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

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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 Belgian schools, participated in the longitudinal study. The results of multilevel analyses show that students' attitudes, motivation, and self-efficacy with regard to science and mathematics tend to become less positive over time in traditional education. On the other hand, iSTEM education had positive effects on attitudes towards science and mathematics. However, negative results were observed with regard to motivation and self-efficacy outcomes. In addition, intervention effects differed for boys and girls and for students at different socioeconomic status levels. Our results indicate that iSTEM has the potential to improve students' attitudes towards STEM, but that we should be careful with regard to the implementation of this approach in terms of student motivation and self-efficacy.

Keywords: attitudes towards STEM, effectiveness, integrated STEM, STEM motivation, STEM self-efficacy.

Introduction

There is international agreement about the importance of students' participation in science, technology, engineering, and mathematics (STEM) (DeWitt & Archer, 2015). There has been a rapid growth in careers related to STEM and a growing shortage of STEM professionals has been observed (Keith, 2018). However, especially in highly-developed countries, students increasingly disengage from STEM subjects (Keith, 2018). Therefore, a great deal of attention has been paid to the personal psychological factors that may influence students' engagement in STEM, or their study or career choice.

Predictors of STEM Engagement and Study Choice

In educational research, several concepts have been described that allow us to understand behaviors and decisions that individuals make throughout their lives. In this regard, Pajares (1992) proposes beliefs as an important focus of inquiry. Beliefs encompass cornerstone concepts such as attitudes, motivation and self-efficacy (Pajares, 1992). 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 that behavior, together with subjective norms and perceived behavioral control. This theory is consistent with empirical research examining the role of attitudes in study choice (Armitage & Conner, 2001; Taylor, 2015; Jeffries, Curtis, & Conner, 2020). 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 has 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-related 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; 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 the 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 particularly autonomous forms of regulation, as the person engages in a particular 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 a school setting, such as learning and performance, psychological well-being, and engagement (Ryan & Deci, 2000; 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, by dint of dropping out at various points along their educational and occupational careers, this phenomenon has described in the literature in terms of a ‘leaky pipeline’ (Watt et al., 2012). Insight into the quality of student motivation helps us to understand and prevent students dropping out from STEM. Extensive research has been devoted to the role of motivation in terms of educational persistence and participation (e.g. Vallerand & Bissonnette, 1992; Vallerand, Fortier, & Guay, 1997; Ntoumanis, 2005). Students with higher levels of autonomous motivation were found to be more persistent in following courses, more willing to perform academic activities or undertake 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 achieve 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 prompts students to make a certain study choice. Indeed, ability-related beliefs have been proven to be of great importance when it comes to making 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 with regard to 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 of 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.

Engaging Students through iSTEM Education

Osborne et al. (2003) argued that there is a need for more research to identify those aspects of the educational environment that make STEM engaging for students. A promising approach to engaging more students in school, and thus attracting more students to STEM fields, is that of integrated STEM (iSTEM) education (Czerniak, Weber, Sandmann, & Ahern, 1999). Many educators provide testimonials about the effectiveness of integrated units, and many professional organizations stress the importance of integration across the curriculum. Traditionally, science, engineering, and mathematics are taught in separate courses, whereas 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 attitudes towards STEM, and enhance the motivation for learning STEM (Honey et al., 2014; Vallera & Bodzin, 2020). Curriculum integration advocates state that clear big picture concepts makes the curriculum more relevant for students, which leads to more interest and motivation in school (Czerniak & Johnson, 2014; Vallera & Bodzin, 2020). Judson and Sawada (2000) for instance, reported that the integration of mathematics into a science course led to significantly more positive attitudes towards mathematics. In a meta-analysis, Yildirim

(2016) found iSTEM to positively impact students' attitudes towards individual STEM disciplines. Czerniak and Johnson (2014) argue that there is a need for more research in the area of iSTEM curricula. As they found no examples of empirical research that includes engineering practices in an integrated curriculum, they particularly called for research that includes all STEM components. Most research into iSTEM education has focused on cognitive outcomes rather than 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.

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 iSTEM subject in which the learning modules were addressed. The schools taught the iSTEM 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 iSTEM 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). To maximize the chance that the iSTEM learning materials were implemented as intended, support was provided to schools and teachers in the experimental condition. The educational umbrella organizations supported schools in the implementation of the materials and ensured that they covered all the learning objectives and followed the curricular guidelines. Furthermore, the designers of the iSTEM learning materials organized intervision moments with the teachers involved. The learning modules consisted of challenges that were relevant in terms of societal and ecological problems, such as 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. In each learning module, all STEM components were integrated, following the definition of interdisciplinary integration (Wang et al., 2011). While the nature and definition of integration and interdisciplinary remains subject to debate (Czerniak et al., 1999), we follow the definition of Wang, Moore, Roehrig, and Park (2011). This definition states that interdisciplinarity starts from a problem that requires an understanding of multiple subjects, where the boundaries between the subjects are blurry. In the learning module of the energy-efficient house for example, students have to build a house that is heated by solar water heaters and underfloor heating. Critical elements in this challenge are the construction of a strong roof, and the regulation of indoor temperatures. To succeed, students have to use knowledge and make use of skills from all STEM disciplines, such as with regard to 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). Importantly, students can only succeed in the challenge of building the energy-efficient house by successfully integrating these STEM concepts and crossing the traditional boundaries. 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 the learning modules. The learning modules were designed to foster positive attitudes, autonomous motivation, and self-efficacy on the part of the students 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 able to understand and apply STEM concepts, their self-efficacy with regard to mastering these topics might increase.

Current Study

Given the declining number of students who choose a STEM career or study (Keith, 2018) and given the predictors of STEM engagement and study choice (Ajzen, 1991; Ryan & Deci, 2000; Lent et al., 1994), 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 increasing positive STEM attitudes, but remains largely under-investigated with respect to other affective outcomes (Honey et al., 2014), 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. **Research question 1)** How do affective outcomes regarding science and mathematics evolve over time in traditional education? **Research question 2)** What is the impact of an iSTEM curriculum on affective outcomes with regard to science and mathematics? **Research question 3)** What is the differential effectiveness of the iSTEM curriculum regarding student characteristics (i.e. sex and socioeconomic status (SES))?

Method

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. The 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. To ensure that the experimental and control condition are equivalent, a matching procedure was undertaken. First, all Flemish schools were listed, and an inventory of relevant characteristics was created, such as number of students, study track options, and membership of an educational umbrella organization. Second, for each experimental school that enrolled in the project, three matching schools were selected at random and invited to participate in the project. A school was considered a matching school when the number of students was similar (e.g. between 900 and 1000), when the study track options were the same (e.g. exclusively engineering and technological study options), and when the school was part of the same educational umbrella (e.g. community education). Control schools were invited to participate through a letter, and if no response was received, school administrators were called by a researcher as a follow-up. Participating control schools were provided with the iSTEM learning modules after the study was finished. Hence, control schools were comparable with the experimental schools with regard to their structural characteristics and with regard to their motivation to participate to the study. The students in this study were taking classes in one of the following three study tracks: 1. Science & Mathematics, 2. Engineering, and 3. Latin & Mathematics. The most important subjects in the Science & Mathematics study track are science, mathematics, and languages. In the Engineering study track, students are presented with a broad foundation (such as science and mathematics), but they also come into contact with additional technological and practical courses such as mechanics, electricity, electronics, etc. The Latin & Mathematics study track has a broad foundation of languages and sciences, but the strongest focus is on Latin and mathematics. For this study, mainly Science & Mathematics and Engineering study tracks were targeted, but all three described study tracks were welcome to participate in the study, as they form the most important STEM study tracks in secondary education. The total number of participants and the division in terms of 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 research 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).

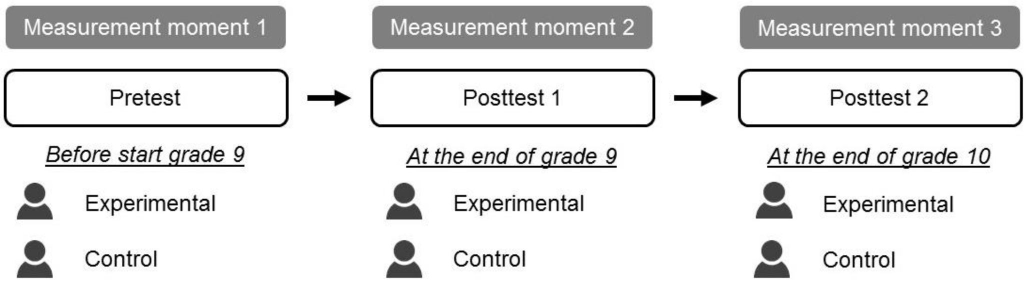

Figure 1. Three measurement moments.

The division of the number of recorded responses on the part 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**

The 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 providing 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 a passive informed consent procedure was used. This procedure was approved by the university's institutional ethical committee.

Instruments

Demographic information. Information regarding the age, sex, and the SES of the participants was acquired from the self-report of students using 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) 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. The 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 with regard to 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 using Cronbach's α internal consistency estimates. Cronbach's alphas were satisfactory for all scales measuring affective outcomes (with values for Cronbach's α of .60 or higher), which are usually considered acceptable levels of internal consistency (Cohen, Manion, & Morrison, 2013).

Plan of Analysis

First, we investigated the correlations between the study variables with regard to science and mathematics. No multicollinearity issues were found, and correlations were generally weak. Hence, we conducted separate univariate analyses for all affective outcomes. 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 the 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.

Observations within students and within schools are not independent. We can expect that repeated measures within an individual student will be more highly correlated than the repeated measures between students. Given that students learn together in class groups in schools, we could also expect that the attitudes, motivation and self-efficacy of students in the same school will be more highly correlated than the attitudes, motivation and self-efficacy of students in different schools. Multilevel modelling allows data to be clustered in groups (in this case, individuals and schools) and can therefore control for specific individual or school effects. Given the adequate sample size for multilevel analyses (Maas & Hox, 2005), 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. For all the investigated outcomes, the 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.

Results

Evolution over time

We investigated the evolution of affective outcomes over time in traditional education (= research question 1). The affective outcomes with regard to science can be found in Table 3. Graphical representations of evolution in affective science outcomes are displayed in Figure 2, under the 'control' curve. In terms of 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 a traditional education context generally develop a negative affective relationship towards science over time. For most of the variables, the significant decline takes place between the beginning and the end of grade 9.

Table 3

Mean scores for affective science outcomes over time in traditional education

	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 4

Mean scores for affective mathematics outcomes over time in traditional education

	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 a traditional education context with regard to mathematics can be found in Table 4. Graphical representations of 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 decreased 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 a traditional education context generally develop a negative affective relationship towards the subject over time. This decline is, in general, most noticeable between the beginning and the end of grade 9.

General Intervention Effects

We employed multilevel analysis to examine to what extent affective outcomes with regard to science and mathematics are explained by iSTEM education (= research question 2). For both science and mathematics, we investigated the impact of iSTEM education on career aspirations, interest, motivation to learn the subject, and self-efficacy with regard to the subject. Table 5 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 with regard to 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 6. 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 5

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 interaction										
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 6

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 interaction										
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. The 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 in terms of 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, in terms of 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 moments 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 with regard to 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.

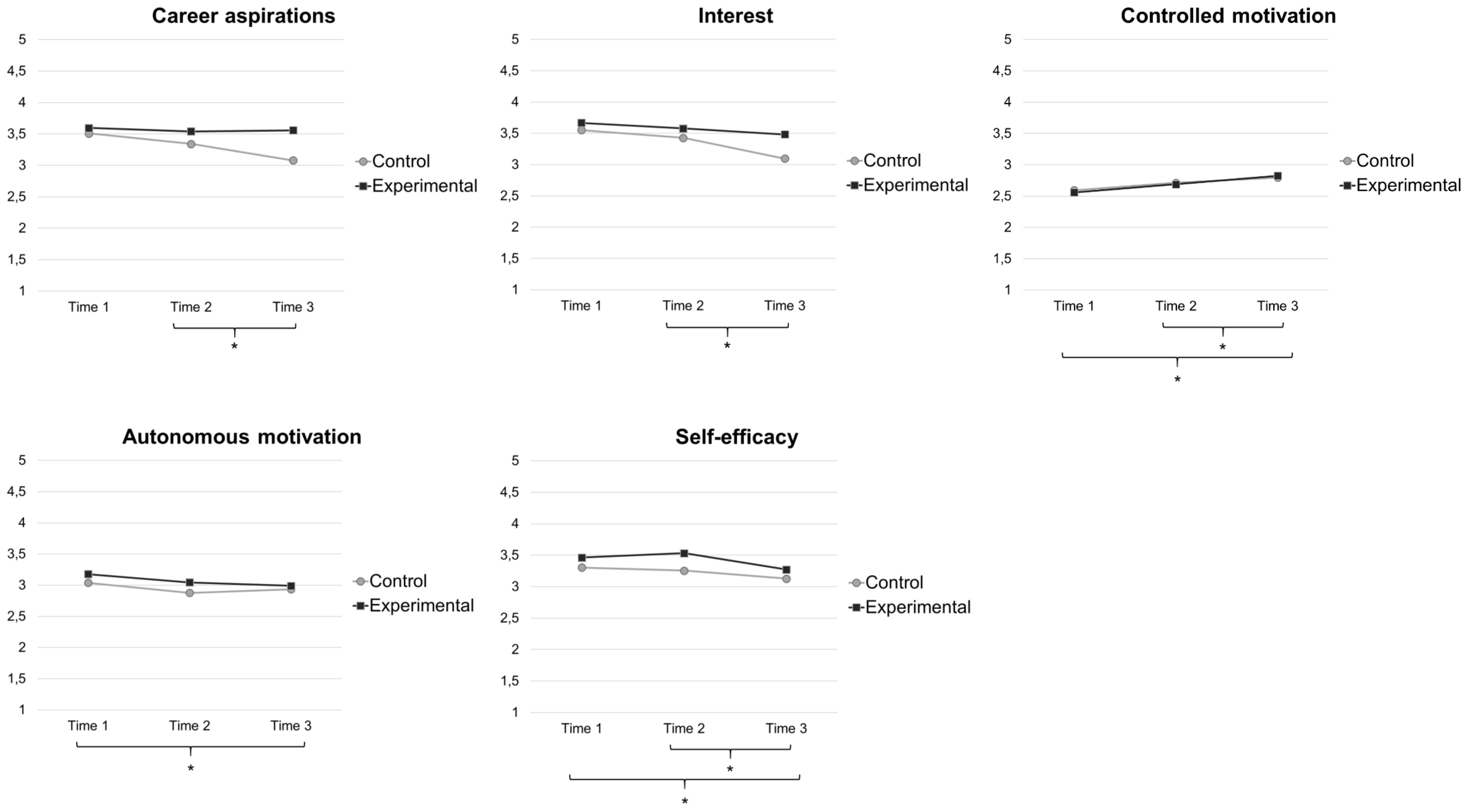

Figure 2. Scores on affective science outcomes in control and experimental conditions on pretest (= Time 1), posttest 1 (= Time 2), and posttest 2 (= Time 3).
Note. Significant interactions between condition and time are indicated with an asterisk.

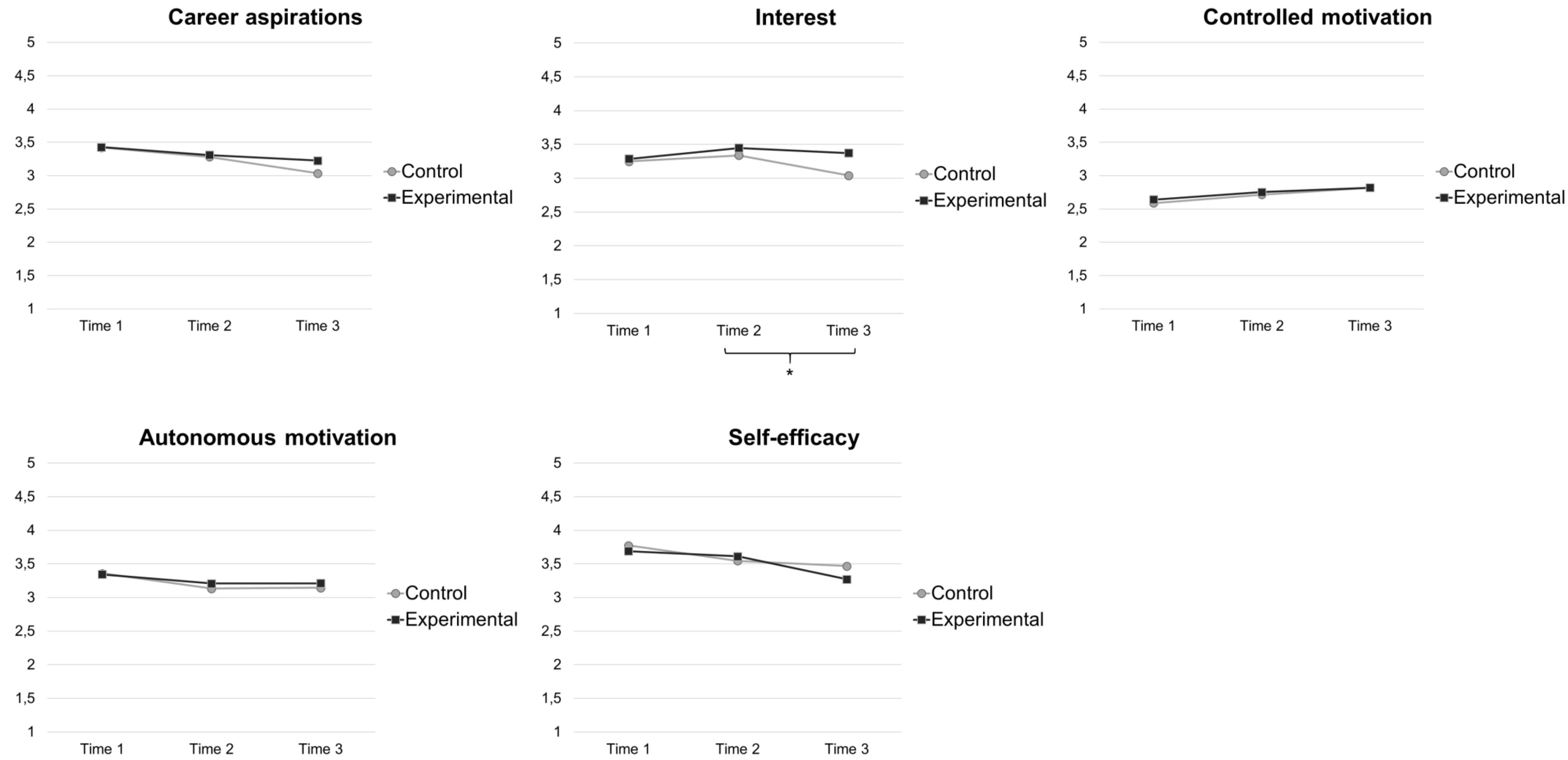

Figure 3. Scores on affective mathematics outcomes in control and experimental conditions on pretest (= Time 1), posttest 1 (= Time 2), and posttest 2 (= Time 3).

Note. Significant interactions between condition and time are indicated with an asterisk.

Differential Intervention Effects

The 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 5 underneath the ‘three-way interaction’ header. The relationship between condition and time differed according to the study track for controlled motivation and self-efficacy. While the students in the experimental condition showed a steeper decline in science self-efficacy than did the students in the control condition, this effect was even stronger for girls (who already had a lower score than boys in terms of 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 to SES in terms of 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 relationship 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 iSTEM.

With regard to mathematics, the three-way interactions between condition, time, and students’ characteristics are presented in Table 6. The relationship between condition and time differed according to the study track for all affective mathematics outcomes. In terms of 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. In terms of mathematics interest, autonomous motivation, and self-efficacy, a three-way interaction between condition, time, and SES was found. SES has a positive relationship 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.

Discussion

The aim of this study was to assess the evolution of students' attitudes, motivation, and self-efficacy with regard to science and mathematics, and to investigate the effect of an iSTEM curriculum on this evolution. We answered the following three research questions: (1) How do affective outcomes regarding science and mathematics evolve 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?

Evolution over time

Our study indicates that there is a general trend towards 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, in terms of 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 a number of 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 researchers 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, 2015). Second, students in our sample were entering puberty, which may have implications for their spontaneous interests (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 et al., 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 a leakage of 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; 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 to drop-out and less feelings of well-being (Vallerand et al., 1997; Ryan & Deci, 2000).

General Intervention Effects

As affective science and mathematics outcomes continue to evolve negatively in a traditional education context, 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 on the part 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 with regard to 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 in terms of 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 with regard to 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 found the learning materials to be more difficult, which might have led to a more negative estimation of their own abilities, resulting in lower scores in terms of self-efficacy. These results indicate that the teacher might have an important role to play. Previous research highlighted the importance of teachers' own attitudes towards iSTEM on a successful implementation of an iSTEM educational approach (Thibaut, Knipprath, Dehaene, & Depaepe, 2019). In the current study, 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 implementing a teaching style that supports autonomous motivation (De Loof, Struyf, Boeve-de Pauw, Van Petegem, 2019), and self-efficacy on the part of students (e.g. Deci et al., 1991).

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 steeper for girls, but less steep in the case of mathematics self-efficacy. 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 in that high SES was less positive in the experimental condition with regard to attitudes, but had a 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 of solving 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 protect the quality of motivation and self-efficacy of the students.

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 researchers 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 the experimental schools (O'Donnell, 2008). Despite the support of the educational umbrella organizations and the organization of intervision moments for teachers, 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 regard to 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 need to be further elucidated. In particular, the differential impact of iSTEM leaves several questions unanswered. Further research should investigate why iSTEM is particularly (dis)advantageous for girls or boys, or for students with different levels of SES.

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 in terms of 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.

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