al., 1991). These qualitatively different motivational regulations are related to various outcomes in school, such as learning and performance, psychological well-being, and engagement (Ryan & Deci, 2000b; Kusurkar, Cate, Vos, Westers, & Croiset, 2013). Autonomous forms of motivation are linked with more positive outcomes than controlled forms of motivation. As students gradually leave STEM through their educational trajectory, with dropping out at various points along their educational and occupational careers, literature has described this phenomenon in terms of a 'leaky pipeline' (Watt et al., 2012).

Insight into the quality of students' motivations helps to understand and prevent students dropping out from STEM. Extensive research has been devoted to the role of motivation in educational persistence and participation (e.g. Vallerand & Bissonnette, 1992; Vallerand, Fortier, & Guay, 1997; Ntoumanis, 2005). Students with higher autonomous motivation were found to be more persistent in following courses, more willing to perform academic activities or optional courses, and had less tendency to develop intentions to drop out of school. There is also growing evidence that the fulfilment or frustration of psychological basic needs (autonomy, belongingness, competence) in the educational context influences career aspirations (Thoman, Arizaga, Smith, Story, & Soncuya, 2014). Psychological need satisfaction is closely related to motivation, as the fulfilment of these needs nurtures intrinsic motivation and promotes internalization (Deci & Ryan, 2000).

Besides attitudes and motivation, **self-efficacy** is also an important factor that predicts willingness to participate in STEM and study choice behavior. Self-efficacy is a person's perceived capability to succeed, or to attain a desired outcome (Bandura, 1997). Self-efficacy is put forward by the Social Cognitive Career Theory (Lent, Brown, & Hacket, 1994) as one of the key factors that prompt students to make a certain study choice. Indeed, ability-related beliefs have been proven to be of great importance when it comes to make a study choice in STEM. Lau and Roeser (2002), for instance, found that students with high levels of self-efficacy with regard to science in secondary education are more inclined to choose to study science in higher education. Students' perceived efficacy is more important than their actual academic achievement with regard to study choice. Watt, Eccles and Durik (2006) found that Australian adolescents' choices for mathematics participation were influenced by ability beliefs over and above prior mathematical achievement. Furthermore, Bandura, Barbaranelli, Caprara and Pastorelli (2001) showed that perceived efficacy was the most important predictor of students' perceived occupational self-efficacy and preferred choice of work-life.

As attitudes, motivation and self-efficacy are crucial determinants for engagement in general, as well as specifically in STEM and STEM study choice behavior, it is important to provide an educational environment that fosters positive attitudes, autonomous motivation, and high self-efficacy with regard to STEM. In this study, we investigated the effectiveness of such an educational environment with regard to these determinants.

1.2. Engaging students through iSTEM education

Osborne et al. (2003) argued that there is a greater need for research to identify those aspects of the educational environment that make STEM engaging for students. A promising approach to engage more students in school, and thus attract more students to STEM fields, is that of integrated STEM (iSTEM) education. Traditionally, science, engineering, and mathematics are taught in separate courses, while iSTEM education aims to merge the content field of the different STEM areas (Roehrig, Moore, Wang, & Park, 2012). By integrating these areas, students learn to recognize the relevance of the subjects in relation to each other and to real-world problems (Honey, Pearson, & Schweingruber, 2014; Thibaut et al., 2018). This, in turn, can improve the attitudes towards STEM and enhance the motivation for learning STEM (Honey et al., 2014). Judson and Sawada (2000), for instance, reported that the integration of mathematics into a science course led to significantly higher positive attitudes towards mathematics. In a meta-analysis, Yildirim (2016) found integrated STEM to positively impact students' attitudes towards individual STEM disciplines.

Most research on iSTEM education has focused on cognitive outcomes instead of affective outcomes (Becker & Park, 2011; Yildirim, 2016; English, 2016). In addition, a skewed focus on attitudes at the expense of other affective mechanisms, such as motivation and self-efficacy, is a common limitation within iSTEM education research (Honey et al., 2014). While the impact of students' characteristics, such as sex and socioeconomic status (SES), on attitudes, motivation, and self-efficacy is well documented (Wang & Degol, 2017; Shin et al., 2015; DeWitt & Archer, 2015), few studies report on the differential impact of iSTEM with regard to these characteristics. Hence, research that targets the effectiveness of iSTEM education is an embryonic field with respect to affective outcomes. To respond to this gap in the literature, we explored the potential impact of an iSTEM intervention on students' affective outcomes.

1.3. Design of the intervention

The iSTEM intervention was a collaborative project between two Belgian universities (KU Leuven, and University of Antwerp) and two educational umbrella organizations GO!, and Catholic Education Flanders) covering approximately 70% of all schools in Flanders. Five iSTEM learning modules were developed: three for grade 9 and two for grade 10. The participating schools introduced an integrated STEM subject in which the learning modules were addressed. The schools taught the integrated STEM subject partly within the teaching hours of the regular mathematics, physics, and engineering classes, and partly within additional hours in the form of optional classes. Separate mathematics, physics, and engineering classes continued to exist, but the content was aligned with the curriculum of the integrated STEM subject. More detailed information about the project and its implementation approach can be found in the project paper of STEM@School (Knipprath et al., 2018).

The learning modules consisted of challenges that were relevant in terms of societal and ecological problems; for instance, the optimization of traffic flow through a green wave of traffic lights, building an energy-efficient house, or designing a rehabilitation device. Students addressed these challenges by applying knowledge and skills across disciplines, thereby making connections between principles and concepts. Problem-solving in an integrated STEM context also requires inquiry and design competences on the part of the students (Thibaut et al., 2018). These characteristics constituted the core of the iSTEM intervention, and were the foundation of all learning modules.

The learning modules were designed to foster students' positive attitudes, autonomous motivation, and self-efficacy with regard to STEM. By underlining the relevance of STEM for real-world problems, it was expected that students' interest in STEM would increase. Also, it could increase the attractiveness of STEM professions. As the learning modules facilitate a student-centered learning environment (Knipprath et al., 2018), this approach could increase students' autonomous motivation. The aim of the learning modules was also to increase students' understanding of STEM concepts. If students were more able to understand and apply STEM concepts, their self-efficacy with regard to mastering these topics might also increase.

1.4. Current study

Given the declining number of students who choose a STEM career or study, and given the predictors of STEM engagement and study choice, it was important to assess the development of students' attitudes, motivation, and self-efficacy towards STEM. As iSTEM education appears to be a promising approach to increase positive STEM attitudes, but remains largely under-investigated with respect to other affective outcomes, we examined the impact of a two-year iSTEM intervention on students' affective outcomes regarding STEM. Given the embryonic status of research with regard to affective outcomes, our aim was to investigate the impact of iSTEM education in a broad way (i.e. the impact on multiple determinants), rather than examine one specific determinant in depth. In this study, we focused on science and mathematics affective outcomes, and put forward three research questions.

1. What is the evolution of affective outcomes regarding science and mathematics over time in traditional education?

2. What is the impact of an iSTEM curriculum on affective outcomes with regard to science and mathematics?

3. What is the differential effectiveness of the iSTEM curriculum regarding student characteristics (i.e. sex and SES)?

2. Method

2.1. Participants and procedure

Participants in this longitudinal study totalled 859 grade 9 students (66% boys and 34% girls) with a mean age of 13.86 years (*SD* =.54) at the start of the study. Participants were students from 39 Flemish (the Dutch speaking community of Belgium) schools that were part of STEM@School. Thirty schools (612 students) implemented the iSTEM education program, and nine schools (247 students) had traditional, non-integrated science, mathematics, and engineering courses. Hence, thirty schools were part of the experimental condition, and nine schools were part of the control condition. The control schools were similar to the experimental schools with regard to relevant characteristics, such as the number of students, study track options, and membership of an educational umbrella organization.

The students in this study were taking classes in one of the following three study tracks: 1. Science and Mathematics, 2. Engineering, and 3. Latin and Mathematics. The total number of participants and the division over condition and study track can be found in Table 1.

Table 1. Number of participants (absolute and relative) divided over condition and study track

	Experimental condition	Control condition	Total	%
Science & Maths.	396	169	565	66%
Engineering	201	47	248	29%
Latin & Maths.	15	31	46	5%
Total	612	247	859	100%
%	71%	29%	100%	100%

We followed a quasi-experimental longitudinal design with three measurement moments that were undertaken over two school years: (1) at the start of grade 9, (2) at the end of grade 9, and (3) at the end of grade 10 (Figure 1).

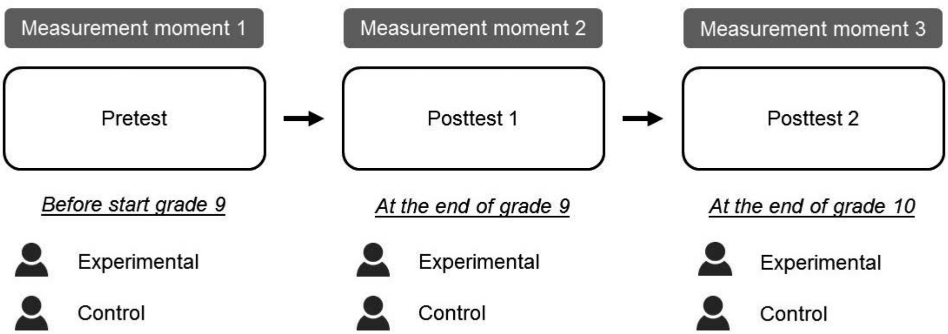


Figure 1. Measurement moments at the start of grade 9, after the end of grade 9, and after the end of grade 10.

The division of the number of recorded responses of students over the three measurement moments can be found in Table 2. While, in total, 859 unique participants were involved in this study, not all students participated at every measurement moment. Absence could be caused by schools dropping out of the project over time, by the failure of schools to administer surveys to students at one measurement moment, or because of the illness of individual students. Little's MCAR test (Little, 1988) showed that the missing data were completely at random, so there was no selective missingness.

Table 2. Number of recorded responses over measurement moments

	Time 1	**Time 2**	**Time 3**
Experimental	599	450	296
Control	246	139	126
Total	845	589	422

Responses of students over different measurement moments were connected by unique participant codes that guaranteed their anonymity. At the first measurement moment, students filled in an online questionnaire determining demographic information, and filled in online questionnaires with regard to attitudes, motivation, and self-efficacy. The affective outcomes were re-assessed at the second and third measurement moments. Students completed the online questionnaires and tests during normal school hours under supervision of the schools' contact person of STEM@School. Students and their parents were provided with information about the aim of the study and with a passive informed consent procedure. This procedure was approved by the university's institutional ethical committee.

2.2. Instruments

Demographic information. Information regarding age, sex, and the SES of participants was acquired from the self-report of students on an online questionnaire. SES was established by language spoken at home, respondents' and their parents' country of birth (Tate, 1997), parents' education, and parents' occupational status (Bornstein & Bradley, 2003). Exploratory factor analysis on these variables with varimax rotation showed that two underlying variables could be identified: (1) origin and (2) occupation and education. The weighted sum of the two factor scores led to a total SES score for each student.

Attitudes. We used an adapted version of the PATT-scale (Pupils Attitude Towards Technology; Ardies, Maeyer, & Gijbels, 2013)"abstract":"In knowledge based economies technological literacy is gaining interest. Technological literacy correlates with attitude towards technology. When measuring technological literacy as an outcome of education, the attitudinal dimension has to be taken into account. This requires a valid, reliable instrument that should be as concise as possible, in order to use it in correlation with other instruments. The PATT instrument as developed in the nineties is an extensive survey that hasn't been revalidated over the last three decades. The Pupils' Attitudes Towards Technology (PATT to assess students' attitudes towards science and mathematics. We made use of two scales: (1) career aspirations and (2) interest. Career aspirations were measured by seven items: for example, "I will probably choose a profession in science," and the interest scale consisted of six items; for example, "If there was a math club at school, I would probably join it." Responses were measured on a five-point Likert scale ranging from 1 = *strongly disagree* to 5 = *strongly agree*.

Motivation. Fifteen items from the Self-Regulation Questionnaire (SRQ; Ryan & Connell, 1989) were adjusted to assess students' controlled and autonomous motivation for learning science (more particularly physics) and mathematics. Participants indicated the importance of their study behavior motivation towards science or mathematics on a five-point Likert scale ranging from 1 = *strongly disagree* to 5 = *strongly agree*. Controlled motivation was composed of the subscales of external regulation (e.g. "I try to do well in physics because that's what I am supposed to do") and introjected regulation (e.g. "I am studying mathematics because I would feel ashamed if I did not"). Autonomous motivation was constructed from the subscales of identified regulation (e.g. "I am trying to do well in physics because I personally value this subject") and intrinsic motivation (e.g. "I usually study mathematics because I find it interesting").

Self-efficacy. Self-efficacy for science learning (namely physics learning) was assessed by five items from the Self-Efficacy and Metacognition Learning Inventory - Science (SEMLI-S; Thomas, Anderson, & Nashon, 2008), and an adapted form of this scale was used to measure self-efficacy for mathematics learning. Students were asked how often certain events happen (e.g. "I understand all the basic concepts in class"), ranging from 1 = *never or almost never* to 5 = *always or almost always*. The focus on physics learning was based on choices in the STEM@School project.

Information on scale reliability was obtained with Cronbach's α internal consistency estimates, and is displayed in Table 3 for science and in Table 4 for mathematics. Cronbach's alphas were satisfactory for all scales measuring affective outcomes, as values for Cronbach's α of .60 or higher are usually considered acceptable levels of internal consistency (Cohen, Manion, & Morrison, 2013).

2.3. Plan of analysis

First, we investigated the correlations between the study variables (i.e. attitude, motivation, and self-efficacy) with regard to science and mathematics. The mean and standard deviations of raw affective scores and correlations between the study variables with regard to science can be found in Table 3. Career aspirations, interest, autonomous motivation, and self-efficacy were all positively correlated. Career aspirations and interest, both giving information regarding attitudes towards science, were strongly correlated (r = .78). The average Variance Inflation Factor (VIF) for career aspirations and interest was 1.00, indicating no multicollinearity issues (O'brien, 2007). As the other correlations were between .09 (no linear relationship) and . 51 (a moderate linear relationship), we conducted separate univariate analyses for all affective science outcomes. Besides statistical arguments for univariate analyses, the literature indicates that these are qualitative different constructs (e.g. Schiefele, 1991), and that autonomous motivation and controlled motivation are not each other's opposite as these constructs appear to be relatively orthogonal (Vansteenkiste, Sierens, Soenens, Luyckx, & Lens, 2009).

Table 3. Descriptive statistics, internal consistency, and intercorrelations among the dependent variables with regard to science

Variables	1.	2.	3.	4.	5.
1. Career aspirations					
2. Interest	.78***				
3. Controlled motivation	-.09***	-.14***			
4. Autonomous motivation	.36***	.41***	-.09***		
5. Self-efficacy	.29***	.34***	-.10***	.51***	
M	3.50	3.54	2.68	3.05	3.39
SD	0.82	0.66	0.70	0.77	0.83
Cronbach's α	.83	.73	.83	.92	.90

Note. The scores on the variables are scores over time. *$p < .05$. **$p<.01$. ***$p<.001$.

Intercorrelations between the affective variables with regard to mathematics can be found in Table 4. The correlation pattern is analogous to the pattern in affective science outcomes: career aspirations, interest, autonomous motivation, and self-efficacy are all positively correlated. Given that the correlations were between .08 (no linear relationship) and .60 (a moderate linear relationship), and given the above-mentioned theoretical arguments, we also conducted separate univariate analyses for all affective mathematics outcomes.

Table 4. Descriptive statistics, internal consistency, and intercorrelations among the dependent variables with regard to mathematics

Variables	1.	2.	3.	4.	5.
1. Career aspirations					
2. Interest	.60***				
3. Controlled motivation	-.11***	-.11***			
4. Autonomous motivation	.57***	.46***	-.08***		
5. Self-efficacy	.46***	.35***	-.15***	.49***	
M	3.33	3.32	2.71	3.26	3.63
SD	0.82	0.63	0.78	0.79	0.84
Cronbach's α	.85	.63	.87	.92	.92

Note. The scores on the variables are scores over time. *$p < .05$. **$p<.01$. ***$p<.001$.

Subsequently, we constructed mixed models (i.e. models containing both fixed effects and random effects) to examine the evolution of affective science and mathematics outcomes over time, and to investigate general and differential effects of the iSTEM intervention. We used linear mixed models in JMP software (John's Macintosh Project) version JMP pro 13 (SAS Institute, 2000) to conduct multilevel analyses. The advantage of this software is that it uses all data (and not only complete cases), thereby also including information of cases with missing values.

The multilevel model consisted of three levels, with measurement moments at level 1 nested within students at level 2, and students nested within schools at level 3. Students and schools were added to the model as random factors, as observations within students, and schools were not independent. For all the investigated outcomes, inspection of a multivariate likelihood-ratio test indicated that a model with a fixed slope fitted better than a model with a random slope. To examine agreement among students and agreement among schools we computed intra-cluster correlation coefficients (ICC).

To examine the evolution of attitudes, motivation, and self-efficacy over time, a multilevel model with time as a fixed factor was constructed. Only students of the control condition were included, as we aimed to investigate the regular evolution over time without any intervention.

With regard to the general effect of the iSTEM intervention, we included six main effects as fixed effects, to control for their direct influence on the cognitive outcomes. Besides condition (0 = control condition, 1 = experimental condition), and measurement moment (1 = time 1, 2 = time 2, 3 = time 3), we also controlled for sex (1= male, 2= female) and SES, as previous research indicated that these variables might influence affective outcomes with regard to science and mathematics (Wang & Degol, 2017; Shin et al., 2015; DeWitt & Archer, 2015). It was also important to control for study track (1= focus on science and mathematics, 2 = focus on engineering, 3 = focus on Latin and mathematics) as this variable was not uniform in our sample. Scores for affective outcomes and SES were standardized.

3. Results

3.1 Evolution over time

We investigated the evolution of affective outcomes over time in traditional education (= research question 1). Affective outcomes with regard to science can be found in Table 5. Graphical representations for evolution in affective science outcomes are displayed in Figure 2, under the 'control' curve. For career aspirations, interest, autonomous motivation, and self-efficacy, a decline over time was detected. Controlled motivation increased over time. Note that the mean score of controlled motivation continued to be lower than the score for autonomous motivation, even with their respective increasing and decreasing trends. These results indicate that students in traditional education generally develop a negative affective relation towards science over time. For most of the variables, the significant decline takes place between the beginning and the end of grade 9.

Table 5. Mean scores for affective science outcomes over time

	Time 1	Time 2	Time 3
Career aspirations	3.51^{a}	3.34^{b}	3.08^{b}
Interest	3.55^{a}	3.43^{b}	3.10^{b}
Controlled motivation	2.59^{a}	2.71^{b}	2.80^{b}
Autonomous motivation	3.04^{a}	2.88^{b}	2.93^{c}
Self-efficacy	3.30^{a}	3.25^{ab}	3.12^{b}

Note. A mean score is significantly different from another mean in the same row if they have different superscripts.

Table 6. Mean scores for affective mathematics outcomes over time

	Time 1	Time 2	Time 3
Career aspirations	3.42[a]	3.28[b]	3.04[b]
Interest	3.25[ab]	3.34[b]	3.04[a]
Controlled motivation	2.59[a]	2.72[b]	2.82[b]
Autonomous motivation	3.36[a]	3.13[b]	3.15[b]
Self-efficacy	3.77[a]	3.55[b]	3.47[b]

Note. A mean score is significantly different from another mean in the same row if they have different superscripts.

Affective outcomes in traditional education with regard to mathematics can be found in Table 6. Graphical representations for evolution in mathematics outcomes are displayed in Figure 3, under the 'control' curve. Affective outcomes regarding mathematics follow the same pattern over time as affective outcomes regarding science. Career aspirations, interest, autonomous motivation, and self-efficacy lowered over time, while controlled motivation increased over time. Also, in this case, autonomous motivation continued to have more influence than controlled motivation, even with their respective increasing and decreasing trends. Likewise, as for science, students in traditional education generally develop a negative affective relation towards the subject over time. This decline is, in general, most noticeable between the beginning and the end of grade 9.

3.2. General intervention effects

We employed multilevel analysis to examine to what extent affective outcomes with regard to science and mathematics are explained by integrated STEM education (= research question 2). For both science and mathematics, we investigated the impact of integrated STEM education on career aspirations, interest, motivation to learn the subject, and self-efficacy with regard to the subject.

Table 7 shows the results of the five univariate analyses with regard to affective science outcomes. The interaction between condition and time, displayed underneath the 'two-way interaction' header, indicates the effect of the iSTEM intervention. This interaction was significant for career aspirations, controlled motivation, autonomous motivation, and self-efficacy, and marginally significant for interest. Students in the experimental condition reported higher science career aspiration, and more interest in science after two years of following the iSTEM courses. However, while their attitudes towards science were more positive, their motivation and self-efficacy to study science as a subject were more negative than the students in the control condition. Students who followed the iSTEM courses reported higher controlled motivation, and lower autonomous motivation and self-efficacy towards science.

Analogous to the results of the analyses regarding the affective science outcomes, the results of the analyses with regard to the affective mathematics outcomes are presented in Table 8. Only a marginally significant result was found for interest in mathematics. Students in the experimental condition reported more interest than students in the control condition.

Table 7. Multilevel analysis of the effects of condition (0= control, 1= experimental), time (1= time 1, 2= time 2, 3= time 3, study track (1= science and mathematics, 2 = engineering, 3 = Latin and mathematics), sex (1= male, 2= female), and SES on affective outcomes regarding physics

Fixed effects	**Career. Asp.**		**Interest**		**Contr. Mot.**		**Auton. Mot.**		**Self-Efficacy**	
	β	**SE**	**β**	**SE**	**β**	**SE**	**β**	**SE**	**β**	**SE**
Intercept	-0.02	0.17	0.04	0.17	-0.22	0.18	-0.06	0.19	0.29	0.18
Main effects										
Condition [0]	**-0.47*** **	**0.11**	**-0.50*** **	**0.11**	0.04	0.13	-0.03	0.15	-0.22	0.15
Time [1]	0.08	0.06	**0.28*** **	**0.06**	**-0.31*** **	**0.06**	**0.30*** **	**0.06**	**0.26*** **	**0.06**
Time [2]	-0.01	0.06	**0.14***	**0.06**	**-0.19** **	**0.06**	**0.13***	**0.06**	**0.33*** **	**0.06**
Study track [1]	**0.31+**	**0.17**	0.19	0.16	0.22	0.18	-0.11	0.18	**-0.55** **	**0.17**
Study track [2]	-0.07	0.18	-0.25	0.18	**0.45***	**0.20**	-0.20	0.21	**-0.47***	**0.20**
Sex [1]	0.05	0.07	0.01	0.07	0.13	0.08	0.14	0.08	**0.26*** **	**0.08**
SES	**0.16*** **	**0.03**	**0.12*** **	**0.03**	0.04	0.04	-0.01	0.04	**0.07***	**0.03**
Two-way interactions										
Condition [0] x time [1]	0.21	0.26	0.18	0.26	**0.52***	**0.25**	**-0.67** **	**0.24**	**-0.54***	**0.24**
Condition [0] x time [2]	**0.60***	**0.29**	**0.47+**	**0.28**	**0.75** **	**0.28**	-0.31	0.27	**-0.86***	**0.27**
Three-way interactions										
Con.[0] x time [1] x study track [1]	0.08	0.28	0.03	0.27	**-0.53+**	**0.29**	0.44	0.27	0.64*	0.27
Con.[0] x time [2] x study track [1]	-0.42	0.32	-0.48	0.31	**-0.68***	**0.33**	0.05	0.31	0.68*	0.31
Con.[0] x time [1] x study track [2]	0.43	0.39	0.36	0.38	**-0.93***	**0.40**	0.53	0.39	0.34	0.38
Con.[0] x time [2] x study track [2]	-0.38	0.44	-0.38	0.43	-0.68	0.46	-0.36	0.44	-0.02	0.43
Con. [0] x time [1] x sex [1]	0.04	0.23	0.02	0.22	0.14	0.24	0.16	0.23	0.13	0.23
Con. [0] x time [2] x sex [1]	0.11	0.28	0.38	0.28	-0.06	0.30	0.21	0.29	**0.53+**	**0.38**
Con. [0] x time [1] x SES	**-0.31** **	**0.11**	**-0.23***	**0.11**	0.13	0.11	0.09	0.10	**-0.17+**	**0.10**
Con. [0] x time [2] x SES	**-0.52** **	**0.16**	**-0.51*** **	**0.15**	-0.16	0.15	0.04	0.14	-0.01	0.14
Random effects										
ICC student	**.26*** **		**0.26*** **		**0.36*** **		**0.42*** **		**0.37*** **	
ICC school	.02		**.04***		0.03		**0.07***		**0.08** **	

Note. +p<.10. *p< .05. **p<.01. ***p<.001. Non-reference categories are specified between brackets.

Table 8. Multilevel analysis of the effects of condition (0= control, 1= experimental), time (1= time 1, 2= time 2, 3= time 3, study track (1= science and mathematics, 2 = engineering, 3 = Latin and mathematics), sex (1= male, 2= female), and SES on affective outcomes regarding mathematics

Fixed effects	**Career. Asp.**		**Interest**		**Contr. Mot.**		**Auton. Mot.**		**Self-Efficacy**	
	β	**SE**	**β**	**SE**	**β**	**SE**	**β**	**SE**	**β**	**SE**
Intercept	0.04	0.19	0.22	0.18	-0.25	0.19	0.26	0.19	0.19	0.18
Main effects										
Condition [0]	**-0.35***	**0.15**	**-0.51*****	**0.12**	0.09	0.14	-0.18	0.16	-0.21	0.16
Time [1]	**0.22*****	**0.06**	**-0.12+**	**0.06**	**-0.22*****	**0.06**	**0.20*****	**0.06**	**0.30*****	**0.05**
Time [2]	0.07	0.06	**0.11+**	**0.06**	-0.08	0.06	0.03	0.06	**0.18*****	**0.05**
Track [1]	-0.09	0.18	0.06	0.17	0.16	0.18	**-0.43***	**0.18**	**-0.46****	**0.17**
Track [2]	0.28	0.21	0.15	0.19	**0.42***	**0.20**	-0.05	0.21	-0.31	0.21
Sex [1]	-0.05	0.08	**-0.14+**	**0.08**	**0.16+**	**0.08**	-0.03	0.08	**0.15+**	**0.08**
SES	**0.07***	**0.03**	0.05	0.02	0.04	0.04	-0.03	0.04	**0.06+**	**0.03**
Two-way interactions										
Condition [0] x time [1]	-0.24	0.28	0.28	0.29	0.35	0.25	-0.35	0.24	-0.25	0.22
Condition [0] x time [2]	0.23	0.31	**0.56+**	**0.32**	0.32	0.28	0.29	0.27	0.14	0.24
Three-way interactions										
Con.[0] x time [1] x track [1]	**0.59***	**0.30**	0.18	0.31	**-0.47+**	**0.28**	**0.78****	**0.27**	**0.82*****	**0.25**
Con.[0] x time [2] x track [1]	0.00	0.34	-0.57	0.35	-0.15	0.32	-0.01	0.31	0.14	0.28
Con.[0] x time [1] x track [2]	0.30	0.41	**-0.87***	**0.42**	**-0.73+**	**0.40**	0.51	0.38	0.48	0.35
Con.[0] x time [2] x track [2]	-0.20	0.46	-0.08	0.48	-0.42	0.45	-0.38	0.44	0.03	0.40
Con. [0] x time [1] x sex [1]	0.13	0.24	0.36	0.25	0.15	0.24	-0.27	0.24	**-0.41+**	**0.21**
Con. [0] x time [2] x sex [1]	0.14	0.30	0.35	0.31	-0.26	0.30	-0.35	0.29	-0.38	0.26
Con. [0] x time [1] x SES	-0.06	0.12	0.02	0.12	0.05	0.11	**0.21***	**0.10**	**0.18+**	**0.09**
Con. [0] x time [2] x SES	-0.04	0.17	**-0.49*****	**0.17**	-0.15	0.14	0.11	0.14	-0.16	0.13
Random effects										
ICC student	**0.28*****		**0.18*****		**0.39*****		**0.43*****		**0.51*****	
ICC school	**0.08****		**0.04***		**0.05***		**0.09****		**0.11****	

Note. +*p*<.10. **p*< .05. ***p*<.01. ****p*<.001. Non-reference categories are specified between brackets.

In Figure 2, the interaction effect between condition and time for affective science outcomes is graphically presented. The scores of the five outcomes, presented as raw scores, are displayed for control and experimental conditions across the three measurement moments. Career aspirations for science of students in the control condition decreased over time, but these aspirations of the students in the experimental condition remained the same. In general, there was a decline for interest in science over time. However, this decline was less steep for students in the iSTEM condition. With regard to motivation for studying science, the outcomes of the students in the iSTEM condition exhibited a less favorable trend. In general, controlled motivation increased and autonomous motivation decreased, but this trend was stronger for students in the experimental condition. Also, for self-efficacy for studying science, the declining trend over time was more pronounced for the students in the iSTEM condition.

For science career aspirations, interest, controlled motivation, and self-efficacy, significant differences between the second and the third measurement moments were observed. For controlled motivation, autonomous motivation, and self-efficacy, the interaction was (also) significant when the first measurement moment was compared to the third measurement moment. No significant difference was found between the first and the second measurement moment for any of the outcomes. This indicates that the effects of iSTEM only become apparent after following the iSTEM courses for the second year.

The graphical representations of the mathematics scores can be found in Figure 3. A significant interaction between condition and time was present only for interest for mathematics. Interest for mathematics declined over time for students in the control condition, but stayed the same for students in the experimental condition. This interaction was significant when the second measurement moment was compared to the third measurement moment.

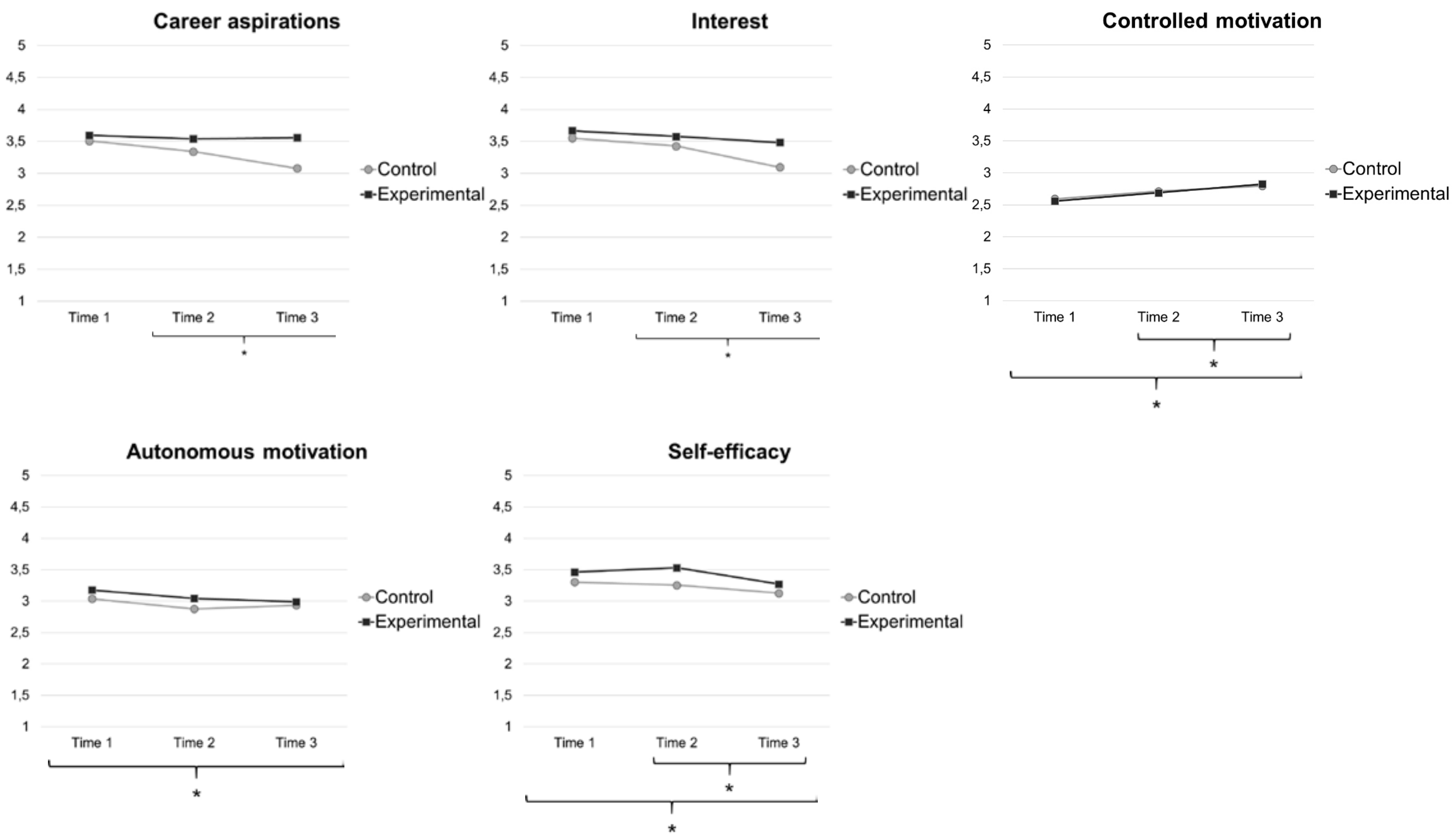


Figure 2. Scores on affective science outcomes in control and experimental conditions on pretest (= Time 1), posttest 1 (= Time 2), and posttest 2 (= Time 3).
Note. Significant interactions between condition and time are indicated with an asterisk.

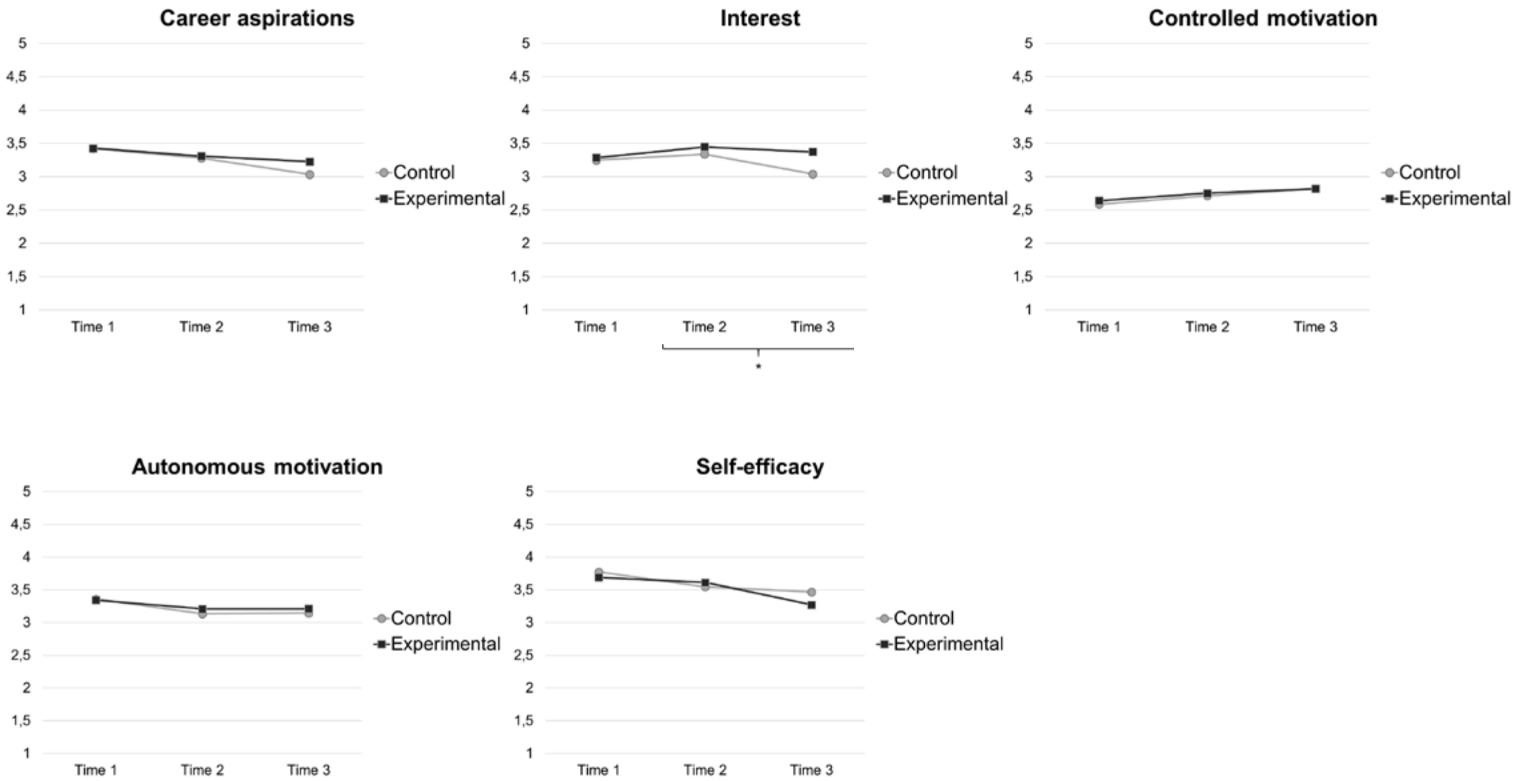


Figure 3. Scores on affective mathematics outcomes in control and experimental conditions on pretest (= Time 1), posttest 1 (= Time 2), and posttest 2 (= Time 3).
Note. Significant interactions between condition and time are indicated with an asterisk.

3.3. Differential intervention effects

Differential cognitive effects of an iSTEM curriculum with regard to student characteristics were examined (= research question 3). More specifically, we investigated whether or not the effects of the iSTEM intervention differed for boys or girls, and for students with different SES.

The interaction between condition, time, and specific student characteristics indicate the differential effect of the iSTEM intervention with regard to science, and are displayed in Table 7 underneath the 'three-way interaction' header. The relationship between condition and time differed according study track for controlled motivation and self-efficacy. While the students in the experimental condition showed a steeper decline in science self-efficacy than the students in the control condition, this effect was even stronger for girls (who already had a lower score than boys on self-efficacy in both conditions to begin with). Otherwise, as stated, the iSTEM courses were particularly disadvantageous for the science self-efficacy of girls.

The relationship between condition and time differed according SES for science career aspirations, interest in science, and self-efficacy for learning science. In the control condition, SES became gradually more important over time for science career aspirations and interest, but in the experimental condition, a negative relationship was observed over time. This means that science career aspirations and interest particularly increased for students with low SES in the experimental condition. With regard to science self-efficacy, there was also a three-way interaction between condition and time. The relation between SES and science-efficacy became more positive for students in the control condition, while this was not the case in the experimental condition. Hence, the impact of SES was lower for students in the experimental condition of integrated STEM.

With regard to mathematics, the three-way interactions between condition, time, and students' characteristics are presented in Table 8. The relationship between condition and time differed according study track for all affective mathematics outcomes. For self-efficacy, an interaction effect with sex was also found. Both in the control and in the experimental condition, self-efficacy with regard to mathematics decreased. However, in the experimental condition, this decrease was less steep for girls.

For mathematics interest, autonomous motivation, and self-efficacy, a three-way interaction between condition, time, and SES was found. SES has a positive relation with mathematics interest over time in the control condition, but this was not the case in the experimental condition. For students in iSTEM there was a negative relationship between SES and interest in mathematics. This means that mathematics interest particularly increased for students with low SES in the experimental condition. For autonomous motivation and self-efficacy, on the other hand, SES in the control condition became less important over time in comparison with the experimental condition. Thus, the impact of SES in the experimental condition differed between outcomes.

4. Discussion

The aim of this study was to assess the evolution of students' attitudes, motivation, and self-efficacy towards science and mathematics, and to investigate the effect of an iSTEM curriculum on this evolution. We answered the following three research questions: (1) What is the evolution of affective outcomes regarding science and mathematics over time in traditional education? (2) what is the impact of an iSTEM curriculum on affective outcomes with regard to science and mathematics? and (3) what is the differential effectiveness of the iSTEM curriculum regarding student characteristics?

4.1. Evolution over time

Our study indicates that there is a general trend of less positive attitudes towards science and mathematics over time. This finding is in line with previous research: George (2006) also detected a decline over the middle school and high school years of students' attitudes towards science. The greatest decline was found in the eighth and the ninth grades, which is consistent with our finding that the steepest decline is most often at ninth grade rather than tenth grade. Also, for motivation and self-efficacy, we found fewer positive responses over time with the largest decline after ninth grade. The decline at that time point could be caused by different mechanisms. First, it could be the case that the traditional curriculum in our study becomes less interesting or motivating for students at that time. However, as other research found similar results, it is not very plausible that this effect was caused by the specific content, pedagogy, or delivery of science and mathematics in our participating control schools (Ardies, De Maeyer, Gijbels, & van Keulen, 2015). Second, students in our sample were entering puberty, which may have implications for their spontaneous interests (Baram-Tsabari & Yarden, 2005; Olsson & Gericke, 2016). Third, it is possible that there is also a decline at another time point, but that we did not record this evolution because of the timing of the measurement moments. Previous research has demonstrated that STEM-related interest does not necessarily evolve linearly (Ardies, De Maeyer, & Gijbels, 2015).

Although students become more disengaged over time within the educational STEM context, it is fair to say that students' attitudes, motivation, and self-efficacy are still positive. Much research has been devoted to identifying the pattern of the leaky pipeline, as well as contributing factors (Watt et al., 2012). Our study has established that it might, thus, partly be caused by leaking positive attitudes, but also by less autonomous and more controlled forms of motivation, and by less self-efficacy with regard to science and mathematics. A lack of interest, career aspirations, and self-efficacy are detrimental for the number of students who are choosing a STEM study, as they have a direct link to the attractiveness of the study (Wang, 2013; Morgan, et al., 2001; Schoon & Parsons, 2002; Bandura et al., 2001). Low scores on autonomous motivation and high scores on controlled motivation will not only lead to fewer students in STEM study tracks (Vallerand & Bissonnette, 1992), but will also have the consequence that the study choice of students is made with poorer quality motivation. Poor quality motivation is linked with drop-out and less well-being (Vallerand et al., 1997; Ryan & Deci, 2000b).

4.2. General intervention effects

As affective science and mathematics outcomes continue to evolve negatively in traditional education, an iSTEM approach was evaluated to assess whether or not this could prevent the so-called leaking pipeline. We found that interest and career aspirations towards science of students in the iSTEM condition remained quite stable over time, where students in the control condition reported less science career aspirations and less interest over time. In the case of interest towards mathematics, the same findings emerged. These results are in line with the positive findings of previous research with regard to the effect of iSTEM education on science and mathematics attitudes (Judson & Sawada, 2000; Yildirim, 2016). We can therefore conclude that an iSTEM approach is successful at preventing attitudes towards science and mathematics deteriorating over time. DeWitt and Archer (2015) argued that although students' attitudes towards science are generally positive, this does not translate into students wanting a career in science. The results of our study demonstrate that the implementation of an integrated approach towards science, with relevant and real-life challenges, might overcome this problem.

While the impact of iSTEM education was generally positive for attitudes towards science and mathematics, contrasting results were found with regard to science motivation and science self-efficacy. Apparently, iSTEM education caused students to be less autonomously motivated and to experience more controlled motivation. A possible explanation for this finding could be the distinction between science as a discipline and science as a school subject. Based on choices in the project, attitudes were measured at the broader level of 'science as a discipline', whereas motivation and self-efficacy were measured on the level of a school subject (i.e. physics). Also, all different science disciplines were included in the meaning of 'science as a discipline', whereas a focus on physics was adopted with regard to the school subject. It is possible that the iSTEM curriculum does not improve affective outcomes related to physics, but mainly improves affective outcomes with regard to biology and chemistry, resulting in more positive scores for science in general. Nevertheless, this explanation might not be sufficient, as the learning modules largely focused on physics with respect to the integration with other STEM disciplines. It is plausible to assume that our results would have been the same if we had investigated motivation and self-efficacy with regard to other science subjects. Students in the experimental condition might have experienced more external and internal pressure to perform well in these subjects, as they were aware that they were participating in an innovative approach with regard to STEM. Also, due to the challenging nature of the project, they might have experienced the learning materials to be more difficult, which might have led to a more negative estimation of their own abilities, resulting in lower scores on self-efficacy. These results indicate that the teacher might have an important role. The teachers' motivating style and teachers' attention for students' self-efficacy might counterbalance these negative effects.

In the literature on the impact of iSTEM on cognitive outcomes, more evidence is found for a positive effect with regard to science outcomes than with regard to mathematics outcomes (Becker & Park, 2011; Honey et al., 2014: English, 2016). Our results led to a similar finding with regard to affective outcomes: the iSTEM intervention impacted all affective science outcomes, in general with medium to large effect sizes, but had only a medium positive effect on affective mathematics outcomes. This indicates that it might be more difficult to change the effects with regard to mathematics than with regard to science. It is also an encouragement to explicitly incorporate and emphasize the integration into other disciplines and the real-life applications of mathematics in iSTEM initiatives.

To conclude, we recommend the integration of STEM disciplines in education focusing on relevant and engaging challenges. However, extra attention should be given to implement a teaching style that supports autonomous motivation and self-efficacy in students (e.g. Deci et al., 1991).

4.3. Differential intervention effects

Effects on affective outcomes regarding science and mathematics differed for girls and boys and for students with different SES scores. The decline in science self-efficacy in the experimental condition was stronger for girls, but the decline in mathematics self-efficacy in the experimental condition was less steep for girls. Thus, with regard to differential sex effects, mixed results have been found. Researchers and practitioners should be aware that the effects of iSTEM might differ for girls and boys. Extra attention should be paid to girls' self-efficacy with regard to science when evaluating the impact of iSTEM educational initiatives. Teachers could consider putting girls together during group work while working with the integrated learning materials, as earlier research indicates that girls gain confidence in physics when they are following classes in a single sex environment.

The negative impact of low SES on affective science outcomes that has been reported in the literature (DeWitt & Archer, 2015), was smaller (or even positive) for students in the experimental condition, when compared to students in the control condition. Thus, in this case, iSTEM provided more equity. The finding that science career aspirations and interest particularly increased for students with low SES in the iSTEM condition indicates that the learning modules are especially appealing to students who typically have less opportunity to interact with stimulating learning materials. This increased interest, in combination with positive learning experiences, might also increase their self-efficacy, which is supported by the data. Results regarding affective mathematics outcomes were more ambiguous; high SES was less positive in the experimental condition with regard to attitudes, but had more positive impact when compared to the control condition with regard to autonomous motivation and self-efficacy.

As mixed evidence was found for differential effects for sex and SES, we do not advocate iSTEM as a means to solve gender and socioeconomic issues with regard to affective STEM outcomes. Instead, we wish to stress the potential of an iSTEM approach to improve students' STEM attitudes in general, but assert that implementation has to be done cautiously to guard the quality of motivation and self-efficacy of the students.

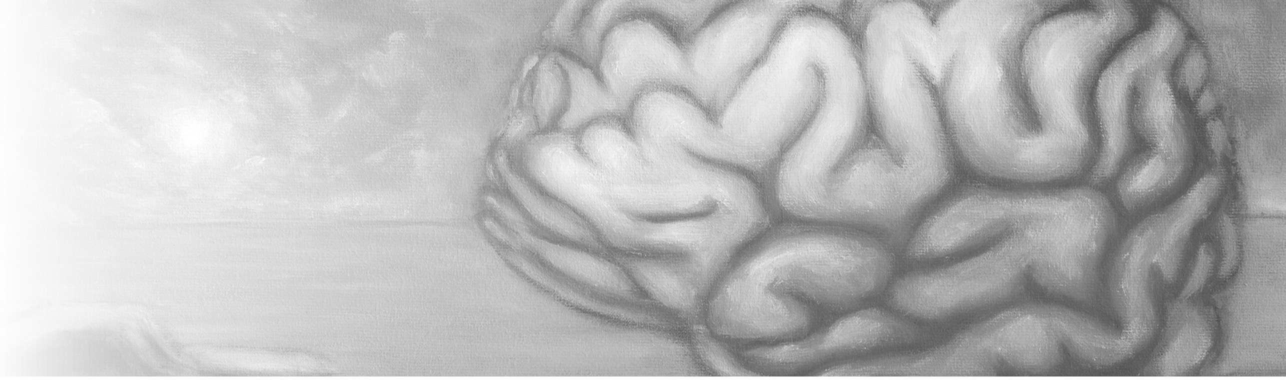
4.4. Limitations and directions for future research

The present study has certain limitations. First, study choice is not only influenced by affective outcomes. A study or career pathway involves both the ability to succeed in a study area and the motivation to employ that ability (Dweck, 2002). In this study, we did not include cognitive variables, but we encourage future research to investigate the impact of iSTEM education on both cognitive and affective outcomes. Also, understanding the interrelation between cognitive and affective variables might improve our capability to design integrated curricula that respond to the challenge of students' disengagement in STEM. Second, we need to acknowledge that in our current study we did not add measures for implementation fidelity in experimental schools (O'Donnell, 2008). It is plausible that the experimental schools varied in the extent to which they implemented the intervention as intended, and that the control schools varied in the degree to which they did not implement (other) STEM initiatives. Third, this study measured the impact of an iSTEM intervention with relevant challenges on students' affective outcomes with regard to science and mathematics, but did not separately analyze the effect of the different active components within the intervention. Future research might differentiate between the impact of the integration of the STEM fields and the presence of a relevant real-life challenge. Fourth, this study was not an in-depth study of the impact of iSTEM on different relevant outcomes. Our study has revealed some interesting findings, which should be further elucidated. In particular, the differential impact of iSTEM leaves several questions unanswered. Further research should investigate why iSTEM is particularly advantageous or disadvantageous for girls or boys, or for students with different levels of SES.

5. Conclusion

This longitudinal study revealed that students' attitudes, motivation, and self-efficacy towards science and mathematics becomes less positive over time. This finding was followed by the finding that iSTEM education had positive effects on attitudes towards science and mathematics, but that fewer positive results were observed for motivation and self-efficacy outcomes. Therefore, we conclude that iSTEM has the potential to improve students' STEM attitudes, but that we should be careful with the implementation of this approach with regard to students' motivation and self-efficacy. This study served as a pioneer study in the field of effects of iSTEM education with regard to various affective outcomes.

CHAPTER 6



Study 5:

Teachers' motivating style, students' motivation and engagement in STEM: the relationship between three key educational concepts.

This chapter is based on:

De Loof, H., Struyf, A., Boeve-de Pauw, J., & Van Petegem, P. (2019). Teachers' motivating style and students' motivation and engagement in STEM: The relationship between three key educational concepts. *Research in Science Education*. https://doi.org/10.1007/s11165-019-9830-3.

Abstract

A key theme in the science education literature concerns the reluctance of students to participate in Science, Technology, Engineering and Mathematics (STEM). Self-determination theory (SDT) states that social factors in an educational setting, such as teachers' motivating style, can influence students' motivation and engagement. This paper investigates the relationship between STEM-teachers' motivating style (autonomy support, provision of structure, involvement) and students' motivation and engagement with regard to STEM. Furthermore, the relationship between students' motivation and students' engagement is investigated. Thirty classroom observations were conducted in different STEM lessons, to assess teachers' motivating style and students' engagement. The students' motivation was assessed at the end of the school year, using an online questionnaire. The results reveal that STEM-teachers' provision of structure is positively linked to students' motivation and engagement with regard to STEM subjects. The impact of teachers' autonomy support was negatively predictive for students' autonomous motivation, and positively predictive for students' engagement. A negative relationship between students' controlled motivation and engagement was found. Based on these results, this study suggests that taking teachers' motivating style into account in future educational initiatives regarding STEM is highly relevant as a means of stimulating students' motivation and engagement.

1. Introduction

A key theme in the science education literature is the increasing reluctance of students to participate in Science, Technology, Engineering and Mathematics (STEM) (Bøe, Henriksen, Lyons, & Schreiner, 2011; Pinxten et al., 2017). Especially in highly developed countries, students are disengaging from STEM subjects (OECD, 2008). This increasing unwillingness on the part of students to participate in STEM is a matter of concern for multiple reasons. Societies need qualified STEM professionals to meet contemporary demands, such as securing sufficient and sustainable energy, efficient healthcare and well-considered technological development (Bøe et al., 2011). Furthermore, all students need to have some understanding of the role of STEM in society (OECD, 2008). Compulsory education plays an important role in responding to these issues, as scientific career attainment is influenced by the early choices made by students (Lavigne, Vallerand, & Miquelon, 2007). Students who have a high quality of motivation, maintain their engagement as the years progress, whereas students who lack motivation tend to become more disengaged over time (Skinner, Furrer, Marchand, & Kindermann, 2008). In order to increase students' motivation and engagement in STEM, it is important to investigate which factors can foster these aspects in a STEM learning environment. In the current study, we focus on the role of STEM-teachers, and we will use the framework of self-determination theory (SDT) to study the relationship between teachers' motivating style and students' motivation and engagement. SDT is an established motivational theory that has proved its value in the educational field (De Naeghel, Van Keer, Vansteenkiste, & Rosseel, 2012).

1. 2. Basic psychological need support

SDT assumes that humans have three basic psychological needs: the need for autonomy, relatedness, and competence (Deci & Ryan, 2002). Importantly, SDT states that satisfaction of these three basic psychological needs will positively affect motivation and engagement. The social context can support or thwart individuals' basic psychological needs, and thus motivation and engagement. In the context of an educational setting or classroom, teachers have a crucial role to play (Wentzel, Muenks, McNeish, & Russell, 2017). Teachers can influence students' motivation and engagement through their *motivating style,* which refers to the degree a teacher supports the students' three basic psychological needs (Tessier, Sarrazin, & Ntoumanis, 2010). Teachers who fulfill these needs have a need supporting or motivating style, in contrast to teachers with a need frustrating motivating style, who tend to define what students should think, feel and do (Reeve, Jang, Carrell, Jeon, & Barch, 2004).

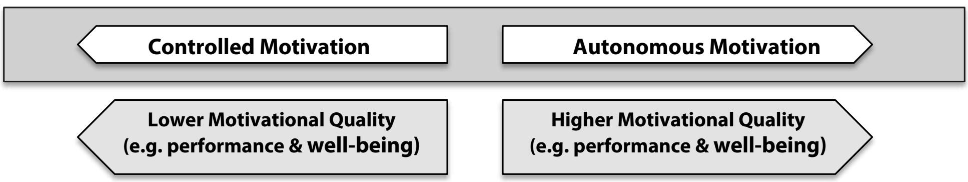
Autonomy refers to *"…being the perceived origin or source of one's own behavior"* (Deci & Ryan, 2002, p. 8). Applied in an educational context, students will experience autonomy when they perceive their engagement in learning as being their own choice, reflecting their own interests and values (Stroet, Opdenakker, & Minnaert, 2013). Importantly, autonomy is not the same as independence (which means not being influenced by outside sources). Regarding SDT, an individual can experience autonomy, even when actions are influenced by external sources (Deci & Ryan, 2002). Teachers can be autonomy supportive in various ways. Autonomy support consists of a number of different components. Teachers can support their students' autonomy by providing them with *choice*. This includes allowing their students – to a certain degree – freedom to choose tasks and subjects that they perceive as being interesting or important (Assor & Kaplan, 2001; Stroet et al., 2013). Also *fostering relevance* (e.g. by linking the learning content to students' everyday environment) and using *informational* (e.g. can, is possible) instead of *controlling language* (e.g. should, must, have to, got to) are acts of autonomy supportive behavior (Assor & Kaplan, 2001; Reeve et al., 2004).

Relatedness concerns feelings connected to, or having a, 'sense of belonging' towards other individuals or one's community (Deci & Ryan, 2002). Baumeister and Leary (1995) state that the need for relatedness or the need to belong has two main components. On the one hand, people need frequent conflict-free personal contact that is ideally affectively positive and satisfying. On the other hand, people need to perceive that their interpersonal relationships are marked by stability, emotional affection and continuation in the future. The need for relatedness can be fulfilled through interpersonal contact or by being integrated in a social group or community. Stroet et al. (2013) argue that within a (secondary) educational context, a teacher's relationship with students is not strong enough to satisfy the students' need for interpersonal relatedness. However, teachers can impact students' feelings of relatedness at school by their degree of *involvement* in the classroom. Relatedness is conceptualized as involvement in the relationship between the teacher and the student (Reeve et al., 2004; Tessier et al., 2010). Reeve et al. (2004) suggest that a teacher can express their involvement in the classroom by, for example, walking over to the students instead of staying up front during the class, expressing care, knowing students' names and investing time and energy.

Competence refers to the satisfaction that people derive from exercising and expressing their capacities (Ryan & Deci, 2002). For students, feelings of competence are enhanced if they obtain more control over school outcomes (Stroet et al., 2013). Teachers can support the basic psychological need for competence by *providing structure*. Structuring the learning environment is not equal to limiting students in the process of exploration or the expression of creativity. Stroet et al. (2013) distinguish four aspects of teachers' provision of structure based on the literature. First, providing *clarity* in terms of giving clear, detailed and understandable instructions. Second, providing students with *constructive and informational feedback*. Third, offering students *guidance* during their class activities by, for example, monitoring their work or offering help when needed can provide structure to students. Fourthly, teachers' *encouragement* can provide students with structure, consequently making students feel they have more control over school outcomes. Teachers can, for example, encourage students by expressing positive expectations with regard to school work.

1.2. Motivation and engagement

According to SDT, different types of *motivation* apply to individuals. Motivation can range on a continuum of 'amotivation' (no motivation towards an activity) to 'intrinsic motivation'. The latter is self-determined motivation, because an individual is motivated by the self, rather than by external factors such as pressure or rewards (Ryan & Deci, 2000a; Tessier et al., 2010). A student who is, for example, strongly interested in STEM and wants to understand the universe, is intrinsically motivated to put effort into STEM classes. In between the continuum of 'amotivation' and 'intrinsic motivation', Deci and Ryan (1985) classified four 'extrinsically-regulated behaviors', varying in the extent to which the motivation is less or more self-determined (Ryan & Deci, 2000a; Ryan & Deci, 2000b). The first is *externally regulated motivation*, which occurs when a person acts to avoid other-controlled punishments or to obtain external rewards (Ryan & Deci, 2000b; Vansteenkiste & Ryan, 2013). In a STEM educational context, a pupil can, for instance, study well for STEM to avoid punishment from his parents or teacher. The second type of extrinsic motivation is entitled *introjected regulated motivation*. In this case an individual is motivated to engage in behavior to avoid feelings of guilt or anxiety or to be admired by others (Ryan & Deci, 2000b); for example, a student will try to obtain good grades for STEM to show that he is a 'good boy' (Vansteenkiste & Ryan, 2013). The third type of motivation is *regulation through identification*, which is more closely allied to being self-determined or autonomous because the individual personally embraces the value of an activity or norm, but does not necessarily find it interesting or enjoyable (Ryan & Deci, 2000b; Vansteenkiste & Ryan, 2013). The student, for instance, does not enjoy studying STEM, but is motivated to do his best because he wants to become a doctor, and realizes that STEM is important to achieving his goal. The last and most autonomous category of extrinsic motivation is *integrated regulation* and occurs when a person expresses a certain behavior because it matches his broader personal values and commitments (Ryan & Deci, 2000b; Vansteenkiste & Ryan, 2013). A student's motivation is, for example, integrated regulated when she participates in STEM because she wants to develop renewable energy in her future career, as this fits into her pro-environment-friendly attitude. Figure 1 offers a visual representation of the motivation continuum.



AMOTIVATION	EXTRINSIC MOTIVATION				INTRINSIC MOTIVATION
	External Regulation	Introjection	Identification	Integration	
- Lack of perceived competence or lack of value	- External rewards of punishments - Compliance - Reactance	- Ego involvement - Focus on approval from self and others	- Personal importance - Conscious valuing of activity - Self-endorsement of goals	- Congruence - Synthesis and consistency of identifications	- Interest - Enjoyment - Inherent satisfaction

Figure 1. Based on the motivation continuum: Organismic Integration Theory Taxonomy of Regulatory Styles (Center for Self-Determination Theory, 2017).

Importantly, the literature based on SDT has shown that higher self-determined motivation has consistently been related to positive outcomes such as higher well-being, better performance, greater persistence, improved academic achievement and increased engagement (Vansteenkiste & Ryan, 2013; Tessier et al., 2010). Among these outcomes, engagement is a critical predictor of students' academic learning, grades, achievement test scores, retention, graduation and academic resilience (Pajares & Graham, 1999; Reeve et al., 2004; Reeve, 2012; Skinner et al., 2008; Tessier et al., 2010).

Engagement is a multifaceted construct, consisting of behavioral, emotional and cognitive components (Fredericks, Blumenfeld & Paris, 2004). Reeve (2012) also suggests a fourth dimension: agentic engagement. In this study, we refer to engagement as the behavioral intensity (e.g. attention) and emotional quality (e.g. interest, enthusiasm) of a person's active involvement during a task (Reeve et al., 2004). However, in other studies, engagement is also often conceptualized as on-task behavior, referring to overt student behaviors at home (e.g. effort and persistence with regard to schoolwork, participation and time on homework), or in the classroom (Lane & Harris, 2015; Raphael, Pressley, & Mohan, 2008; Ryan, 2000). Engagement can be measured at an individual level (e.g. Jang, Kim, & Reeve, 2012; Lee, Hayes, Seitz, DiStefano, & O'Connor, 2016) or at group level such as the classroom (e.g. Reeve et al., 2004; Sinatra, Heddy, & Lombardi, 2015). The latter is called collective engagement by Reeve et al. (2004). In the current study, we approach engagement as collective engagement.

1.3. Relationship between basic psychological need support, motivation and engagement

Tessier et al. (2010) have argued that motivation and engagement are both linked to basic psychological need support. In classes where teachers successfully improved their teaching style in terms of psychological need support, both students' self-determined motivation and engagement increased. In the study by Tessier et al. (2010), a pre-test post-test design was used, within a time period of three weeks. The teaching style was assessed, the students' engagement was observed, and the students psychological need satisfaction and motivation were measured by self-report. The successful improvement of the teachers' motivating style as measured in the post-test was assumed to be the originator of the positive student outcome. However, the authors did not explicitly test the link between the observed teaching style and the student outcomes.

Reeve et al. (2004) on the other hand, have explicitly investigated the link between teachers' observed teaching style and observed students' collective engagement. In their experimental study involving a delayed-treatment control group, they found that teachers displayed more autonomy-supportive behavior after training, which resulted in more engagement on the part of the students. Also, Skinner et al. (2008) investigated the link between teachers' motivating style and student engagement. They found that students who felt externally or internally pressured (low autonomy) at the beginning of the school year were increasingly feeling emotionally and behaviorally disengaged. On the other hand, students who felt highly autonomous and competent, and students who experienced secure relationships with teachers at the start of the school year, showed improvements in terms of engagement throughout the school year. However, in the studies by Reeve et al. (2004) and Skinner et al. (2008), although the link between basic psychological need support and collective engagement was tested in a direct manner, they did not connect these concepts with student motivation.

The relationship between motivation and engagement remains a subject of debate (Appleton, Christenson, & Furlong, 2008; Lee et al., 2016). Several authors consider engagement as an externalization of motivation, and thus as a motivational outcome (Stroet et al., 2013; R. Ryan, personal communication, February 6, 2017). Reeve et al. (2004) suggest that engagement contains intrinsically-motivated behavior and self-determined extrinsic motivation. Nevertheless, other authors consider motivation and engagement as two separate concepts, but not orthogonal. One could, for example, be motivated but not necessarily actively engaged in a task (Appleton et al., 2008; Connell & Wellborn, 1991). A few studies have investigated the possibility of a direct link between motivation and engagement in the context of physical education (Aelterman et al., 2012) and reading (De Naeghel et al., 2012). One study by De Naeghel et al. (2012) found that autonomous reading motivation related to qualitatively higher reading engagement. In other words, they found that students pay more attention and are more focused when they read for their own enjoyment, or when they believe that reading is personally relevant for them, than when they feel internally or externally pressured to read in their leisure time. A study in the context of physical education found that students who are more autonomously motivated are more engaged, whereas students who felt amotivated or externally pressured to participate in physical education activities show lower levels of engagement (Aelterman et al., 2012).

To the best of our knowledge, no studies have investigated a direct link between motivation and engagement in a STEM context. It is exactly this gap that we aim to address in the current study; we aim to directly link teachers' basic psychological need support with students' motivation and students' engagement. Consequently, we aim to combine the strengths of the studies by Tessier et al. (2010) and Reeve et al. (2004). Based on the literature investigating the direct link between motivation and engagement, we consider engagement as an externalization in terms of a behavioral and emotional expression of motivation. This implies that autonomous motivation contributes to higher levels of student engagement, while controlled motivation is negatively related to it.

In this study, we address the theoretical concepts of teachers' motivating style, students' motivation and students' engagement within the class context. The motivational atmosphere in a class is a result of social interactions between students and teachers and can vary across different classes (Aelterman et al., 2012). Hence, we approach motivation and engagement as collective class dynamics (Reeve et al., 2004). As shown in Figure 2, this paper hypothesizes that teachers' motivating style is directly linked to students' class motivation and students' collective engagement and, in addition, a predictive relationship between student motivation and engagement is assumed. More specifically, we hypothesize that controlled motivation (i.e. external regulation and introjected regulation) is negatively predictive for engagement, and that autonomous motivation (i.e. identified regulation and intrinsic motivation) is positively predictive for engagement.

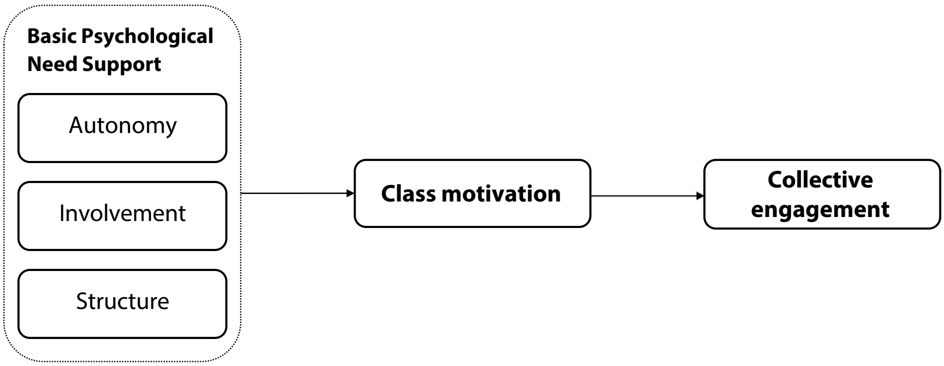


Figure 2. Link between basic psychological need support, class motivation and collective engagement.

Besides lacking an explicit link between the three key concepts of this paper, to the best of our knowledge, no previous research has yet investigated the link between teachers' motivating style and student motivation and engagement within the educational context of various STEM subjects. For instance, no such studies were reported in the review studies of Stroet et al. (2013) and Núñez and León (2015) about the effects of basic psychological need support in an educational context.

1.4. Aim and hypotheses

The purpose of the present study is to investigate:

1. The relationship between STEM-teachers' motivating style and (1a) students' motivation towards STEM and (1b) students' engagement. We hypothesize that higher teachers' basic psychological need support predicts higher students' self-determined motivation, lower controlled motivation, and higher engagement.

2. The relationship between students' motivation towards STEM and their engagement. We hypothesize that autonomous or self-determined motivation in terms of studying a STEM subject is positively predictive, and that controlled motivation is negatively predictive for students' engagement in the classroom.

2. Method

2.1. Participants and research setting

This study is embedded and conducted within the research project STEM@School (Knipprath et al., 2018). The project's aim is to develop and study the implementation of integrated STEM education in Flanders (northern region of Belgium). This resulted in an integrated STEM course in which students were challenged to solve authentic STEM problems. Integrated STEM education is an interdisciplinary educational approach which aims to remove the barriers between the four STEM disciplines (Wang, Moore, Roehrig, & Park, 2011). One of the overall aims of this approach is to increase students' achievement and motivation with regard to studying STEM in order to attract more students to professions that involve the use of STEM. To measure the effectiveness of the integrated STEM approach in terms of these student outcomes, a pre-posttest design was used in this project. However, we also took into account other meaningful factors that may influence students' motivation with regard to studying STEM subjects. In this study, we focused on STEM-teachers' role, and more specifically STEM-teachers' motivating style.

A convenience sample of schools associated with the STEM@School project was used. To select a suitable number of participants in schools with varying characteristics, a stratified random sampling approach (based on the number of students and the provided fields of study) was used among the population of schools associated with the research project. This resulted in 17 schools, from each of which one 9th grade class was selected to participate in this study. All classes could be considered as STEM classes, however, in 12 of these classes students followed a study track in which STEM is more theoretically addressed (named 'Science and Mathematics'), and in the other 5 classes students followed a study track in which STEM is more practical-oriented (named 'Industrial Sciences'). In each of these classes, one mathematics lesson, one physics lesson, and - when included in the curriculum - one integrated STEM or engineering lesson, was observed. Hence, both traditional domain-specific STEM lessons and integrated STEM lessons were included in the observations.

After screening the visual and auditory quality of the observational data, 30 observations remained, resulting into 27 participating teachers (41% male, 59% female) and 359 9th grade students (64% male, 36% female, age: M = 14.55; SD =.85). From these 27 teachers, four were physics teachers, seven mathematics teachers, three engineering teachers and 11 were teachers that taught the integrated STEM course. integrated STEM-teachers. One teacher taught mathematics, physics and (integrated) STEM and one teacher taught both mathematics and physics.

2.2 Procedure

30 classroom observations were conducted between January and May 2016. Each lesson was videotaped and had a duration of between 50 and 100 minutes. The teachers' motivating style was observed, as well as students' engagement. At the end of the school year during the post-test of the project, students' motivation was assessed using an online questionnaire. In line with Belgian legislation, teachers voluntarily participated in the observations, and permission was obtained from the students and their parents using a passive informed consent procedure.

2.3. Measures

Teachers' motivating style and students' engagement. To assess the teachers' motivating style and the students' collective engagement, we used an observation rating scale (Figure 3) developed by Reeve et al. (2004), including predetermined coding categories (Renninger & Bachrach, 2015). This observation scale was developed after an extensive review of the SDT literature (Reeve et al., 2004). The scale consists of 18 items which assessed four measures: teachers' autonomy support (4 items), teachers' provision of structure (5 items), teachers' provision of involvement (4 items) and one measure of students' engagement, which included both behavioral and emotional engagement (5 items). Based on video recordings, each item was rated on a continuum ranging from 1 to 7. Sample items include, for example, controlling language versus informational language (autonomy support), teacher seems cold versus teacher seems warm (involvement), poor versus strong leadership (structure) and dispersed versus focused attention (students' engagement). Both the frequency and intensity of the teachers' and students' behavior were considered during the rating procedure. We used number 4 as anchor or starting point. Then, we gradually moved to the left when behavior from the left column was more present, and we moved to the right when behavior from the right column was more present. For instance, we started from 4 at the start of the lesson on the item 'Physical Proximity'. If the teacher kept staying up front during class, the score gradually decreased. But if we observed that the teacher regularly walked over to students, the score increased. If the teacher was most of the time involved with the students in close proximity, a 7 was allocated. A high single class-level score to each of the five items was given on students' engagement when engaged behavior or emotions were expressed by most or almost all students in the classroom.

Influence Attempts:
Behavior intended to produce a change in the flow of the class or the behavior of the other person.
Teacher-Initiated Hits (Influence attempts):
Student-Initiated Hits (Influence attempts):

Rater:
Teacher:
Classroom:
School:

Rating Period (circle one):
1st10m 2nd10m 3th10m 4th10m 5th10m
Number of Students:
Day/Date/Hour:

Teacher's **Autonomy Support**

Relies on Extrinsic Motivational Resources • Incentives, Consequences • Directives, Deadlines • Makes Assignments • Seeks Compliance	1 2 3 **4** 5 6 7	**Nurtures Intrinsic Motivational Resources** • Interest, Enjoyment • Challenge • Competence/Confidence • Choice-Making
Controlling Language • Controlling, Coercive • Should, Must, Have to, Got to • Pressuring, Rigid, No nonsense	1 2 3 **4** 5 6 7	**Informational Language** • Informational • Flexible • Not at All Controlling
Neglects Value, Importance of Task/Lesson/Behavior • Neglects Value, Meaning, Use, Benefit, Importance	1 2 3 **4** 5 6 7	**Identifies Value, Importance of Task/Lesson/Behavior** • Identifies Value, Meaning, Use, Benefit, Importance • This is important because...
Reaction to Negative Affect: Is Not OK: Change it • Neg. Affect is Unacceptable • Tries to Fix, Counter, or Change • into Something Else	1 2 3 **4** 5 6 7	**Is OK: Listens, Accepts** • Listens Carefully • Open to Complaints • Accepts as OK, Valid Reaction

Teacher's **Structure**

During Introductions/Directions: **Absent, Confusing**	1 2 3 **4** 5 6 7	**Clear, Predictable**
Unclear, Complicated • Rules, Procedures are Confusing, Absent • Little or no organization		**Understandable, Detailed** • Clearly Stated Procedures • Frames Upcoming Lesson Well • Clear Organization
During Lessons/ While students learn **Poor Leadership** • Fails to Show Leadership • No Plan, No Goals	1 2 3 **4** 5 6 7	**Strong Leadership** • Organized, Leader, Conductor • Clear Plan, Clear Goals
Low, Easy Workload • Little Challenge, Slow Pace • Asks for only Small Capacity	1 2 3 **4** 5 6 7	**High, Hard Workload** • Much Challenge, Fast Pace • Asks for Full Capacity
Scaffolding is Fully Absent • Lack of Hints, Clues, Tips • Questions Missed, Answered Poorly	1 2 3 **4** 5 6 7	**Scaffolding is Richly Present** • Hints, Clues, Tips, Reminders • Answers Questions Well, Fully
During Feedback, Post-Performance Commentary **None, Ambiguous, Off-Task, Rambling**	1 2 3 **4** 5 6 7	**Skill-Building, Informative, Instructive**

Teacher's **Involvement**

Seems Cold, Closed • Business-like • Doesn't Enjoy Time with Ss	1 2 3 **4** 5 6 7	**Seems Warm, Open** • Expresses Affection, Caring • Does Enjoy Time with Ss
Withholds Personal Resources • Time, Attention, Energy	1 2 3 **4** 5 6 7	**Invests Personal Resources** • Time, Attention, Energy
Physical Proximity: Distant • Keeps Distance • Stays Up Front During Class	1 2 3 **4** 5 6 7	**Physical Proximity: Close** • Walks over to Students • Stands Near/Sits Close
Knows Students: No Not at All • No Mention of Names, Academic/Personal Histories	1 2 3 **4** 5 6 7	**Knows Students: Yes, Detailed Knowledge** • Knows Names, Academic/Personal Histories

Students Collective **Engagement**

Dispersed Attention	1 2 3 **4** 5 6 7	**Focused Attention**
Passive, Slow, Minimal Effort	1 2 3 **4** 5 6 7	**Active, Quick, Intense Effort**
Verbally Silent • Students Don't Talk, Ask Questions, Discuss	1 2 3 **4** 5 6 7	**Verbally Participating** • Students Do Talk, Ask Questions, Discuss
During Challenge, Failure or Confusion **Gives Up Easily** • Decreases Effort over Time	1 2 3 **4** 5 6 7	**Persists** • Increases Effort over Time
Flat Emositive Tone • Bored, Disinterested, Flat	1 2 3 **4** 5 6 7	**Positive Emotional Tone** • Enjoyment, Interested, Fun

Note for Each Rating: Use the bold, underlined **4** as your anchor/starting point.

Figure 3. Observer's rating sheet to score teachers' autonomy support and students' engagement (Reeve et al., 2004).

Two researchers rated the items independently to avoid social influence bias. The interrater reliability, based on the correlation coefficients, was satisfactory (*IRR* = .87). For the first five observations, the raters explicitly discussed each score they gave. Hence, we guaranteed that the scales were interpreted in the same way by both researchers. In the event of a different interpretation of the observation measure, the scores were modified after discussion. For the remaining observations, scores were not justified when a conflict in scores occurred. After this observation process, the two independent scores of the raters were converted to an average score per item for conducting the analyses.

The reliability of the subscales was examined by calculating Cronbach's alpha, as shown in Table 1. Teachers' autonomy support, teachers' involvement and students' engagement all showed Cronbach's alpha > .80, and teachers' structure initially showed Cronbach's alpha = .71. As the reliability improved as a result of deleting the first item (Cronbach's alpha = .78), the item 'structure during introduction' was removed, resulting in a scale of 4 items instead of 5. This means that a teacher might clearly frame the upcoming lesson during the introduction, which might be relatively easy to ensure. Still, this does not have to imply that a teacher also shows strong leadership skills and provides structure throughout the lesson.

Table 1. Reliability of the subscales of the rating scale for teachers' motivating style and students' engagement

	Autonomy support	**Structure**	**Involvement**	**Engagement**
Cronbach's alpha	.80	.78	.82	.92

Students' motivation. As motivation with regard to STEM-related subjects is difficult to observe as a general class group characteristic, we used individual self-report questionnaires. Two controlled types of motivation (external regulation and introjected regulation) and two autonomous types of motivation (identified regulation and intrinsic motivation) were assessed at the end of the school year. The timing of this assessment was based on choices in the project. Students' individual scores on controlled motivation and autonomous motivation were averaged to create a class score. The questionnaire was based on the Self-Regulation Questionnaire (SRQ; Ryan & Connell, 1989) and consists of 15 items which assess the motivation for learning physics, engineering, mathematics and integrated STEM. The participants indicated for each separate subject how important a motivational reason was for their own study behavior on a five-point Likert scale, ranging from 1 = *strongly disagree* to 5 = *strongly agree*. The number of items, an example item and the reliability of each subscale can be found in Table 2. The validity of the SRQ has been demonstrated by studies in various domains (e.g. Levesque et al., 2007). All subscales in the current study showed sufficient psychometric properties, as Cronbach's alpha > .80 was achieved.

Table 2. Number of items, example item and reliability of the subscales of students' motivation

	Controlled motivation		Autonomous motivation	
	External regulation	**Introjected regulation**	**Identified regulation**	**Intrinsic motivation**
N items	4	4	4	3
Example item	I try to do well in mathematics because that's what I am supposed to do	I am studying engineering because I would feel ashamed if I didn't	I am trying to do well in physics because I personally value this subject	I usually study mathematics because I find it interesting
Cronbach's alpha	.83	.85	.87	.85

2.4. Plan of Analysis

To test the hypothesis concerning the effect of STEM-teachers' motivating style on students' engagement, a statistical regression model was created, in which class group characteristics were linked with student outcomes. Considering that students learn together in class groups, we could expect that students' motivation and the engagement between students in the same class group will be more highly correlated than students' motivation and engagement between students in different class groups. Multilevel modelling allows data to be clustered in groups (in this case, class groups) and is therefore suitable for this research context. This study used a two-level model where students at level 1 were nested within class groups at level 2. Multilevel analyses were computed using JMP (John's Macintosh Project) version JMP pro 13. Similarly, multilevel analysis was performed to discover the relationship between teachers' motivating style and students' motivation. Next, multilevel analysis was performed to evaluate whether or not students' controlled or autonomous motivation can predict students' engagement.

3. Results

In Table 3, the means, standard deviations and correlations between teachers' motivating style, students' motivation and students' engagement are shown. The concepts autonomy support, structure and involvement are mutually strongly correlated (correlations varied from .72 to .84) and furthermore consecutively correlated with engagement (correlations varied from .82 to .83). The average Variance Inflation Factor (VIF) for autonomy support, structure and involvement was 2.64, indicating no problems with collinearity between the three variables of basic psychological need support.

Table 3. Means, standard deviations and correlations between teachers' motivating style, students' motivation, and engagement

	Teachers' motivating style			Students' motivation		Students' engagement
	1. Autonomy support	2. Involvement	3. Structure	4. Controlled motivation	5. Autonomous motivation	6. Engagement
1.						
2.	.84***					
3.	.72***	.73***				
4.	-.38*	-.33	-.14			
5.	-.01	.12	.32	-.10		
6.	.83***	.82***	.82***	-.39*	.25	
M	4.65	5.21	5.11	2.64	3.14	4.66
SD	1.10	.95	.94	.32	.41	1.25

Note. *$p< .05$. **$p<.01$. ***$p<.001$.

3.1. Relation between STEM-teachers' motivating style and students' motivation

Multilevel analysis with class group as a random factor was performed for the prediction of students' motivation for learning STEM subjects due to the teachers' motivating style. Results can be found in Table 4. The model with teachers' autonomy support, involvement and structure and class group as random effects did not consistently predict students' motivation, as linear regression showed that only structure could positively predict autonomous motivation ($\beta = .26$, $p<.05$), while autonomy support negatively predicted autonomous motivation ($\beta = -.22$, $p<.05$). No significant results for controlled motivation were found. Note that teachers' involvement was never predictive for students' motivation. Approximately 80% of the variation in students' controlled motivation is a function of the class group to which they belong (ICC = 0.80), while 76% of the variation in students' autonomous motivation is a function of the class group (ICC = 0.76). These correlations indicate strong average within-group agreement for the motivation measures.

Table 4. Relationship between teachers' motivating style and students' motivation

	β Autonomy support	β Structure	β Involvement
Controlled motivation	-.08	.07	-.01
Autonomous motivation	-.22*	.26**	.10

Note. *$p<.05$. **$p<.01$. ***$p<.001$.

3.2. Relation between STEM-teachers' motivating style and students' engagement

The relation between STEM-teachers' motivating style and students' engagement with class group as the random effect is reported in Table 5. Higher levels of teachers' autonomy support were marginally predictive (β = .40, p=.06) and structure was significantly predictive (β = .55, p<.05) for students' engagement. With regard to involvement, no significant relationship between students' engagement was found. Hence, a positive relationship between STEM-teachers' motivation style and students' engagement was found: the more the teachers provided autonomy support and structure, the more students displayed engaged behavior. 24% of the variation in engagement is a function of the class group to which they belong (ICC = 0.24).

Table 5. Relationship between teachers' motivating style and students' engagement

	β Autonomy support	β Structure	β Involvement
Engagement	.40	.55*	.27

Note. **p*<.05. ***p*<.01. ****p*<.001.

3.3. Relation between motivation and engagement

Multilevel analysis with class group as a random factor was performed for the prediction of students' engagement with motivation for learning STEM subjects. These regressions indicated that controlled motivation (extrinsic regulation and introjected regulation) could negatively predict engagement in a marginally significant way (β = -1.43, *p*=.06). Engagement could not be predicted by autonomous motivation (identified regulation and intrinsic motivation) in this study. The strengths of the relationship between motivation and engagement can be found in Table 6, where the standardized coefficients are reported. Multilevel analysis revealed that approximately 3% of the variation in students' engagement is a function of the class group to which they belong (ICC = 0.03).

Table 6. Relationship between students' motivation and engagement

	β Controlled motivation	β Autonomous motivation
Engagement	-1.43	.65

Note. **p*<.05. ***p*<.01. ****p*<.001.

4. Discussion

Using SDT as a theoretical approach, the aim of this study was to gain more insight into the impact of teachers' motivating style on students' motivation and engagement, particularly in a STEM educational context. Furthermore, we aimed to build further on the existing literature with regard to motivation and engagement, by exploring the relationship between these two concepts. In Figure 4, a summary of the results is displayed graphically.

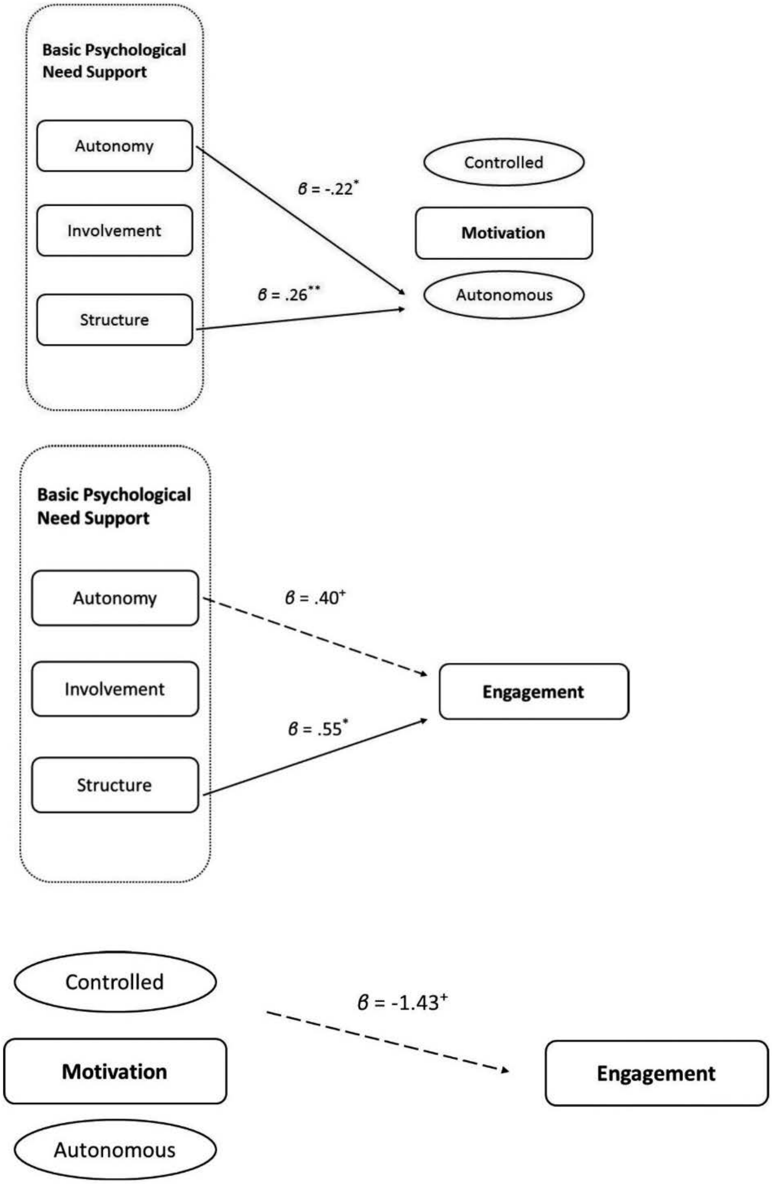


Figure 4. Summary of results: link between basic psychological need support, students' motivation and engagement.

The design of this study was unique, as in previous research no explicit link between the three key concepts examined in this paper was made within the educational context of various STEM-subjects (Stroet et al., 2013; Núñez & León, 2015). Other studies exclusively focused on one particular STEM-subject within the perspective of SDT, e.g. mathematics (Valås & Søvik, 1994), organic chemistry (Black & Deci, 2000), physics (Zhang, Bobis, Wu, & Cui, 2018), and biology (Hofferber, Basten, Großmann, & Wilde, 2016).

4.1. STEM-teachers' motivating style and students' motivation

Conforming to the SDT and other empirical studies (e.g., Black & Deci, 2000; Valås & Søvik, 1994), we hypothesized that greater teachers' basic psychological need support (provision of autonomy, relatedness and structure) in STEM lessons predicts higher autonomous class motivation and lower controlled class motivation in terms of studying STEM (hypothesis 1a).

The results in this study show that *teachers' provision of structure* is positively linked with autonomous motivation (i.e. identified regulation and intrinsic motivation), which is in line with our hypothesis. Feelings of competence have been considered central to motivation in achievement settings (Nicholls, 1989), which is also reflected in the results of the current study. No relationship was found between teachers' provision of structure and controlled motivation.

Furthermore, *teachers' involvement* was not predictive for either students' autonomous or controlled motivation. In the literature, less attention has been given to the role of relatedness in educational settings (Cox & Williams, 2008; Lavigne et al., 2007; Curran, Hill, & Niemiec, 2013). One could hypothesize that it is less likely to find a relationship between feelings of relatedness and motivation.

Regarding teachers' autonomy support, no predictive relationship was found for students' controlled motivation. Surprisingly, *teachers' autonomy support* was negatively associated with autonomous motivation, given that we expected a positive relationship to emerge. A possible explanation for this unexpected result could be that we did not include intermediate variables such as students' self-reported basic psychological need satisfaction. Lavigne et al. (2007) for example, did find that science teachers' autonomy support positively influences students' self-perceptions of autonomy. In turn, the latter has a positive impact on students' autonomous motivation in science. Another explanation could be associated with a time-related factor. The self-report of students' motivation took place a few months after the class observations, and therefore certain personal or school-related events could have affected students' motivation towards STEM. For instance, teachers' motivating styles towards the end of the school year could differ due to time pressure before the exam period, which might subsequently influence students' motivation. Learning materials could also influence students' motivation. For instance, Hofferber et al. (2016) found that autonomy-supportive teaching behavior led to more intrinsic motivation, but these positive effects seemed to be dependent on the interestingness of the teaching materials.

4.2. STEM-teachers' motivating style and students' engagement

In line with our hypothesis (1b), this study confirms that STEM-teachers' motivating style positively affects students' collective engagement. For two of the three basic psychological needs (autonomy support and structure), a positive association was found with students' engagement. The finding that basic psychological need support is predictive of students' engagement is in line with the study by Skinner et al. (2008) who investigated the link between teachers' basic psychological needs support and students' self-reported engagement. Skinner et al. (2008) made use of self-report measures for teachers and students, and argued that teacher support, through its effects on students' perceptions of their teacher's motivating style, influences their engagement. The results in the current study also confirm the findings of Reeve et al. (2004), who made use of observational data, and found a clear effect of teachers' motivating style on students' collective engagement. In conclusion, the findings of this study - in combination with the evidence of studies using different methodological approaches - demonstrate the relevance of teachers' motivating style when it comes to students' engagement.

4.3. Student motivation and engagement

The hypothesis that higher mean levels of autonomous motivation are positively predictive, and higher mean levels of controlled motivation negatively predictive for students' collective engagement in the classroom (hypothesis 2) has partially been confirmed. In this study, only controlled motivation was negatively linked to students' engagement. This means that low levels of engagement can be considered as an externalization of controlled motivation. Other studies found mixed evidence with regard to the relationship between motivation and engagement. De Naeghel et al. (2012) discovered a positive link between autonomous motivation and reading engagement, but did not find a negative link with controlled motivation. The study by Aelterman et al. (2012) did find a positive link between autonomous motivation and engagement in physical education, and a negative link between controlled motivation and engagement. The mixed evidence of these previous studies indicates that the link between motivation and engagement could be dependent on the context. A possible explanation for the results of the current study could be that the design of the study (i.e. different measurements and different time frames; see limitations) was not sufficient to reveal a positive relationship between engagement and autonomous motivation. If these measurements were all self-reported, finding a direct link could have been more likely. At the same time, we argue that the use of different measurement instruments in this study to capture students' engagement (observational data) and students' motivation (student self-reports), are a strength as a multi-method approach can have a positive impact. A combination of measures has an advantage over the use of a single instrument; self-reported measures have the problem of retrospection, and observations have the possibility of observer bias such as seeing what one is expecting (Greene, 2015; Sinatra et al., 2015).

4.4. Implications for STEM educational practice

Based on the findings regarding hypotheses 1a and 1b, we can conclude that taking into account teachers' motivating style is highly relevant for STEM education research and practice, in order to motivate and engage students within the class context. We found a clear link between teachers' provision of structure and students' autonomous motivation and engagement. Although the relationship between autonomy support and autonomous motivation was less clear in this study than in some others, we found a clear link with engagement. Hence, we suggest that efforts to increase STEM-teachers' basic psychological need support are important to enhance the motivational atmosphere in various STEM classes. Moreover, a previous empirical study (Lavigne et al., 2007) found that the teacher motivating style in general can lead to more students pursuing a STEM-career.

Importantly, some STEM learning environments could be perceived as being better suited to nurturing one of the three basic psychological needs. A teacher-centered learning environment such as a lecture could be suited to allowing teachers to provide structure, but might be less evident when it comes to supporting a class group's need for autonomy and relatedness. In contrast, a student-centered learning environment might provide more room for supporting the class group's need for autonomy and relatedness (Baeten, Dochy, & Struyven, 2013). This has important implications, taking into consideration the fact that plenty of literature and educational practitioners advocate a shift in teaching and learning STEM towards student-centeredness (Sawada et al., 2002). The current international focus on integrated STEM education (iSTEM education), also requires a student-centered learning environment (Nadelson & Seifert, 2017). As stated, such environments might provide more room to support students' need for autonomy and relatedness (e.g. through problem-centered learning and cooperative learning), but at the same time these student-centered learning environments entail the risk that teachers provide insufficient structure to students (Struyf, De Loof, Boeve-de Pauw, Van Petegem, 2019). As we found that both autonomy and competence support are crucial in order to supporting students' classroom engagement, we emphasize in line with Kirschner, Sweller and Clark (2006), the necessity of teacher's guidance throughout students' learning process, especially in student-centered learning environments. An illustration of this issue was provided by Eckes, Groβmann and Wilde (2018). They argued that students' feelings of competence were usually frustrated in extracurricular settings such as museums, but found that extra provision of structure in these settings was effective in terms of fostering this basic psychological need. Consequently, professional development programs that aim to improve STEM teachers' motivating style within student-centered learning environments, can especially focus on how teachers can sufficiently provide both autonomy and structure.

Also, professional development programs could incorporate information and guidance for teachers on how to use a need-supportive motivating style during instruction in all possible STEM learning environments, in order to increase students' engagement in STEM. Additionally, it should be noted that providing structure in the classroom is one possible way in which teachers can support students' feelings of competence. Other approaches could also enhance competence support, such as giving personalized feedback.

Furthermore, attention should be paid to STEM teachers' own feelings of competence with regard to teaching STEM, as previous research shows that the more teachers feel competent, the more their teaching is autonomy-supportive (Bennett, Ng-Knight, & Hayes, 2017).

4.5. Limitations and directions for future research

The current study adds to the SDT-literature in the STEM-context, and links the concepts of psychological need support, engagement and motivation in one study using multiple measures. However, it has some limitations which future researchers can attempt to eliminate in order to enhance our understanding of the subject.

A first important limitation is that observations were conducted during one particular period of time during the school year, and were linked to students' motivation towards STEM-related subjects at the end of the school year. Hence, this paper involves a cross-sectional study which means that no causal inferences can be made about the influence of basic psychological need support on engagement and motivation. Further research could add causal inferences to the relationships that were discovered in the current study. Therefore, we suggest a cross-lagged longitudinal study which measures teaching style, engagement and motivation at multiple points in time.

Furthermore, observational research has some limitations. It is possible that teachers' observed motivating style and students' engagement is not representative of the teachers' and students' usual behavior. Nevertheless, an observation involving a video camera can always have an effect as the camera effect does not necessarily disappear after more than one observation. Future research that uses observational data to capture students' engagement ideally needs to conduct a number of observations during the school year. Also, future research could measure teachers' motivating styles based on students' perceptions, to eliminate the possibility that a teacher's motivating style is perceived differently by students than by the researchers. However, the combination of observational data with self-reported measurements in the current study also has advantages, such as that no retrospection bias is likely to occur for the variables that are observed.

An interesting path for future research, is the investigation of a possible differential impact of the subject. The current study included only thirty class observations (divided over mathematics lessons, physics lessons, integrated STEM lessons and engineering lessons), and did not allow to make conclusions with regard to this matter.

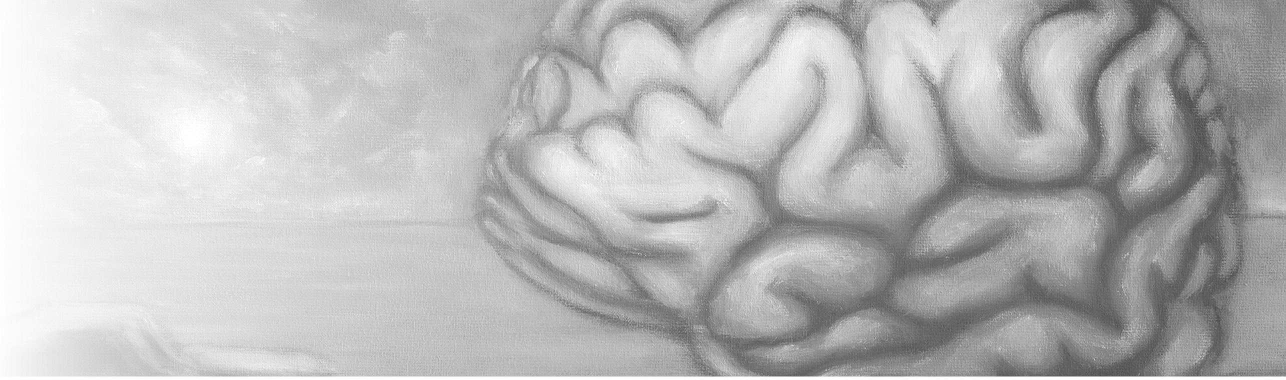
A final remark is that engagement was measured at a meso-level (collective engagement from the class group), while motivation was measured at a micro-level (individual student) and scores were averaged to create a class score (group level). Future research, investigating the link between motivation and engagement on an individual level, can use students' self-reported motivation as well as self-reported engagement in order to create a more comprehensive and fine-grained view of the link between engagement and motivation.

5. Conclusion

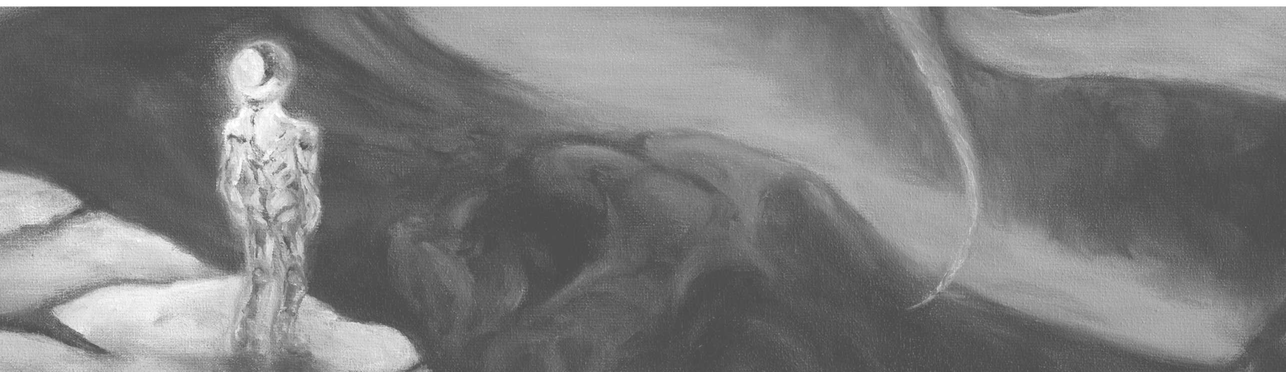
This study showed the importance of teachers' motivating style in a STEM educational context. In particular, teachers' provision of structure is significant in terms of increasing students' motivation to study STEM-related courses on the one hand, and students' engagement in STEM classes on the other. In addition, teachers' autonomy specifically was significantly predictive of students' engagement. Regarding the link between motivation and engagement, a negative relationship was found between controlled motivation and engagement. The direct investigation of the connection between the concepts of teachers' motivating style, students' motivation and students' engagement in one study is novel. Also, the application of SDT-concepts in the broad STEM-context is innovative, and adds to the STEM-literature.

CHAPTER 7

7



General discussion



This dissertation contributes to our understanding of students' relationships with STEM, and of the effectiveness of an iSTEM educational approach to change this relationship. In this chapter, we provide an outline of the main findings, and aim to answer some pressing questions regarding an iSTEM educational approach. Furthermore, we discuss several insights that we have gained from our work. The limitations and directions for future research are also included in the discussion, which aims to shed light on the research opportunities lying ahead. Throughout the discussion, both theoretical and practical implications are addressed. We conclude with the key findings of this dissertation.

Main outcomes

STEM-schooled professionals are essential to safeguarding and developing human well-being, economic growth, and sustainability (Kjærnsli & Lie, 2011). However, students' interest in STEM study or careers has been declining over the past few decades (Bøe, Henriksen, Lyons, & Schreiner, 2011; Moore & Smith, 2014; Keith, 2018). Students gradually leave STEM throughout their educational trajectory, with drop-out at various points along their educational careers. This phenomenon, also described as a leaky pipeline (Watt et al., 2012), has given rise to research about students' relationships with STEM and the effectiveness of an integrated approach to STEM education (Ardies, De Maeyer, & Gijbels, 2015; Keith, 2018), in order to face the challenge of students' increasing disengagement with STEM. The research questions of the current dissertation were based on these research lines, and their answers provide valuable contributions for research and practice.

All studies contribute to the two central challenges of providing **insight into students' relationships with STEM** and the assessment of the **effectiveness of an iSTEM educational approach**. Studies 1, 4, and 5 provide answers to the first research topic, and studies 2, 3 and 4 shed light on the second research topic.

Study 1: To what motives do students attach importance when considering studying a particular area of STEM, and which profiles regarding STEM motives can be identified?

In study 1, we validated an instrument to assess the importance of STEM study choice motives and showed that there were six underlying dimensions in the motives: external motives, self-efficacy and interest, career status, social motives, future perspectives, and intellectual status. Self-efficacy and interest appeared to be the most important STEM study choice motives, which indicates that students place great emphasis on aspects that are related to the topic of the study itself. External motives appeared to be the least important. A cluster analysis of the dimensions provided evidence for four distinct STEM-profiles: motivated choosers, non-motivated choosers, typical choosers, and external choosers. The profile of 'motivated chooser' appeared to be highly adaptive given the high importance of self-efficacy and interest (Deci & Ryan, 2000; Fransson, 1977), while a less adaptive profile was that of the non-motivated choosers, as they displayed relatively low scores on all STEM motives. As the latter profile represented 19% of the students, this might partially shed light on one of the mechanisms within the 'leaky pipeline': students who wanted to become a STEM professional at the beginning of secondary education but were reluctant to choose STEM study when entering higher education might have been part of the group of non-motivated choosers.

Study 2: How can we conceptualize integrating ability, and how can this construct be measured?

In order to comment on the effectiveness of iSTEM educational initiatives, it was crucial to make informed decisions about the constructs included. Integrating ability seemed to be an important outcome to assess; however, to date, no clear definition nor validated instrument to measure integrating ability is available. In study 2, we defined integrating ability as the ability to purposefully combine recently acquired knowledge and skills from two or more distinct STEM disciplines to solve a problem in a familiar context that necessitates this very combination to solve it. We also provided a framework to understand the components of integrating ability: it combines the two notions of *integrated ability* (i.e. the ability to select and combine STEM concepts) and *appropriate content knowledge*. A multiple-choice instrument for testing integrated physics and mathematics in the ninth grade (IPM9) was developed and validated. The definition and framework for integrating ability, and the construction guidelines for an integrated test, can be used by researchers and practitioners to develop new instruments regarding the ability to integrate STEM subjects; for instance, when evaluating iSTEM initiatives.

Study 3: What is the effect of an iSTEM intervention on students' cognitive performance, and what is the differential effectiveness with regard to student characteristics?

Study 3 focused on the effects of iSTEM education on cognitive outcomes. We developed a large-scale intervention where physics, technology, engineering and mathematics components were integrated in the specially-developed learning modules and examined the impact this integrated STEM curriculum had on cognitive performances regarding physics (both knowledge and application), mathematics (both knowledge and application), technological concepts, and integrated physics and mathematics. The results showed that after two years iSTEM education had positive effects on cognitive performance in terms of mathematics knowledge and application and technological concepts. With regard to integrated physics and mathematics, as conceptualized in study 2, no significant results were found. This result is remarkable, as the intervention explicitly focused on the integration of the STEM domains. This finding demonstrates that the emphasis in the curriculum on connections between STEM domains, does not necessarily improves students' own ability to integrate STEM concepts. Furthermore, differential intervention effects were found with regard to student characteristics: the intervention had a positive impact on the performance of girls in physics application, the negative impact of low SES was smaller in the case of physics application, and students with high abstract reasoning capabilities were favored when it came to mathematics knowledge and application.

Study 4: How do affective outcomes regarding science and mathematics evolve over time, and what is the general and differential effectiveness of iSTEM with regard to these affective outcomes?

In study 4, we focused on the evolution of attitudes towards STEM, motivation to learn STEM, and STEM self-efficacy in secondary school students (grade 9 and 10) in general. Also, we assessed the affective effects of iSTEM education. The same large-scale intervention as in study 4 was evaluated over two years in terms of affective outcomes. This longitudinal study revealed that students' attitudes, motivation, and self-efficacy towards science and mathematics became less positive over time. This finding was followed by the discovery that iSTEM education had positive effects on attitudes towards science and mathematics after two years. We found that interest and career aspirations towards science of students who followed iSTEM courses remained quite stable over time, whereas students in traditional education reported less science career aspirations and less interest over time. In the case of interest towards mathematics, the same findings emerged. Less positive results were observed for motivation and self-efficacy outcomes: students who followed iSTEM education reported less autonomous motivation (and more controlled motivation) and less self-efficacy. Mixed differential intervention effects were found with regard to student characteristics (i.e. sex and SES).

These results indicate that iSTEM has the potential to improve students' STEM attitudes, but that we should be careful with the implementation of this approach with regard to students' motivation and self-efficacy. Extra attention should be given to safeguard autonomous motivation and self-efficacy of students. This could be accomplished by incorporating opportunities to mastery experiences in the learning modules (Van Dinther, Dochy, & Segers, 2011), or by explicitly indicating how teachers could stimulate students' feelings of autonomy, belongingness, and competence. Besides adaptations in the learning materials, teacher education could also help teachers to support students' psychological needs and self-efficacy. In *study 5*, more attention was given to how teaching style can affect motivation. Theoretically, the different results for attitudes, motivation, and self-efficacy indicate a divergent association between these variables. It might be possible that low self-efficacy results in low autonomous motivation (Van Dinther et al., 2011), but that low self-efficacy does not automatically translate into less positive attitudes.

Study 5: What is the relationship between STEM teachers' motivating style, students' motivation towards STEM, and students' engagement?

In *study 5*, we used the framework of self-determination theory (SDT) to investigate the relationships between the theoretical concepts of teachers' motivating style, students' motivation, and students' engagement. This investigation was embedded in the STEM context, as classroom observations occurred in STEM courses, and questionnaires were related to these STEM courses. The results revealed that STEM-teachers' provision of structure was positively linked to students' autonomous motivation and engagement with regard to STEM subjects. The impact of teachers' autonomy support was negatively predictive for students' autonomous motivation (which is surprising), and positively predictive for students' engagement. A negative relationship between students' controlled motivation and engagement was found. Based on these results, this study suggests that taking teachers' motivating style into account in future educational initiatives regarding STEM is highly relevant as a means of stimulating students' motivation and engagement. First, teachers should be aware that their teaching style has, potentially, a motivational impact on students. Secondly, teachers should be given guidance to strengthen their motivational approach. This could be in the form of teacher education, but also in the form of practical reminders or suggestions in the learning materials that help teachers to support students' basic psychological needs.

Not all results were in line with expectations. No results were found for the effect of need satisfaction with regard to belongingness, and autonomy support was negatively predictive for autonomous motivation. Hence, the relationship between psychological need support and motivation in the STEM educational context could be elucidated more extensively. It is possible that this study has not uncovered all effects, but it is also plausible that other mechanisms could explain some of these findings. Either way, this could lead to some interesting additional insights with regard to the self-determination theory literature.

Implications for an iSTEM educational approach

Could iSTEM education be a solution for the 'leaky pipeline'?

Our research has shown that an integrated approach yields some benefits that might help to prevent students from dropping out of STEM programs. As students indicated self-efficacy and interest were the main reasons to choose a STEM study (*study 1*), an educational approach that stimulates these two elements, would be beneficiary. From this perspective, iSTEM has both advantages and opposing arguments. Our research (*study 4*) has shown that an integrated approach increases students' interest in science and mathematics, but that it decreases students' self-efficacy with regard to science. An explanation for the latter could be the perceived difficulty of rather challenging learning modules. Nevertheless, students who followed the iSTEM courses reported more career aspirations towards science than students who followed the traditional curriculum. A second consideration is students' cognitive performance with regard to STEM. Despite the fact that students in iSTEM education reported less self-efficacy, they did perform better on the cognitive tests (*study 3*), albeit in different domains. Students who followed iSTEM courses reported less self-efficacy with regard to physics (*study 4*) but scored better on mathematics and technological concepts (*study 3*). Nevertheless, this result has to be taken into account when we consider iSTEM as a possible solution for the 'leaky pipeline'. As a study or career pathway is both influenced by the ability to succeed in a study and by the motivation to employ that ability (Dweck, 2002), cognitive factors may not be overlooked with regard to that matter.

Taking all these points into consideration, we might conclude that iSTEM is a promising approach to prevent students from losing interest in STEM topics and a STEM career by extension. At the same time, iSTEM improves students' cognitive performance. While iSTEM might be a partial solution for students' disengagement from STEM, we should be cautious about adopting this as a complete solution. Our research still found some obstacles with regard to STEM education that are not entirely addressed by employing an iSTEM approach. In *study 1*, for instance, we did not find a societal profile, which could suggest that the added value of STEM for social matters is underexposed in contemporary education. Hence, future STEM initiatives should take into consideration that iSTEM is a part of the solution, but that extra efforts to attract students to the STEM field should be made.

Do we have to implement iSTEM in secondary education?

Study 4 has demonstrated that students' attitudes towards STEM are declining over time in secondary education. A failure to address the problem of students' disengagement in STEM might have severe consequences for societies around the globe (Bøe et al., 2011). Hence, it seems that a status quo in STEM education is not a viable option. Despite some drawbacks (i.e. outcomes with regard to motivation and self-efficacy in *study 4*), iSTEM education has been shown to be a promising approach to address this issue. Students who followed iSTEM education did not show the traditional decline in interest and career aspirations towards STEM (*study 4*). Moreover, their cognitive outcomes were better than students who followed a traditional curriculum (*study 3*). Regardless of the problem of students' disengagement in STEM, an educational approach that enhances students' cognitive performance must be taken into consideration. All students could benefit from a better understanding of STEM concepts, both from the 'need for skilled STEM professionals' perspective and from the 'STEM literacy for all' perspective.

An important consideration is that the teacher has a decisive role in the implementation of an iSTEM educational approach. Since *study 5* has indicated that the teaching style matters when it comes to motivational outcomes in STEM learning, it can be argued that the key may not lie in the materials themselves. Maybe the integrated learning modules are ideally suited for teaching practices that are beneficial to various student outcomes. Besides the integration of STEM disciplines, problem-centered learning, cooperative learning, inquiry-based learning, and design-based learning, also form part of an iSTEM didactical approach. Due to the integration of different STEM disciplines, teachers might, for instance, also be facilitated to stimulate problem-centered learning, which can in turn lead to more positive student outcomes (Dunlap, 2005). Hence, implementing iSTEM education without acknowledging the role of the teacher (or the interaction between the learning materials and the teacher), might have negative implications for the effectiveness of the iSTEM approach.

After evaluating the successes and shortcomings of iSTEM education, we can conclude that the decision to implement iSTEM depends on the desired outcomes. If the goal is to improve students' cognitive performance, or to improve their attitudes towards STEM, iSTEM education can be recommended. In such cases, we would thus advocate an iSTEM approach in secondary education. However, implementation must be done cautiously to safeguard the quality of motivation and self-efficacy of the students. A key role herein is again reserved for the teachers. Our research has shown that teachers' motivating style might influence students' motivation and engagement (*study 5*). It is important that students' psychological needs are fulfilled, in order to facilitate autonomous motivation to learn STEM subjects. When implementing an iSTEM educational approach, it is crucial to remain critical towards STEM education. First, it should be taken into consideration that extra time for STEM implies less time for other subjects that are also valuable for students' education and development in general. Second, educators must refrain from falling into the trap of an ideological discourse without verifying its assumptions (Weinstein, Blades, & Gleason, 2016). If a certain approach or buzzword in education receives a lot of attention in the media, and is quickly adopted by various schools, there is a risk of becoming less critical towards the respective educational approach. We advocate an evidence-based approach that continues to rely on the latest scientific insights.

For which students in particular is iSTEM beneficial?

Our research has shown that an iSTEM approach has the potential to improve students' cognitive performance in STEM and STEM attitudes in general but might yield extra advantages for students with certain characteristics (*study 3 and 4*). First, students with a high abstract reasoning ability (which is a proxy for intelligence) benefit, in particular, from an integrated approach to STEM education (*study 3*). For students who follow iSTEM education, the impact of abstract reasoning ability on both mathematics knowledge and application was larger than for students who followed a traditional curriculum. This implies that iSTEM is better suited for realizing students' pre-existing potential. A possible explanation for this observation is that the iSTEM modules developed could be considered to be highly challenging. This type of learning material could be more suited to the needs of gifted students. A second observation is that iSTEM education reduced the negative impact of low SES (Yerdelen-Damar & Peşman, 2013). Both for cognitive (*study 3*) and several affective outcomes (*study 4*), the negative impact of low SES was smaller for students who followed iSTEM courses. Thus, iSTEM education has the potential to create more equality. Third, we found a remarkable result for the effect of sex on the physics application scores (*study 3*). In general, male students performed better in this subject than did female students. However, females in iSTEM classes performed significantly better after two years than females in traditional classes, while no difference was observed for males. As the lower physics scores of females is a well-known concern in the literature (Halpern et al., 2007), this might be an extra argument to support the implementation of an integrated approach to STEM. Results with regard to affective outcomes, however, were less straightforward (*study 4*). Nevertheless, all these findings indicate that the effectiveness of iSTEM goes beyond the general changes in students' cognitive and affective outcomes. This approach enhances pre-existing potential and creates more equality for students who are traditionally underprivileged with regard to multiple STEM outcomes.

Insights of the dissertation: 7 lessons learned

1. Students' relationships with STEM are not as dreadful as we might assume

Despite the alarming sounds from education and industry, students' attitudes towards STEM are still quite positive. While there is certainly a problem with students' disengagement over time, assuming that students have generally negative attitudes towards STEM might be a bridge too far. Students generally indicate that they are interested in STEM, and that they aspire to a career in STEM (*study 4*). These positive attitudes may be not sufficiently high, and do decrease over time, but they are not detrimental in themselves. Also, students who want to opt for a STEM career indicate that their main reasons are because of interest and their belief that they will do well in this field (*study 1*). External motivations are the least important, after social motives and status-oriented motives. This demonstrates that students who want to pursue a STEM career are generally positively motivated. This has positive implications for the well-being and performance of the students, as autonomous motivation can be linked with higher psychological well-being (Vansteenkiste, Sierens, Soenens, Luyckx, & Lens, 2009). In the debate about students' relationships with STEM, we must not lose sight of the general positive tenor.

2. The social aspect of STEM has to be highlighted

While iSTEM has been proven to be an adequate strategy to improve students' attitudes and cognitive outcomes (*study 3 and 4*), extra efforts should be undertaken to emphasize the social aspect of STEM. *Study 1* has revealed that this aspect of STEM application is underexposed. First, students who wanted to pursue a STEM career did not indicate social factors as important for their choice. Second, no social profile could be detected in STEM-choosers. This does not indicate that people who choose STEM are, by definition, not socially oriented, but this finding demonstrates that we did not capture the socially-oriented students in STEM. Making use of real-life challenges is a good first step to awaken students' interest and to make STEM concepts more relevant. Adding the social component to some of these challenges would be a further improvement.

3. The teacher has an important role

In the current debate about STEM education, there is a strong emphasis on the role of learning materials. Indeed, making use of appropriate and interesting learning materials has been proven to be crucial (*study 3 and 4*). However, integrated learning materials might only be a part of the story. A critical factor is how the teacher addresses these learning modules. Our research has shown that the motivating style of the teacher impacts the motivation and engagement of the students (*study 5*). As our findings indicate that iSTEM is generally advantageous for students' attitudes, but not for students' motivation (*study 4*), this issue is of particular importance. Teachers could counterbalance the possible negative effects of iSTEM on learning motivation with regard to STEM-topics. Also, it may be possible that the positive effects of iSTEM education are attained because of the opportunities that lie in the learning materials to employ advantageous teaching practices. iSTEM education entails the implementation of five key principles: problem-centered learning, cooperative learning, inquiry-based learning, design-based learning, and integration between STEM disciplines. The teacher plays an important part in the implementation of these principles and may consequently determine the effectiveness of the iSTEM approach. Another role of the teacher might be the role of academic advisor. In *study 1*, future prospects were one of the main reasons (after interest and self-efficacy) why students choose a STEM career. Four different STEM profiles were found, of which 'the typical chooser' and 'the motivated chooser' were two profiles that valued future prospects as an important reason to choose STEM. A teacher might emphasize the various professions or fields of study that benefit from a solid foundation of STEM knowledge. In this way, it becomes clear to students what the future career and study possibilities are.

4. Measurement is the key to knowledge

When implementing iSTEM, it is important to test the assumptions that are made about iSTEM education. For instance, we would expect integrated ability to benefit from an integrated approach to STEM. However, when we tested this assumption (*study 3*), no effect of an iSTEM education on scores for integrated physics and mathematics was found. Hence, effects might not always be intuitive. Before measuring a construct, it is also essential that a good conceptualization of the construct is made. *Study 2* has provided a framework for discussing and measuring integrating ability. To conclude, we have to decide which aspect we aim to improve and be aware of implicit assumptions. The next step is to depart from a solid theoretical framework and to empirically test the hypotheses that have been made.

5. The implementation of iSTEM education requires a long-term vision

One of the key findings in our research is that an iSTEM education only takes effect after students have been following integrated learning modules for two years. This is both the case for cognitive outcomes (*study 3*) and for affective outcomes (*study 4*). If we had only measured the effect on iSTEM education after one year, we would have erroneously concluded that this approach is not beneficiary to students' cognitive and several affective outcomes. A long-term vision, both with regard to research and with regard to iSTEM educational initiatives, is required. This has implications for the design of new integrated STEM programs. Long-term approaches with iSTEM incorporated in the standard curriculum are better suited to increasing students' cognitive performance than short-term interventions. From the perspective of this dissertation, two years seems to be the minimum implementation timeframe in which cognitive and affective effects may be reasonably expected. Given the importance of the duration of the iSTEM implementation, even larger effects may emerge when an iSTEM educational approach is employed through the entire course of secondary education.

6. Beware of the STEM hype

The outcomes of our research remind us to exercise caution with regard to STEM hype (Weinstein et al., 2016). While students' interest in STEM was higher for students who were following iSTEM courses, they reported less autonomous and more controlled motivation than students who were following traditional courses (*study 4*). A plausible explanation for this phenomenon is that students in the experimental condition of our study (i.e. the iSTEM intervention) might have experienced more external and internal pressure to perform well in these subjects, as they were aware that they were participating in an innovative approach to STEM. The external pressure could, for example, come from parents who insist on good performance in STEM because a great deal of media attention is given to this subject. Internal pressure could originate from feelings of guilt or shame if a student did not perform well in this hyped subject. Besides the possible detrimental effect of STEM hype on quality of motivation to learn for STEM subjects, the STEM hype might also have an impact on the motives of students to choose STEM studies or careers. We have demonstrated that status-related motives are quite common in the reasons why students opt for a STEM career (*study 1*). This is not necessarily an unfavorable observation, but when extrinsic goals (such as wealth and status) are dominant, this might lead to lower feelings of well-being and study and career satisfaction (Vansteenkiste, Simons, Lens, Sheldon, & Deci, 2004), and less engagement in learning activities (Vansteenkiste, Lens, & Deci, 2006). Hence, the hype around STEM that is often accompanied by an emphasis placed on financial and status-related characteristics of a STEM career is something to be cautious about.

7. Education can be both interesting and advance the quality of learning outcomes

This dissertation demonstrates that the apparent contradiction between interesting, entertaining, and engaging education, on the one hand, and the protection of the quality of learning outcomes, on the other hand, is not a concern when it comes to iSTEM. In many educational debates, policy makers put forward that students' well-being and the interestingness of the subjects is important, but that these should not be at the cost of inferior learning outcomes. Students who follow iSTEM education report more interest in STEM and in a STEM career (*study 4*) and have higher scores on cognitive outcomes (*study 3*). This is a strong indicator that iSTEM education, and education in general, can be both interesting and can advance the quality of learning outcomes at the same time.

Limitations and directions for future research: 8 research opportunities

While the current dissertation has several strengths, such as the comprehensive approach to effectiveness (both cognitive and affective) within a longitudinal design and with attention to general processes that help us to understand students' relationships with STEM, some limitations should also be acknowledged. These limitations, however, could serve as inspiration for further research and point to intriguing research opportunities.

1. Evaluation of a more comprehensive conceptualization of iSTEM

In the current body of knowledge regarding iSTEM education, an important gap is the number of studies that have integrated all components of STEM (Becker & Park, 2011). This dissertation made a major contribution to the literature by reporting on the effectiveness of an intervention that incorporated all STEM components. Nevertheless, the conceptualization of iSTEM could be even more comprehensive, as we incorporated only physics as part of the science component. Obviously, chemistry, biology, or geography are also very relevant science domains to integrate with other STEM domains (e.g. Nugent, Barker, Grandgenett, & Adamchuk, 2010). The incorporation of more science domains could possibly lead to additional results, especially with regard to affective outcomes. In *study 4* we found that the motivation for learning science (more specifically physics) decreased in the iSTEM condition, while students' interest in science in general increased. This might indicate that students are interested in science in general (i.e. the totality of all sub-domains) and not *per se* in the sub-domain of physics. When researchers take full advantage of this knowledge and, thus, make extra connections with other science sub-domains in their intervention, this could result in more benefits in the observed outcomes. It is possible that the inclusion of extra science sub-domains in the learning modules would, for instance, highlight the social aspects of STEM, which makes the challenge, in return, more relevant for some students.

2. Exploration of the possible effects of iSTEM for a prolonged time period

Our research has revealed that no cognitive or affective effects were found after the evaluation of one school year. Only when students had followed the integrated courses for over two years were positive effects of the iSTEM intervention found. Even though we adopted a two-year longitudinal design, which is rather uncommon in iSTEM effectiveness research (English, 2016), it is possible that we have not yet discovered the full potential of iSTEM education. Potentially, the impact of ISTEM could continue to increase after the second year, and cognitive performance and attitudes towards STEM could keep improving. Therefore, our finding that attitudes are less negative in the iSTEM condition might even improve. If we monitored students for a prolonged time period it might become possible to conclude that attitudes with regard to STEM not only become less negative over time, but that they also ameliorate. However, we should be aware that the less positive findings of *study 4* might also become more pronounced. Nevertheless, it is worth investigating this hypothesis.

3. Going into more depth with regard to the investigated outcomes

The main goal of the effectiveness research within this dissertation was to provide an overview of the effects on a variety of outcomes. This means that this dissertation contains valuable information with regard to diverse matters, but it also implies that some outcomes are only broad indicators of a measured outcome. For instance, we measured the cognitive performance in physics in *study 3,* but we could not comment on all relevant aspects (such as kinematics) or sub-competences (such as the ability to work with different representations) of physics. Therefore, more labor-intensive and time-consuming tests are required. With regard to affective outcomes, the same limitation applies. In *study 4*, we investigated, for example, the effect of iSTEM on students' self-efficacy. However, this concept was only examined in a general manner with five questions per STEM domain. With qualitative analyses, researchers could question students about what exactly makes them feel less or more self-effective, and how the intervention has contributed to this.

4. Expansion of the research to other age categories

Due to the context of this dissertation, we only investigated the relationship with STEM and the impact of an integrated STEM education in the population of grade 9 and grade 10 students. Yet, the literature has demonstrated that it might be important to put students from a younger age group in touch with engaging STEM didactics (Maltese & Tai, 2010). Hence, the possibility of incorporating iSTEM in primary education or the first years of secondary education and the assessment of its impact remain subjects for future research.

5. Looking further than the effects on STEM-related outcomes

We did not investigate the impact of the implementation of an iSTEM education on learning content or interest towards subjects that are not STEM-related. The adoption of an iSTEM educational approach can take away attention and time from initiatives or learning contents that target outcomes from other domains. Future research could include learning outcomes of other subjects, to learn whether or not iSTEM has disadvantages for learning outcomes of other subjects.

6. Provision of explanations for contra intuitive results

Over the course of this dissertation, some interesting and contra intuitive results were found. In *study 3,* for instance, we found that iSTEM education was particularly advantageous for girls' performance in physics applications. At the same time, *study 4* revealed that the iSTEM courses were particularly disadvantageous for the science self-efficacy of girls. Hence, girls improved more than boys in the iSTEM condition but felt simultaneously less secure about their capacities. Another example of a contra intuitive result is the finding that students' interest in STEM increases, but their autonomous motivation decreases. As interest can be linked to intrinsic motivation – which is the most autonomous form of motivation (Deci & Ryan,1985) – this finding can be considered surprising. We hypothesized that this could be caused by the operationalization of science in *study 4* or by participants' experience of external and internal pressure to perform well in these subjects in the experimental condition, as they were aware that they were participating in an innovative approach to STEM.

More research is needed to provide an explanation for these findings by interviewing students and the investigation of the learning materials. It is apparent that the explanation of these contra intuitive results will be a result of more in-depth research (see research opportunity 3).

7. Conducting further research into differential effectiveness

This dissertation has revealed that the iSTEM intervention did not only have a general effect, but also that differential effects were present with regard to sex, SES, and reasoning ability. These effects were only briefly discussed as our research aimed to identify their general impact, but these results demand further elaboration. Future research should investigate why iSTEM is particularly advantageous or disadvantageous for girls or boys, or for students with different levels of SES or reasoning ability. It could be possible that not all learning modules are suited for the needs of students with different characteristics. For instance, girls might identify less with the selected subjects (Tytler & Osborne, 2012) and might therefore feel disconnected from the subject, which could result in a lower score or less self-efficacy.

8. Unravel the active components of iSTEM education

This dissertation has addressed the impact of iSTEM education, but not which component of iSTEM education causes which effect. Hence, the intervention might appear to be a 'blackbox'. However, we do know what is inside the alleged blackbox of integrated STEM education. The learning modules within the examined intervention were built upon a set of five key principles: (1) problem-centered learning, (2) cooperative learning, (3) inquiry-based learning, (4) design-based learning, and (5) integration between STEM disciplines. The main difficulty is to separate one component from another, and to identify the exact active component(s). As the components are probably not independent from one another, and the integration of STEM components has functioned as a key facilitator for the other didactical approaches, an iSTEM educational approach is considered to be a comprehensive term for all didactical practices that are built around the integration of STEM components. Therefore, instead of referring to this limitation as a blackbox, we might speak of a 'grey fogbox': we know what should be present in the fog and we can distinguish the contours. However, we cannot see exactly what is happening. Observations and focus groups can help to gain more insight in what is happening in the 'grey fogbox' (Struyf, De Loof, Boeve-de Pauw, Van Petegem, 2019).

The notion that the integration of the STEM components is essential for the measured effects is derived from the assumption that the implementation of the other principles is also possible and have also most likely been adopted in non-integrated settings. Control schools could also have been implementing teaching strategies such as cooperative learning, but they did not implement this in the form of an integrated STEM approach. Thus, we assume that each of the key principles might have had some weight in the total effect of the iSTEM educational approach, but that the integration of the STEM components is the key facilitating factor that is necessary to utilize its full potential. Future research could measure different characteristics (e.g. the presence of a design challenge) of STEM initiatives in experimental and control settings and determine the relationship with students' cognitive and affective outcomes. In this way, a concurrent measure for implementation fidelity is also provided.

Another component of influence could be the factor of time-on-task (Scherer, Greiff, & Hautamäki, 2015). It could be argued that the time-on-task was higher in the experimental schools if they chose to allocate extra time from optional teaching hours to the learning modules. This extra time-on-task could accordingly have led to improved cognitive performances on STEM domains. Nonetheless, two remarks should be made in this matter. First, variation in cognitive performance is not consistently explained by differences of instructional time: only 1 to 15 percent of the variance in previous research was explained by time-on-task (Karweit, 1984), and explained variance varied depending on the time-on-task estimation method (Kovanovic, Gašević, Dawson, Joksimovic, & Baker, 2016). Therefore, providing extra time is not a sufficient condition for learning to take place. Second, if time-on-task was a crucial factor, we could expect that all learning outcomes would benefit from extra learning time. However, this was not the case. Also, with regard to the cognitive outcomes, time-on-task is not sufficient to explain the differences between the control and experimental conditions. For instance, it cannot explain the different results for affective science and mathematics outcomes, and it is difficult to explain some surprising results, such as the lower science self-efficacy in the experimental group.

Key findings

- While self-efficacy and interest are the most important motives for choosing a STEM study for almost all students, and external motives are considered least important, students can be assigned to sub-groups with varying importance with regard to STEM motives.

- Integrating ability can be defined as the ability to purposefully combine recently acquired knowledge and skills from two or more distinct STEM disciplines to solve a problem in a familiar context that necessitates this very combination to solve it. Integrating ability can be measured by a validated instrument: the IPM.

- An iSTEM educational approach benefits students' cognitive performance in terms of mathematics knowledge and application and technological concepts.

- Students' relationships with STEM are not as dreadful as we might assume, as they generally reported positive attitudes towards STEM. However, students' positive attitudes, motivation, and self-efficacy decrease over time in grade 9 and grade 10.

- An integrated approach to STEM education can prevent students from developing negative attitudes towards STEM as a domain and STEM as a career option. Students who are following iSTEM report fewer negative attitudes towards STEM over time. However, autonomous motivation and self-efficacy is lower for students who follow iSTEM in comparison with students who follow traditional science, technology, and mathematics education.

- The impact of iSTEM education goes beyond the general effects, since differential effects were also found with regard to students' abstract reasoning ability, sex, and SES.

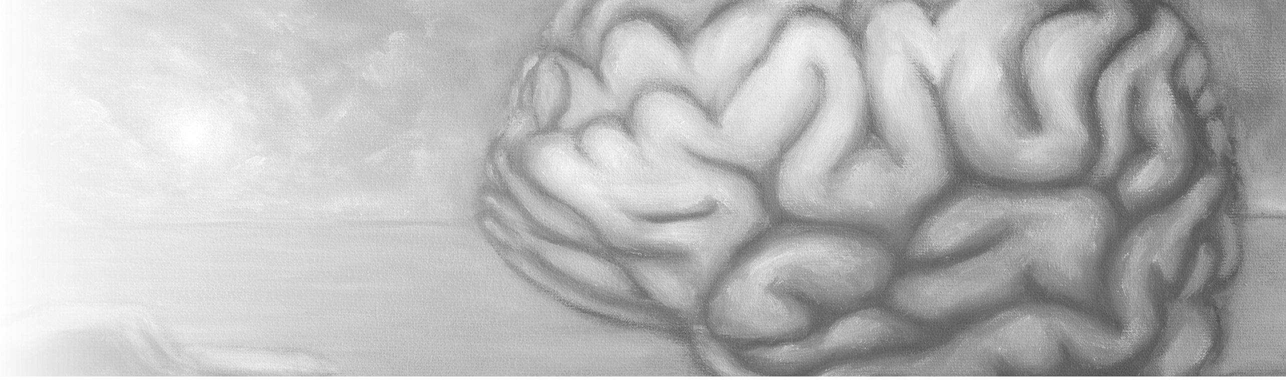
- An iSTEM education only has an effect after students have been following integrated learning modules for two years, which implies that a long-term vision on iSTEM education is required.

- Taking teachers' motivating style into account in educational initiatives regarding STEM is highly relevant as a means of stimulating students' motivation and engagement.

To conclude, the present dissertation sheds light on the phenomenon of students' disengagement from STEM and contributes to the literature on an iSTEM educational approach as a way to mend the 'leaky pipeline'. We hope to provide some valuable insights on both matters and encourage further research to uncover more knowledge with regard to STEM education.

CHAPTER 8

8



Nederlandse samenvatting

Dutch summary

Dit proefschrift draagt bij aan inzichten over hoe studenten zich verhouden tegenover STEM. STEM is het acroniem voor *Science, Technology, Engineering* en *Mathematics.* Bijzondere aandacht wordt besteed aan de effectiviteit van een geïntegreerde STEM (iSTEM) aanpak in het secundair onderwijs. Deze samenvatting biedt een overzicht van de belangrijkste bevindingen, en poogt daaraan enkele conclusies en aanbevelingen te verbinden.

STEM-professionals gezocht

De laatste decennia klinkt een steeds luidere roep om STEM-professionals. Jongeren blijken niet warm te lopen voor STEM-gerelateerde onderwerpen en studierichtingen (Sjøberg & Schreiner, 2010; Bøe, Henriksen, Lyons, & Schreiner, 2011; Keith, 2018), wat resulteert in een te beperkte uitstroom van STEM-geschoolde professionals (Organisation for Economic Co-operation and Development, 2008). Zowel internationaal (National Science and Technology Council, 2013) als in Vlaanderen (Vlaamse Dienst voor Arbeidsbemiddeling en Beroepsopleiding, 2018) raken STEM-vacatures moeilijk ingevuld. In het licht van de uitdagingen waarvoor we als maatschappij in de 21ste eeuw staan, is het gebrek aan enthousiasme voor STEM-beroepen op zijn minst problematisch te noemen. Klimaatsverandering, slinkende grondstoffen, verkeersproblemen, epidemieën en een vergrijzende bevolking zijn voorbeelden van problemen waarvoor STEM een deel van de oplossing zal moeten betekenen (Bøe et al., 2011). Ook de hoge vraag naar technologie in ons dagelijkse leven noopt tot een kwalitatief en kwantitatief hoge uitstroom van STEM-professionals in het onderwijs (Wang, Moore, Roehrig, & Park, 2011; Kjærnsli & Lie, 2011).

Geïntegreerd STEM-onderwijs

Waar 45% van de leerlingen in het Vlaamse secundair onderwijs een STEM-richting volgt, kiest slechts 45% daarvan om verder te gaan in een STEM-richting in het hoger onderwijs (STEM monitor, 2018). De cijfers voor meisjes zijn zelfs nog lager; slecht 39% van de meisjes die een STEM-richting volgde in het secundair, kiest ervoor een STEM-richting in het hoger onderwijs te volgen (STEM monitor, 2018). Leerlingen verliezen dus in de loop van hun secundaire schoolloopbaan hun interesse in STEM. Deze bevindingen hebben geleid tot de ontwikkeling van nieuwe onderwijsbenaderingen, in een poging leerlingen blijvend te boeien (Thibaut et al., 2018; Keith, 2018). Een veelbelovende aanpak is die van geïntegreerde STEM.

Bij geïntegreerd STEM-onderwijs worden de grenzen tussen de afzonderlijke vakken gesloopt, en worden leerlingen geconfronteerd met uitdagende en (maatschappelijk) relevante uitdagingen (Roehrig, Moore, Wang, & Park, 2012; Honey, Pearson, & Schweingruber, 2014). Ze hebben kennis en vaardigheden uit verschillende STEM-disciplines nodig om een goede oplossing te vinden. Dit doctoraatsonderzoek kadert binnen een project dat geïntegreerd STEM-onderwijs in Vlaanderen heeft geïmplementeerd: het STEM@School-project.

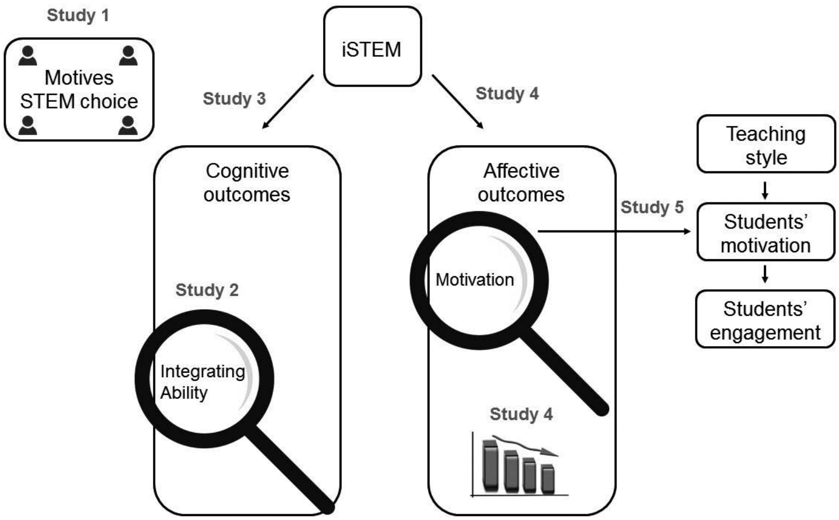
STEM@School

STEM@School is een interuniversitair project (Katholieke Universiteit Leuven en Universiteit Antwerpen), waarbinnen leermodules werden ontwikkeld voor de tweede graad van het secundair onderwijs. Het project liep van 2014 tot en met 2018 en werd ondersteund door de onderwijskoepels van Katholiek Onderwijs Vlaanderen en GO! onderwijs van de Vlaamse Gemeenschap. De ontwikkelde leermodules zijn gebaseerd op het principe van integratie van STEM-leerinhouden. Andere principes die binnen de modules werden geïncorporeerd zijn probleemgecentreerd leren, coöperatief leren, onderzoekend leren, en ontwerpend leren.

Een voorbeeld van zo'n leermodule is het bouwen van een energieneutraal huis. Leerlingen krijgen de opdracht om een huis te ontwerpen dat wordt verwarmd via zonnecollectoren en vloerverwarming. Hierbij leren leerlingen hoe ze een stabiel dak moeten bouwen en hoe ze de binnenhuistemperatuur kunnen reguleren. Om in hun opzet te slagen, hebben de leerlingen kennis en vaardigheden nodig van de verschillende STEM-disciplines: druk, gaswetten, thermische energie en faseovergangen (wetenschappen), het bouwen van zonnecollectoren met de juiste materialen (technologie), regeltechniek (engineering), en goniometrie, wiskundige functies en rekenkundige rijen (wiskunde).

Doelstelling proefschrift

In het licht van de nood aan STEM-professionals en de afnemende interesse van jongeren in STEM, is het nodig om vernieuwende onderwijsbenaderingen aangaande STEM te evalueren. Dit proefschrift onderzoekt hoe leerlingen zich verhouden tegenover STEM, en of geïntegreerd STEM-onderwijs een effectieve aanpak is om de verminderde interesse van jongeren in STEM tegen te gaan. Hiervoor werden vijf studies ondernomen (zie Figuur 1).



Figuur 1. Schematisch overzicht van de studies binnen dit proefschrift.

In een eerste verkennende studie werd onderzocht welke motieven leerlingen belangrijk vinden wanneer ze een STEM-studie kiezen. Hierbij werd ook nagegaan of er verschillende 'types' of profielen STEM-kiezers zijn. Vervolgens focust dit proefschrift op de evaluatie van een geïntegreerde STEM-aanpak. In studie 2 wordt er dieper ingegaan op de ontwikkeling en validatie van een instrument dat het vermogen tot het oplossen van geïntegreerde problemen meet. Studie 3 en studie 4 evalueren de effectiviteit van geïntegreerd STEM-onderwijs op respectievelijk cognitief en affectief vlak. In studie 4 wordt ook dieper ingegaan op de ontwikkeling van attitudes, motivatie, en zelf-effectiviteit binnen de algemene populatie van leerlingen in de tweede graad secundair onderwijs. Tot slot biedt studie 5 inzicht in hoe leerkrachten via hun motivatiestijl de motivatie en de betrokkenheid van leerlingen aangaande STEM kunnen beïnvloeden.

Hoofdbevindingen proefschrift

Zelf-effectiviteit en interesse zijn de belangrijkste motieven om voor een STEM-studie te kiezen

In studie 1 valideerden we een instrument om het belang van STEM-studiekeuzemotieven in kaart te brengen. Er werden zes onderliggende dimensies gevonden met betrekking tot soorten motieven: externe motieven, zelf-effectiviteit en interesse, carrière status, sociale motieven, toekomstperspectieven, en intellectuele status. Zelf-effectiviteit en interesse waren de belangrijkste motieven om voor een STEM-studie te kiezen. Deze bevinding duidt erop dat studenten veel belang hechten aan inhoudsgerelateerde aspecten van de studie. Externe motieven (e.g. praktische redenen, of aanbevelingen van anderen) werden dan weer minder belangrijk geacht. Opvallend is dat ook sociale motieven relatief weinig werden genoemd als belangrijke reden om een STEM-studie aan te vangen. Dit kan erop wijzen dat het sociale aspect van een STEM-beroep nog onvoldoende belicht is binnen het huidige onderwijs.

Aan de hand van een clusteranalyse van de antwoorden op de dimensies, werden er vier verschillende STEM-profielen gevonden: de gemotiveerde kiezers, de niet-gemotiveerde kiezers, de typische kiezers, en de externe kiezers. Het profiel van de gemotiveerde kiezers blijkt het meest adaptieve te zijn, gezien het relatief grote belang dat gehecht wordt aan zelf-effectiviteit en interesse (Deci & Ryan, 2000; Fransson, 1977). Een minder adaptief profiel is dat van de niet-gemotiveerde kiezers met lage scores op alle STEM-studiekeuzemotieven. Van alle leerlingen die een STEM-studie willen volgen, valt 19% binnen het profiel van de niet-gemotiveerde kiezers. Dit kan deels verklaren waarom studenten na hun secundaire schoolloopbaan toch niet verder willen gaan in een STEM-richting. Het is mogelijk dat de studenten die aan het begin van het secundair onderwijs wel nog een STEM-beroep wilden uitoefenen maar uiteindelijk toch niet voor een STEM-richting kiezen in het hoger onderwijs, behoren tot de groep van niet-gemotiveerde kiezers.

'Integratievermogen' kan gedefinieerd en gemeten worden

Voordat we uitspraken kunnen doen over de cognitieve effecten van geïntegreerd STEM-onderwijs, is het belangrijk om een gefundeerde keuze te maken met betrekking tot de variabelen die worden meegenomen in het onderzoek. Integratievermogen van leerlingen is een relevante uitkomstmaat, gezien er in geïntegreerd STEM-onderwijs expliciet wordt ingezet op de integratie van verschillende leerinhouden binnen één probleem. Tot op heden werd er echter geen duidelijke definitie opgesteld voor integratievermogen, noch werd er een instrument ontwikkeld om dit concept te meten. In studie 2 definieerden we integratievermogen als het vermogen om doelbewust recent verworven kennis en vaardigheden van twee of meer STEM-disciplines te combineren, om binnen een vertrouwde context een probleem op te lossen waarbij deze combinatie noodzakelijk is voor het vinden van de oplossing.

Studie 2 voorziet ook een kader waarbinnen we de componenten van integratievermogen kunnen begrijpen. Integratievermogen is het geheel van *geïntegreerd vermogen* (i.e. het vermogen om STEM-concepten te selecteren en te combineren) en *juiste inhoudelijke kennis*. Er werd een meerkeuze-instrument ontwikkeld en gevalideerd voor geïntegreerde fysica en wiskunde in het derde jaar secundair. De definitie en het kader voor integratievermogen, alsook de manier waarop de test ontwikkeld werd, kan door onderzoekers en mensen uit de praktijk gebruikt worden om in de toekomst gelijkaardige instrumenten te ontwikkelen die integratievermogen binnen STEM pogen te meten. Dit kan bijvoorbeeld nuttig zijn voor het evalueren van andere geïntegreerde STEM-initiatieven.

Geïntegreerd STEM-onderwijs heeft een positief effect op cognitieve prestaties van leerlingen

Studie 3 focuste op de effecten van geïntegreerd STEM-onderwijs op cognitieve prestaties van leerlingen. Hiervoor werden 859 leerlingen uit 39 scholen opgevolgd gedurende hun derde en vierde jaar secundair. De klassieke onderwijsaanpak (met aparte vakken wetenschappen, wiskunde, en engineering) werd vergeleken met de geïntegreerde STEM-aanpak van de leermodules die binnen STEM@School ontwikkeld werden. De onderzochte cognitieve uitkomsten waren de prestaties op fysica (kennis en toepassen), wiskunde (kennis en toepassen), technologische concepten, en geïntegreerde fysica en wiskunde.

Twee jaar geïntegreerd STEM-onderwijs had positieve effecten op vlak van wiskunde kennis en toepassen, en technologische concepten. Opmerkelijk was dat er geen significante resultaten werden gevonden voor geïntegreerde fysica en wiskunde, terwijl er net op integratie werd ingezet in de leermodules. Hieruit kunnen we afleiden dat de nadruk op integratie binnen een STEM-curriculum niet noodzakelijk betekent dat studenten zelf ook beter de leerinhouden kunnen integreren. Verder wees studie 3 ook op enkele differentiële effecten van geïntegreerd STEM-onderwijs. Zo hadden de leermodules een positieve impact op de prestaties van meisjes op de toepassingsvragen van fysica, en werd de negatieve impact van een lage socio-economische status op toepassingsvragen van fysica kleiner. Daarnaast bleek ook dat leerlingen met goede abstracte redeneervaardigheden extra profiteerden van de geïntegreerde leermodules op vlak van wiskundekennis en -toepassingsvaardigen.

Geïntegreerd STEM-onderwijs heeft zowel positieve als negatieve effecten op affectieve uitkomsten

Net als in studie 3 werden in de vierde studie 859 leerlingen uit 39 scholen gedurende twee jaar opgevolgd. Studie 4 focuste op de evolutie van attitudes tegenover STEM, motivatie om STEM te leren, en zelf-effectiviteit met betrekking tot STEM. Daarnaast werd ook nagegaan wat het effect is van geïntegreerd STEM-onderwijs op deze affectieve uitkomsten. Deze longitudinale studie bracht aan het licht dat leerlingen hun attitudes, motivatie, en zelf-effectiviteit met betrekking tot wetenschappen en wiskunde minder positief wordt naarmate de tijd vordert. Wanneer leerlingen echter gedurende twee jaar les kregen binnen geïntegreerd STEM-onderwijs werden hun attitudes niet slechter. In vergelijking met de leerlingen die volgens de traditionele methode les kregen, rapporteerden ze meer interesse in wetenschappen en wiskunde en waren ze eerder geneigd om een wetenschappelijke carrière te ambiëren.

De resultaten aangaande motivatie en zelf-effectiviteit lieten een ander beeld zien. Daar was de geïntegreerde STEM-aanpak net gelinkt aan minder autonome motivatie en meer gecontroleerde motivatie voor het leren van wetenschappen en wiskunde. Ook rapporteerden leerlingen die geïntegreerd STEM-onderwijs volgden minder zelf-effectiviteit dan leerlingen die op de traditionele manier les kregen. Deze resultaten laten de mogelijkheden van geïntegreerde STEM zien op vlak van attitudes, maar waarschuwen toch voor een ondoordachte implementatie met negatieve gevolgen voor motivatie en zelf-effectiviteit.

De motivatiestijl van leerkrachten kan de motivatie en betrokkenheid van leerlingen aangaande STEM beïnvloeden

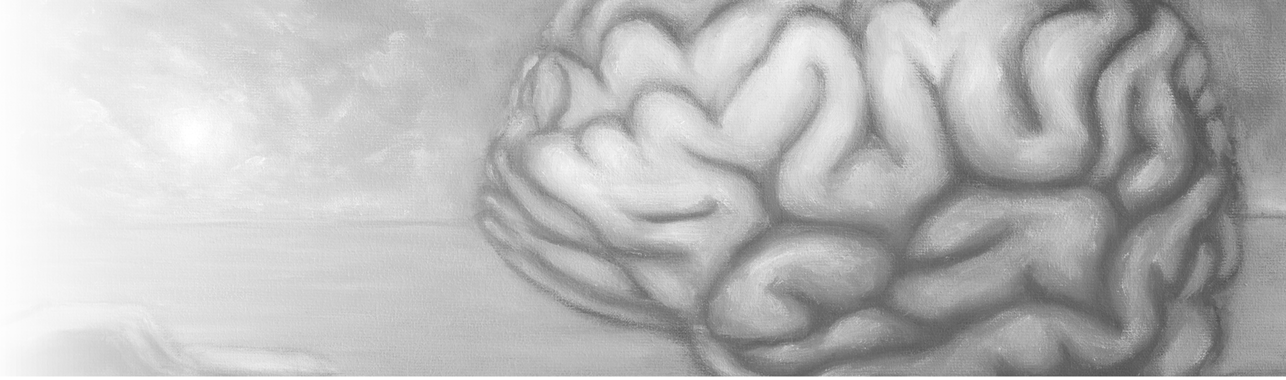
In het licht van de resultaten van studie 4, is het extra belangrijk om te weten hoe motivatie van leerlingen kan beïnvloed worden in de STEM-context. Studie 5 onderzocht de rol van de leerkracht door de lens van de zelfdeterminatietheorie. De relatie tussen drie theoretische concepten werd in kaart gebracht; de motivatiestijl van leerkrachten, de motivatie van leerlingen, en de betrokkenheid van leerlingen. Voor deze studie werden in het derde jaar secundair onderwijs 30 klasobservaties in STEM-lessen gedaan, die vervolgens werden gekoppeld aan vragenlijsten aangaande motivatie.

De mate waarin STEM-leerkrachten structuur aanboden was gerelateerd aan de mate waarin leerlingen autonome motivatie en betrokkenheid vertoonden. Vreemd genoeg was de mate waarin leerkrachten autonomie ondersteunden negatief gelinkt aan autonome motivatie bij leerlingen. Autonomie-ondersteuning van leerkrachten was wel positief gelinkt met de mate van betrokkenheid bij leerlingen. Wat betreft de relatie tussen leerlingmotivatie en –betrokkenheid, werd een negatief verband gevonden tussen gecontroleerde motivatie en engagement. Deze resultaten benadrukken het belang van de motivatiestijl van de leerkracht, en zijn in het bijzonder relevant bij de implementatie van onderwijsinitiatieven aangaande geïntegreerde STEM.

Conclusie

Dit proefschrift bracht aan het licht dat de meeste studenten die voor STEM kiezen dit doen uit interesse voor het onderwerp en omdat ze geloven dat ze de studie tot een goed einde zullen brengen. Andere motieven zoals praktische redenen, de aanbeveling van anderen, of de mogelijkheid om iets voor de maatschappij te kunnen doen, waren minder belangrijk. Dit laatste illustreert dat het sociale aspect van STEM-beroepen wellicht nog onvoldoende zichtbaar is voor studenten. Ook werd duidelijk dat studenten relatief positieve attitudes hebben tegenover STEM en STEM-beroepen, maar dat hun attitudes doorheen de tijd minder positief worden. De effectiviteit van geïntegreerd STEM-onderwijs werd op verschillende manieren geëvalueerd. Leerlingen die geïntegreerd STEM-onderwijs volgden, haalden betere scores op wiskunde- en technologietesten dan leerlingen die het klassieke onderwijs volgden. Ze hadden ook meer interesse in STEM en gaven vaker aan een STEM-carrière te willen. De minder positieve attitudes die zich doorgaans tijdens de secundaire schoolloopbaan ontwikkelen, werden dus getemperd door de geïntegreerde STEM-aanpak. Echter, geïntegreerd STEM-onderwijs had niet alleen positieve effecten. Bij geïntegreerd STEM-onderwijs vertoonden leerlingen minder positieve vormen van motivatie voor het leren van hun vakken, en ze geloofden ook minder in hun eigen capaciteiten. Dit toont aan dat geïntegreerde STEM positieve effecten kan hebben, maar dat voorzichtigheid geboden is bij de implementatie van deze onderwijsaanpak. Een cruciale rol is weggelegd voor de leerkracht, die door diens motivatiestijl de motivatie en betrokkenheid bij leerlingen kan beïnvloeden. Een opvallende bevinding van dit proefschrift is dat de verschillen tussen klassiek onderwijs en geïntegreerd STEM-onderwijs pas werden gevonden na twee jaar. Een langetermijnvisie is dus noodzakelijk als men met geïntegreerd STEM-onderwijs een impact wil maken.

CHAPTER 9



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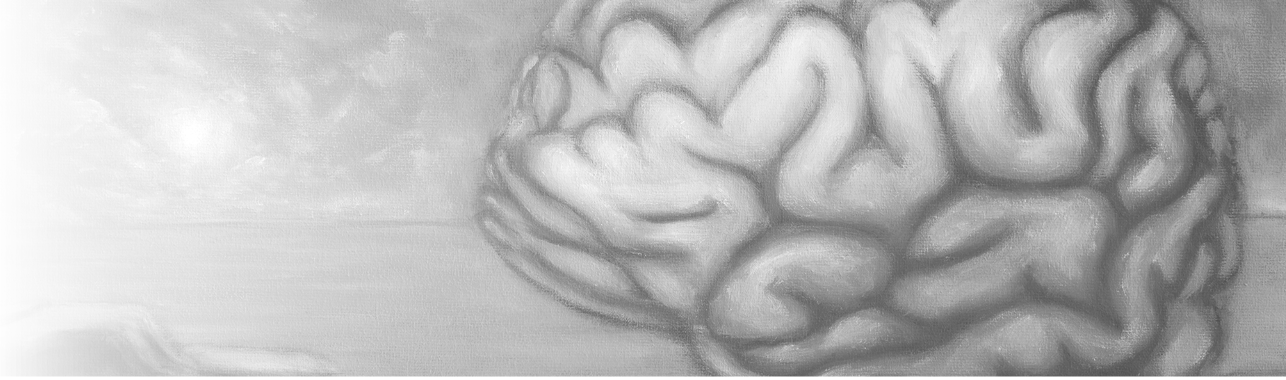
CHAPTER 10

10



Appendices

Appendix A: statements study choice motives

Statements regarding the importance of motives for the choice of a study field

1. This study is prestigious.
2. This study is good for my general development.
3. I am interested in the courses of this study.
4. This study leads to an interesting job.
5. This study offers a lot of development opportunities.
6. I do not know what to choose otherwise.
7. My parents recommend this study.
8. The amount of teaching hours in the curriculum.
9. The study is in line with my secondary education study.
10. Student coaches have recommended this study.
11. In this study, various directions are possible.
12. I can perform well in the courses of this field.
13. This study allows me to achieve my great visions.
14. This study allows me to acquire a high social status.
15. This study offers a good possibility of employment.
16. My friends have also chosen this study.
17. The amount of study years.
18. I think I am capable of mastering the subjects in this study.
19. I want to make an effort for others.
20. I absolutely want to acquire this qualification.
21. Later in life, I want to be prosperous.
22. I think my chances of succeeding are rather high in this study.
23. It is the only study that suits me.
24. I want a profession with a lot of human contact.
25. This study offers a lot of opportunities to have a career.

Appendix B: Integrated physics-mathematics problem

Example of an integrated physics-mathematics problem, applied to the four possible situations

Question: Driver A drives on a straight road from north to south with a constant speed of 15 m/s. Driver B is driving on the same road from south to north with a constant speed of 20 m/s. At time t = 0 s, the two drivers are 1 km apart and driving towards each other.
Determine the position and the time at which the two drivers cross each other.

Steps towards the ideal answer:

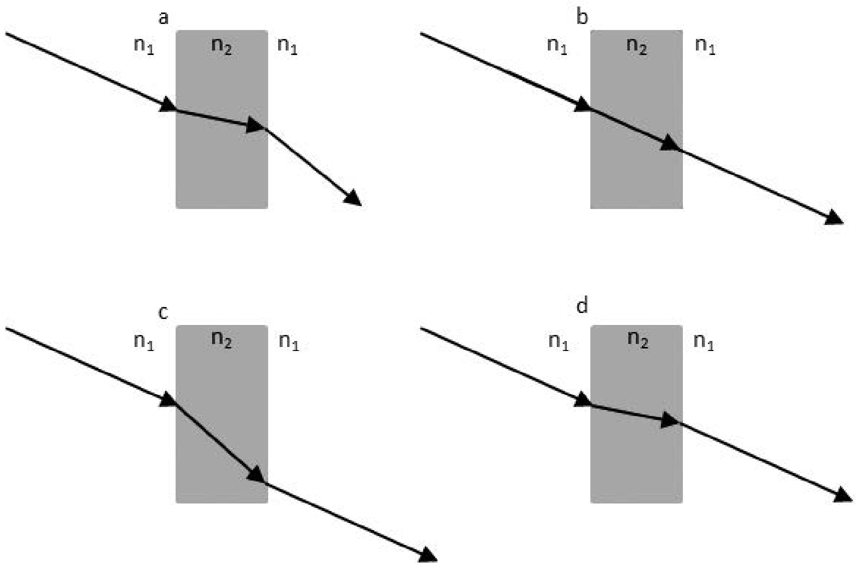
1. Driver A and B perform a uniform linear motion which can be described by a linear equation: $x(t) = x_0 + v \cdot t$.
2. The origin (t_0, x_0) of the reference system must be defined. The reference time is chosen to be t_0 = 0 s. In this solution, the initial position of Driver A is chosen to be the reference position: $x_{0A} = x_A(t_0)$ = 0 m. The initial position of Driver B with respect to this reference position is then: $x_{0B} = x_B(t_0)$ = 1000 m.
3. The linear equation describing Driver A's motion is: $x_A(t)$ = 15 m/s · t, with the initial position at $x_{0A} = x_A(t_0)$ = 0 m, and the linear equation describing Driver B's motion is: $x_B(t)$ = 1000 m – 20 m/s · t.
4. To determine the position and time at which the two drivers cross, it must be true that the positions of the cars are equal; the corresponding time is then the time of crossing. The system of equations describing the motion of the cars must be constructed and solved.
5. Setting $x = x_A = x_B$, the following system of equations has to be solved:
$$\begin{cases} x = 15 \text{ m/s} \cdot t \\ x = 1000 \text{ m} - 20 \text{ m/s} \cdot t \end{cases}$$
6. The system of equations must be solved for x and t, where x and t are the position and time of crossing respectively.
7. The straightforward method to solve the system of equations, i.e., calculate the intersection, is as follows:
x = 15 m/s · t = 1000 m – 20 m/s · $t \Leftrightarrow$ 35 m/s · t = 1000 m $\Leftrightarrow$ t = 1000 m / (35 m/s),
thus x = 15 m/s · 1000 m / (35 m/s) = 15000/35 m.
8. The drivers cross each other at position $x_A = x_B$ = 15000/35 m at time t = 1000/35 s.

	Integrated ability present	Integrated ability absent
Appropriate content knowledge	Steps 1) through 8) of the ideal answer are present in some form. The respondent understands the concepts of speed and velocity and understands that both cars perform a uniform linear motion described by a linear equation. The respondent can set up the equations for the drivers and understands that, to find the crossing point, the system of equations must be solved for x and t. He/she is then able to solve the system of equations.	No steps of the ideal answer are present, except possibly step 1). The respondent writes down some correct equations relating to velocity (such as $v = \Delta x/\Delta t$) and position (such as $x(t) = x_0 + v \cdot t$), but doesn't know what to do with them. No mathematics are present because the respondent doesn't know which mathematics to use, though this doesn't mean the respondent doesn't have the appropriate mathematical content knowledge; he/she just doesn't know how it can help solve the question.
Inappropriate content knowledge	The respondent understands that Step 4) of the ideal answer must be performed, but cannot perform Steps 1), 2) and 3); even if the correct equations were provided, he/she would not be able to perform Steps 5), 6), 7) and 8). For example, the respondent might write the equation for Driver B without accounting for the opposite direction of the motion (i.e., the minus sign for the velocity): $x_B(t) = 1000\text{ m} - 20\text{ m/s} \cdot t$. Even if the correct system of equations were provided, the respondent would not be able to solve it correctly (e.g., he/she could only solve it for x and would not understand how to find the related time t).	None of the steps of the ideal answer are present. The respondent doesn't know what to do at all. The answer probably remains blank since there is no, or incorrect, content knowledge about velocity, or the respondent employs some incorrect formulae for velocity. Likely no mathematics will be observable in the solution at all, since the respondent doesn't know which mathematics to use.

Appendix C: Example items cognitive outcomes

Physics Knowledge

A light beam passes through a plate. Which of the images below is correct when the refractive indices are n1 <n2?



A) a
B) b
C) c
D) d

Physics Application

The spring constant of three identical massless springs is 0.200 N / cm. What is the stretching of the feathers when they are hung next to each other in order to carry a common load with a mass of 300 g?

A) 0.667 cm
B) 4.905 cm
C) 14.715 cm
D) 19.62 cm

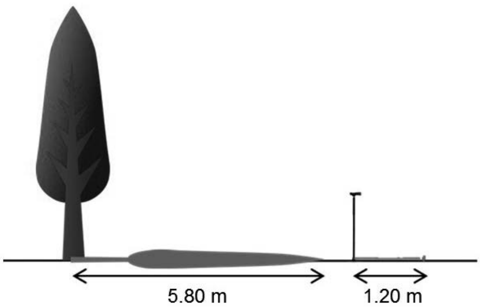
Mathematics Knowledge

The directional coefficient of the line through (a, 0) and (0, b) equals:

A) a/b
B) –a/b
C) b/a
D) –b/a

Mathematics Application

Peter would like to know the height of the tree. For this purpose he can use grandma's walking stick, which is 1.0 m long. Given the illustration below, what is the height of the tree?



A) 6.8 m
B) 5.8 m
C) 4.8 m
D) 0.2 m

Technological Concepts

Given the program code below:

```
number i = 0
number j = 5

        REPEAT AS LONG AS ( i < 3 and  j + 1 < 10 ) {
            PRINT ( i , j )
            i = i + 1
            j = j + 1
            MEMORIZE i
            MEMORIZE j
            }
        PRINT ( i , j )
```

what will be the printing output?

A) 0 5 1 6 2 7 3 8
B) 0 5 1 6 2 7 3 8 4 9 5 10
C) 0 5 1 6 2 7 3 8 4 9
D) 0 5 1 6 2 7 2 7

Integrated Physics and Mathematics

A jogger leaves for a run at 9 km/h. Ten minutes later, a cyclist leaves from the same starting point as the jogger, riding his bike at 24 km/h. After how many minutes does the cyclist cross the jogger?

A) 16 minutes
B) 12 minutes
C) 20 minutes
D) 10 minutes

Appendix D: IRT information cognitive outcomes

The ltm-package of R (open source software for statistical computing) was employed, using latent trait models under IRT, which is fit for an analysis of multivariate dichotomous data (Rizopoulos, 2006). Difficulty (i.e. the ability required to guarantee a 50% probability of answering the item correctly) and discrimination of the items (i.e. an index of an item's capability to differentiate between students in different positions on the latent ability) were analyzed, and items with a discrimination value of less than 0.15 were removed from the item battery. Subsequently, IRT was re-performed with the remaining items. Thereafter, the model with the best fit for the data was identified by analysis of variance (ANOVA). The Rash model (i.e. all items have a discrimination index of 1 logit) was compared with the one-parameter logistic model (1-PL; i.e. the discrimination index are the same for all items, but can have a value other than 1) and with the two-parameter logistic model (2-PL; i.e. the discrimination index can vary over items). For each instrument, the model with the best fit, the initial number of items, the remaining number of items, and information regarding discrimination values (α) and difficulty (β) are presented.

Instruments Measurement Moment 1

In Table 1, the results of the IRT analyses of the pretest instruments (measurement moment 1) are shown. Analysis of variance (ANOVA) showed that for physics (knowledge and application) and mathematics (knowledge and application) the 2-PL model had the best fit for the data. The 1-PL model had the best fit for the data on technological concepts. All items from the mathematics tests (knowledge and application) were retained, as no item had low discrimination values ($\alpha < 0.15$). For the other instruments, one or more items were omitted.

Table 1. IRT analyses of instruments measurement moment 1

	Phys. Know.	Phys. App.	Math. Know.	Math. App.	Techn.	IPM
Model	2-PL	2-PL	2-PL	2-PL	1-PL	
# initial items	10	15	8	25	25	
# remaining items	9	14	8	25	18	
Min α	0.35	0.36	0.41	0.15	0.61	/
Max α	1.33	1.72	1.24	1.62	0.61	
Mean α	0.65	0.70	0.84	0.93	0.61	
Min β	-4.26	-1.94	-2.81	-2.00	-6.36	
Max β	-0.77	3.93	0.49	3.45	2.93	
Mean β	-1.88	0.30	-0.74	-0.67	-2.33	

Instruments Measurement Moment 2

ANOVA showed that for all the instruments used in the first posttest (measurement moment 2) the 2-PL model had the best fit for the data (Table 2). For each instrument one or more items were omitted due to low discrimination values.

Table 2. IRT analyses of instruments measurement moment 2

	Phys. Know.	Phys. App.	Math. Know.	Math. App.	Techn.	IPM
Model	2-PL	2-PL	2-PL	2-PL	2-PL	2-PL
# initial items	29	22	10	31	25	14
# remaining items	22	15	9	29	20	9
Min α	0.19	0.20	0.24	0.29	0.18	0.18
Max α	1.87	2.02	1.37	2.38	2.31	17.91
Mean α	0.78	0.68	0.60	0.91	0.90	2.30
Min β	-2.82	-1.56	-2.30	-1.55	-1.47	-0.92
Max β	9.68	4.92	1.49	3.45	8.36	5.60
Mean β	0.73	1.09	-0.02	0.40	0.65	2.02

Instruments measurement moment 3

Table 5 shows the results of the IRT analyses of the second posttest (measurement moment 3). The 2-PL model best fitted the data of physics (application) and mathematics (knowledge and application), whereas the 1-PL model best fitted the data of technological concepts and integrated physics and mathematics questions. Of all 17 items in the physics knowledge test, only one item had a discrimination index of $\alpha > 0.15$, which was insufficient to perform further analysis. As a result, no reliable indicators of physics knowledge were collected in the second posttest of the study.

Table 5. IRT analyses of instruments measurement moment 3

	Phys. Know.	Phys. App.	Math. Know.	Math. App.	Techn.	IPM
Model		2-PL	2-PL	2-PL	1-PL	1-PL
# initial items	17	13	15	29	19	12
# remaining items	1	11	15	28	10	9
Min α		0.16	0.37	0.35	0.64	0.5
Max α		1.95	2.51	8.36	0.64	0.5
Mean α		0.64	1.45	1.77	0.64	0.5
Min β		-3.03	-1.73	-1.48	-1.07	0.83
Max β		8.39	3.76	5.06	1.90	3.54
Mean β		1.12	0.55	0.45	0.22	1.92

Over the past few decades, growing concern has been reported about young people's reluctance to participate in science, technology, engineering, and mathematics (STEM). Students' lack of interest in pursuing a STEM study or career is problematic because STEM-schooled professionals are essential to safeguarding and developing human well-being, economic growth, and sustainability. This phenomenon has given rise to the development of educational approaches all over the globe that aim to motivate students to choose a STEM study or profession. One of the potential promising approaches that could be employed is integrated STEM (iSTEM). iSTEM aims to merge the fields of the different STEM areas into a single curricular project that emphasizes concepts and their application across the four disciplines. This dissertation provides insight into students' relationships with STEM and investigates the effectiveness of an iSTEM educational approach. More specifically, its effects on cognitive and affective student outcomes are examined. As such, this book answers some pressing questions regarding iSTEM education, and provides valuable contributions for research and practice.

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