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Students' engagement in different STEM learning environments: integrated STEM education as promising practice?

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Students' engagement in different STEM learning environments: integrated STEM education as promising practice?

In this paper, we explore how students' engagement varies in different STEM (Science, Technology, Engineering, Mathematics) learning environments. More specifically, we focus on the significance of a learning environment applying an integrated STEM (iSTEM) approach and the significance of STEM learning environments' student-centredness. Moreover, we explore the relative importance of different student-centred principles (lesson plan and implementation, communicative interactions, student-teacher relationships) for students' engagement in the STEM learning environment. Applying a mixed-method approach, we draw from observational data of 24 STEM lessons in combination with data from seven focus groups with 67 grade 9 students. The quantitative findings, based on the observational data, show that a learning environment applying an iSTEM approach seems to support students' engagement. Further investigation made it clear that the student-centredness in this learning environment is especially significant. Regarding the specific student-centred principles, all principles had a significant impact on students' engagement. The focus group data make clear that, besides student-centredness, the integrative aspect and the use of authentic real-world problems in iSTEM can also be engaging for students. These results indicate that iSTEM is a good practice to engage students in the STEM learning environment, as it facilitates teachers' implementation of a general student-centred approach.

Keywords: student engagement; integrated STEM; student-centred learning, mixed methods

Introduction

Policymakers and educational researchers worldwide, increasingly focus on ensuring students' persistence and success in Science, Technology, Engineering and Mathematics (STEM) (Skinner, Saxton, Currie, & Shusterman, 2017) and students' preparation for the labour market in which STEM takes a prominent place (World Economic Forum [WEF], 2017). Compulsory education plays a central role in achieving this goal. However, according to the World Economic Forum (2017), many education systems today prepare students insufficiently for the labour market as they are based on educational models introduced over a century ago. For instance, most STEM education in primary and secondary schools focuses on theory rather than on application and experiential learning and is taught in a way that reinforces a disconnect between the different STEM disciplines (Nadelson & Seifert, 2017; WEF, 2017).

In order to attract a larger number of students who are more engaged in STEM and provide them with essential 21st century skills such as complex problem-solving and teamwork (see e.g. Salonen, Hartikainen-Ahia, Hense, Scheersoi, & Keinonen, 2017; Struyf, Boeve-de Pauw, & Van Petegem, 2017), a shift towards more student-centred learning environments is generally assumed to be needed (Gasiewski, Eagan, Garcia, Hurtado & Chang, 2012; Sawada et al., 2002). A student-centred learning environment provides students with opportunities to take a more active role in their own learning, rather than being passive receivers of information (Anderson, 2007; Brush & Saye, 2000). Students need to analyse and synthesise the learning content themselves through e.g. examining complex problems, using a variety of means and developing their own strategies to solve these problems in a collaborative manner (Brush & Saye, 2000).

Within this shift towards more student-centred learning environments, the current international focus in STEM education includes a movement towards integrating the separate STEM disciplines in the curriculum through 'integrated STEM' (iSTEM) (Honey, Pearson, & Schweingruber, 2014; Koul, Fraser, Maynard, & Tade, 2017; Moore & Smith, 2014; Nadelson & Seifert, 2017; Sanders, 2009). 'iSTEM' can generally be defined as 'the seamless amalgamation of content and concepts from multiple STEM disciplines. The integration takes place in ways such that knowledge and process of the specific STEM disciplines are considered simultaneously, without regard to the discipline, but rather in the context of a problem, project or task' (Nadelson & Seifert, 2017, p. 221). In contrast to traditional 'segregated' STEM, integrated STEM requires the application of knowledge and practices from various STEM disciplines to solve complex and transdisciplinary problems (Nadelson & Seifert, 2017).

As engaging students in STEM is an urgent need in society, it is important to investigate which learning environments can foster and promote pupils' engagement towards STEM (Skinner et al., 2017).

Using a mixed method approach, we draw in this research from observational data of diverse STEM lessons in combination with data from focus groups with grade 9 students. The observations include lessons of segregated domain-specific STEM disciplines and iSTEM lessons. Through quantitative analysis of the observational data, we examine how student engagement varies in different STEM learning environments. More specifically, we investigate the significance of an iSTEM approach and the STEM learning environment student-centredness for students' engagement. Furthermore, we explore the relative importance of different student-centred principles in terms of engaging students. Focus group data enrich these findings with the narrative experiences of students.

Students' engagement

In this study, we conceptualise engagement as 'the behavioural intensity and emotional quality of a person's active involvement during a task' (Reeve, Jang, Carrell, Jeon, & Barch, 2004, p. 147). The behavioural dimension of students' engagement consists of effort, attention and persistence during learning activities. The emotional dimension of engagement includes students' emotional involvement during learning activities, such as enthusiasm, interest and enjoyment (Reeve et al., 2004; Skinner, Furrer, Marchand & Kindermann, 2008). In contrast to engagement, disengagement or *disaffection* is evident in students who are passive, discouraged and give up easily (Skinner et al., 2008; Skinner et al., 2017). Engagement is an important educational construct as it causes many positive student outcomes such as academic learning, achievement, skill development, and academic resilience in different educational fields, (Reeve, 2012; Skinner et al., 2008) including the STEM educational field (Bathgate & Schunn, 2017; Skinner et al., 2017). Engagement can be approached and measured differently based on the 'grain size' of the context. This can range from an individual level, such as a person's individual engagement during a task, to a macro level. The latter refers to the engagement of a group of learners in a class, course, school or community (Sinatra, Heddy, & Lombardi, 2015). In the current study, we conceptualise and measure students' *collective* engagement in the classroom.

Student-centred learning environments

Student-centred learning environments are inspired by the constructivist learning theory, which has gained much attention in educational research over the past few decades (Baeten, Dochy, & Struyven, 2012). The ideology behind this theory is that learning is an active process of knowledge construction in which learners construct meaning for themselves, based on prior constructions. While some educational researchers argue that active knowledge construction can take place regardless of the teaching method or type of learning environment, others highlight the need to create constructivist learning environments which are typically student-centred (Anderson, 2007; Baeten et al., 2012). Other labels, besides 'student-centred' that can be found in the literature and refer to constructivist teaching methods (Baeten et al., 2012) are, for example, 'inquiry-based' (Anderson, 2007; Loyens & Rikers, 2011) or 'student-activating' (Baeten et al., 2012; Struyven, Dochy, & Janssens, 2008).

Sawada et al. (2002) defined several overarching student-centred principles, based on a review of the literature, that allow researchers to measure the degree to which a learning environment is student-centred. These principles; lesson plan and implementation, communicative interactions and student-teacher relationships will be discussed. Typically, both teachers and students take on a different role in a student-centred learning environment, in contrast to a traditional teacher-centred or 'lecture based' learning environment, resulting in different *student-teacher relationships* (Anderson, 2007; Brush & Saye, 2000). The teacher's role transforms to that of a coach and facilitator instead of a dispenser of knowledge. (S)he encourages students' active participation through 'hands-on' and 'minds-on' activities. Moreover, the teacher's role is to stimulate students to find more than one solution for a problem (Sawada et al., 2000). (S)he walks around, listens to students and helps students to process information, communicates with student groups and models the learning process (Anderson, 2007). Students, meanwhile, become self-directed learners instead of passive receivers of information. Students focus on processing information instead of recording it and interpret and explain information rather than solely memorising it (Anderson, 2007; Schmid & Bogner, 2017). Additionally, the type of student work changes. For instance, students need to direct their own work to a larger extent; tasks vary among students and often include solving and explaining complex problems (Anderson, 2007). *Communicative interactions* taking place in a student-centred classroom are consequently more diverse and decentralised (Sawada et al., 2002). In contrast to a traditional learning environment, the teacher is not the centre of attention during the lesson. Students communicate with the teacher and with each other by, for instance, brainstorming, critiquing or group work (Anderson, 2007; Sawada et al., 2000). Moreover, the *lesson plan and implementation* in a student-centred learning environment is organised in a manner that the ideas that students bring to the classroom are acknowledged and respected. Students are considered as a community of inquirers (Sawada et al., 2002).

Previous studies investigating the link between student-centred STEM learning environments and students' engagement found mostly positive to mixed results. In a study, Wu and Huang (2007) found that students in a student-centred technology-enhanced STEM learning environment reported higher levels of emotional engagement, compared to students in a teacher-centred learning environment. But, when comparing different student groups, low-achieving students in the student-centred learning environment demonstrated more disengagement and engaged in fewer conceptual discussions, while they achieved better in a teacher-centred STEM learning environment. Research by Hampden-Thompson & Bennett (2013) examined the variance in students' reports of engagement in science across science teaching and learning activities. Higher levels of students' emotional engagement towards science were found in classrooms where students reported higher levels of interaction, hands-on activities and applications in science. Gasiewski et al. (2012) investigated the relationship between students' engagement and introductory STEM courses and found that students were more emotionally and behaviourally engaged in STEM classrooms where professors applied a student-centred approach and where collaboration with others frequently took place. More research in diverse contexts, using a number of different research methods, is needed to gain more insight into how different STEM learning environments can play a role in promoting students' engagement.

The iSTEM approach as a student-centred STEM learning environment

STEM can be placed on a continuum, with segregated domain-specific STEM at one end (e.g. separated mathematics, physics) and integrated domain-general STEM (iSTEM) at the other end of the continuum (Nadelson & Seifert, 2017). Complex research problems occurring in today's industry and society mostly need the use of iSTEM (Nadelson & Seifert, 2017; Wang, Moore, Roehrig, & Park, 2011), while, in contrast, most STEM education in primary and secondary education is more aligned to segregated domain-specific STEM (Nadelson & Seifert, 2017). At the same time, there is a pedagogical shift in favour of integrating the four disciplines of STEM at school level into one class or a unit, based on the connections among the disciplines and real-world problems (Moore & Smith, 2014).

As problems requiring an iSTEM approach are typically ill-structured with multiple solutions, iSTEM education requires a student-centred learning environment (Moore & Smith, 2014; Nadelson & Seifert, 2017). Based on a review of existing literature identifying multiple characteristics of iSTEM education, Thibaut et al. (2018) discerned five specific key principles that are used for iSTEM education and can guide the design of an iSTEM approach in secondary education.

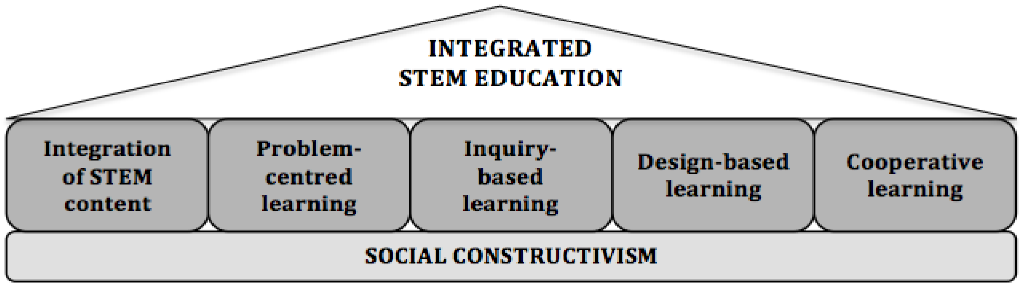

Figure 1. Theoretical framework for integrated STEM education (Thibaut et al., 2018a)

The first key principle is *the integration of STEM content*, which entails purposefully integrating content from various STEM disciplines. Secondly, *problem-centred learning* indicates the use of authentic real-world problems to increase the relevance of the learning content. Third, *inquiry-based learning,* in this context, refers to engaging students in questioning, experiential learning and hands-on activities that allow them to discover new concepts and develop new understandings. The fourth key principle, *design-based learning,* refers to learning environments that engage students in technological or engineering design. The final principle, *cooperative learning*, relates to the promotion of teamwork and collaboration with others through the use of, for example, small learning groups. In contrast to the instructional practice of ‘collaborative learning’, ‘cooperative learning’ emphasises teachers’ guidance (Thibaut et al., 2018a). In the latter, the teacher moves from one student group to the other, observes and intervenes when necessary. In the case of collaborative learning, the teacher will not actively monitor the different student groups and will refer all substantive questions back to the group to resolve (Matthews, 1995; Thibaut et al., 2018a).

Obviously, there are some overarching aspects that relate these key principles to each other. All key principles, for instance, are supported by a constructivist view on learning (Thibaut et al., 2018a). Thus, it is not surprising that the last four key principles (problem-centred learning, design-based learning, inquiry-based learning and collaborative learning) are student-centred teaching methods. Students need to take an active role in their learning and the teachers should become a guide on the sideline Moreover, these last principles all promote the development of 21st century skills, such as problem solving (problem-centred learning), critical thinking (inquiry-based learning), creative and innovative thinking (design-based learning) and collaboration and teamwork skills (cooperative learning) (Binkley et al., 2012; Thibaut et al., 2018a).

Regarding the effect of iSTEM education on students’ cognitive and affective outcomes, several empirical studies have found a positive impact. It has been found to improve students’ achievement (Austin, Hirstein, & Walen, 1997; Hurley, 2001), interest in STEM (Mustafa, Ismail, Tasir, Said & Haruzuan, 2016; Riskowski, Todd, Wee, Dark & Harbor, 2009), motivation to learn (Gutherie, Wigfield, & VonSecker, 2000; Stohlmann, Moore, & Roehrig, 2012) and career interest in STEM (Koul et al., 2017). To our knowledge, no study has investigated the effect of iSTEM education on students’ engagement. However, Skinner et al. (2017, p. 2437) argue that students’ engagement in STEM could be promoted by interesting authentic academic work which they define as work that is 'hands-on, heads-on, experiential, project-based, authentic, relevant, progressive and integrated across subject matter'.

Aim of the present study

The aim of this study is to investigate how grade 9 students' engagement occurs in different STEM learning environments. We examine which of these STEM learning environments supports students' engagement, with a specific focus on a learning environment applying the iSTEM approach and the STEM learning environment's student-centredness. Furthermore, we investigate the relative importance of different student-centred principles in terms of facilitating students' collective engagement. We assume that the iSTEM approach is in reality not always implemented in a highly student-centred manner. On the other hand, domain-specific STEM might include a high degree of student-centredness. Therefore, we choose to split up both concepts theoretically: (a) iSTEM versus domain specific STEM and (b) degree of student-centredness (see Figure 2). Specifically, we aim to answer the following research questions (RQs):

RQ1: To what extent does (a) an iSTEM approach and (b) the degree of student-centredness in the STEM learning environment support grade 9 students' collective engagement?

RQ2: To what extent do the different student-centred principles support grade 9 students' collective engagement in the STEM learning environment?

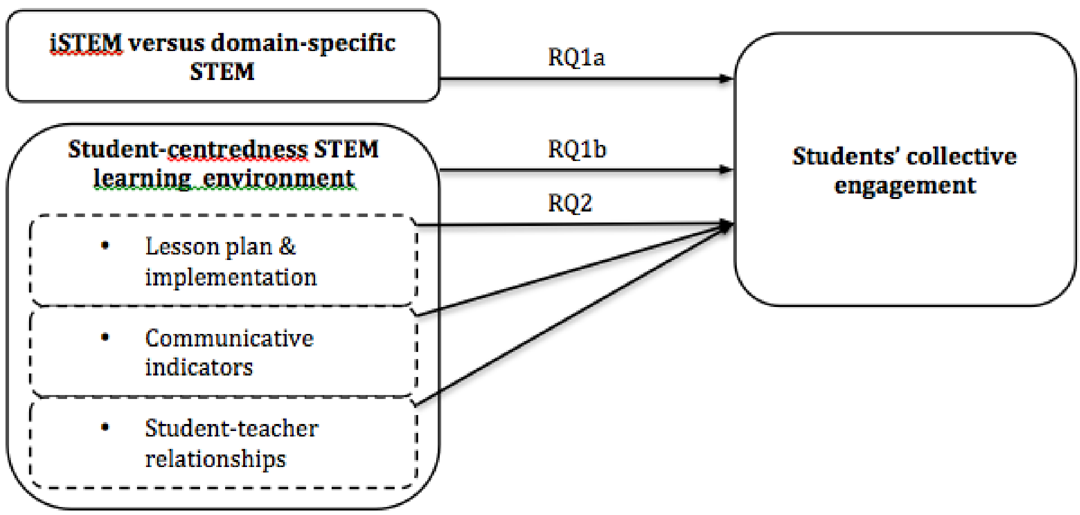

Figure 2. Visualised scheme of research questions in this study

Methodology

Research context, procedure and participants

We conducted our study within the STEM@School research and development project

(Knipprath et al., 2018). The overall aim of this project is to increase students' achievement, motivation and engagement with regard to STEM. Within this project, a team of researchers with a professional background in STEM - who were not involved in this specific study - developed iSTEM learning modules for students in secondary education. For 9^{th} graders, they developed three different modules. In the first module, students were challenged to design and build an autonomous driving car that could drive through a 'green wave'. In the second module students had to design and build a museum security system and, in the last module, a rehabilitation device. The five key principles of iSTEM education provide a well-defined framework for instructional practices in iSTEM in secondary education and guided the design of the three modules.

In order to provide a rich understanding of students' engagement with regard to different STEM learning environments, we applied a mixed method approach. Observations were chosen to provide a general picture of how different STEM learning environments relate to students' engagement. Focus groups were chosen as complementary methodology to enrich the observational data through students' narrative experiences. Thus, we aimed to explore in more detail, through the qualitative focus group data, how students' engagement manifests itself within these different STEM learning environments.

We conducted observations between January and May 2016, during the implementation of the last two STEM@School modules. For the observations during the second module, we randomly selected nine schools among the 41 Flemish schools that participated in the project. From each of these schools we selected one 9th grade class to participate in this study. In each of these classes, we selected one mathematics lesson, one physics lesson and, when included in the curriculum, one iSTEM lesson for observation. We videotaped each observation and after screening the visual and auditory quality of the observational data, 18 observations remained, including eight mathematics lessons, five physics lessons and five iSTEM lessons. To provide extra observational data, we videotaped six extra iSTEM lessons during the third module, in six other randomly selected schools participating in the project. Each observed lesson lasted between 50 and 100 minutes.

All selected classes for the observations followed a curriculum with a general focus on STEM (note: not necessarily iSTEM). However, 12 of them had a curriculum that focused on science and mathematics, while the other three classes had a particular focus on technology and engineering. Moreover, two of those classes followed a traditional curriculum without the iSTEM course. In all the other classes, the iSTEM course was included in the curriculum. Approximately 10% of the curriculum was devoted to the iSTEM course in these classes. In total 321 9^{th} grade students attended the observed lessons (68% male, 32% female, age: M = 14.54; SD = .88).

On the same day of the observation(s) in the second module, we held focus groups with randomly selected students from these observed classes. Altogether, 67 respondents, of whom 42 were male, participated. The group size ranged from 7 to 12 students, which is an appropriate group size for a focus group (Osborne & Collins, 2001). Each focus group had a duration of approximately one hour and was audio recorded. In line with Belgian legislation, we obtained permission from the students and their parents to participate in the observations, using a passive informed consent procedure. For the focus groups, we obtained an active informed consent from the participating students.

Observations

Measures and variables

To measure *students' engagement* we used a subscale of the observation instrument of Reeve et al. (2004), measuring students' collective classroom engagement. This scale includes both behavioural and emotional engagement. Each item is placed on a continuum ranging from 1 to 7 with bipolar descriptors of students' (dis)engagement. Items and the reliability of the scale can be found in Table 1. The first two authors of this study rated all videotaped observations on students' engagement independently to avoid social influence bias. The interrater reliability, based on the correlation coefficients, was satisfactory (*IRR*= .80). Based on the video recordings, the researchers considered both the frequency and intensity of the students' behaviour and emotions during the rating procedure. A high score for students' engagement was given when most or almost all the students in the classroom were behaviourally and emotionally engaged. Average engagement scores in the observed lessons varied from a score of 2.1 to 6.8. The researchers explicitly discussed each score they gave for the first five rated observations, in order to ensure that they were interpreting the various items in the same way. When there was a different interpretation of an item, scores were justified after agreement was reached. When a conflict in scores occurred after rating the remaining observations, scores were not modified.

The learning environment's *student-centredness* was observed with the Reformed Teaching Observation Protocol (RTOP) (Sawada et al., 2002). We took two of the three scales into account: *Lesson Design and Implementation* and *Classroom Culture.* The first scale focuses on measuring to what extent ideas brought to the classroom by pupils were acknowledged and respected. The latter includes the diversity of communicative interactions and student-teacher relationships, including the degree of teacher support towards the initiatives coming from the pupils (Sawada et al., 2002). Table 1 shows the reliability of the different scales and all the items included. After carefully going through the RTOP training guide (Sawada et al., 2000), the two observers discussed all the items to guarantee that they were interpreted in the same way. As a next step, they rated the items on a scale from 0 (not observed) to 4 (very descriptive). Higher scores reflected a higher degree of the learning environment's student-centeredness (Sawada et al., 2000). This rating procedure was performed approximately six months after rating students' engagement. Both researchers rated the first five observations independently and the interrater reliability was satisfactory (*IRR* = .88).

Table 1. Variables in this study and reliability coefficients

	C. α
Dependent variable	

Collective classroom engagement	0.94
‘Dispersed’ versus ‘focused attention’	
‘Passive, slow, minimal effort’ versus ‘active, quick, intense effort’	
‘Verbally silent’ versus ‘verbally participating’	
During challenge, failure or confusion: ‘students give up easily’ versus ‘persist’	
‘Flat’ versus ‘positive emotional tone’	
Independent variables	
Lesson plan & implementation	0.83
Instructional strategies and activities respected students’ prior knowledge and the preconceptions inherent therein	
The lesson was designed to engage students as members of a learning community.	
Student exploration preceded formal presentation	
Students were encouraged to seek and value alternative methods of investigation or of problem solving	
The focus and direction of the lesson was often determined by ideas originating from the students.	
Communicative interactions	0.79
Students were involved in the communication of their ideas to others using a variety of means and media.	
The teachers’ questions triggered divergent modes of thinking.	
There was a high proportion of student talk and a significant amount of it occurred between and among students.	
Student questions and comments often determined the focus and direction of classroom discourse.	
There was a climate of respect for what others had to say.	
Student- teacher relationships	0.82
Active participation of students was encouraged and valued.	
Students were encouraged to generate conjectures, alternative solution strategies and ways of	

interpreting evidence.
In general the teacher was patient with students.
The teacher acted as a resource person, working to support and enhance student investigations.
The metaphor ‘teacher as listener’ was very characteristic of this classroom.

Quantitative analysis

Considering that students’ engagement could differ across different class groups, regardless of the iSTEM approach and the STEM learning environment’s student-centredness, we took into account the class group as a variable in order to answer RQ1. We performed multilevel analyses using JMP (John’s Macintosh Project) version pro 13. First, we performed multilevel analysis, exploring the significance of the iSTEM approach for students’ engagement, including the class group as a random effect (Model I). Note that only one class group was included per school, which implies that no separate level for the school was included in the model. Second, we added the total student-centredness of the STEM learning environment to the first model, which resulted in Model II. In order to understand which student-centred principles could predict students’ engagement (RQ2), we performed additional multilevel analyses taking the three different subscales into account instead of the overarching student-centredness variable. However, due to insufficient power (the mean power of the three scales was 0,49), we were not able to investigate the predictive value, taking the three different scales together in one model. As an alternative approach, we built three different models, with the separate scales, to predict engagement while still taking the random effect of the school into account (Models IIIa, IIIb, IIIc). To examine agreement among class groups, we computed intra-cluster correlation coefficients (ICC) (e.g. Mouratidis, Vansteenkiste, Sideridis, & Lens, 2011).

Focus groups

For the focus groups, we developed a semi-structured interview guide including questions regarding students’ perceptions of the STEM learning environment and their experiences with it. At the start of the focus group we explained the focus group’s aim, the confidentiality of the data and some general focus group rules. As an icebreaker, students could present themselves by sharing the reason for their current study choice and their career aspirations. Next, students were asked to write down a description of a typical physics, mathematics and, if applicable, iSTEM lesson. Specific focus was given to the teacher’s role, the students’ roles and student work. After this, students were asked to discuss with the other respondents what they had written down and share their positive and negative experiences about the learning environment. More specific questions were provided and related to students' perceptions and experiences about the amount of group work and discussions during the lessons, the relevance of the lesson and what the teacher would do if pupils were stuck when trying to solve an exercise. At the end of the focus group, students could also indicate what they would change about the learning environment.

In Table 2, an overview of the focus groups can be found, accompanied by a description of the collective engagement level in each observed lesson that respondents in the focus group attended. We categorised students' engagement level as; 'high' if the scores of students' observed engagement ranged between 5 and 7, 'average' with scores between 3 and 4.9 and 'low' with scores between 0 and 2.9. For focus groups, where no description of the engagement level in iSTEM can be found in Table 2, there was no iSTEM lesson included in the STEM learning environment.

Table 2. Overview of focus groups and students' observed engagement in the STEM learning environment

(1)	**Students' collective engagement level**		
Focus group (FG)	**iSTEM**	**Physics**	**Mathematics**
FG1	High	Average	High
FG2	-	High	average
FG3	High	High	Low
FG4	Average	-	High
FG5	Average	-	-
FG6	high	-	average
FG7	-	Low	average

Qualitative analysis

We analysed the focus groups, using thematic analysis (Braun & Clarke, 2006). First, the focus groups were transcribed and the process of (re)reading began to enable familiarity with the data. Notes of initial thoughts and reflections aroused by fragments in the transcript were simultaneously taken. The qualitative data analysis software Nvivo 10 supported the next steps in the analysis process. We generated initial codes across the whole data set and thereafter, gathered these under broader codes. Coding during this step of the analysis was theory-driven. Based on students' expressions of emotions and behaviour, we categorised students' narratives using the motivational conceptualisation of engagement and disaffection in the classroom of Skinner et al. (2008). The latter provides a fine-grained categorisation of students' emotions and behaviours. Students' descriptions of the STEM learning environment were categorised under the five key principles of iSTEM (Thibaut et al., 2018a) and the student-centred principles included in the RTOP (Sawada et al., 2000). The fourth step consisted of reviewing the themes in relation to the coded fragments and the whole data set, with a thematic map of analysis as a result. Fifth, we refined the specifics of each theme and divided certain themes into smaller sub-themes. Finally, we selected and further analysed vivid quotes from the students in the focus group, relating back to the research questions and the literature (Braun & Clarke, 2006). In order to protect the respondents' privacy, only pseudonyms are reported in this paper.

Results

First we discuss the results regarding the significance of the iSTEM approach and the STEM learning environment's student-centredness for students' collective engagement. Next, we report the results about the significance of the three student-centred principles (lesson plan and implementation, communicative interactions, student-teacher relationships) in this regard.

Students' engagement in different STEM learning environments

The results reveal that the iSTEM approach was not significant. However, we should be cautious about accepting the null hypothesis (Pritschet, Powell, & Horne, 2016), as the iSTEM approach was marginally significant [F (1, 21.7)]= 3.01, p = 0.09 (Model I). Students' average engagement in a STEM learning environment with an iSTEM approach was 5.10, while students' engagement in a learning environment with 'domain-specific' STEM was 4.19. When we added the learning environment's total student-centredness to the model (Model Π), the latter was significant [F (1, 21)]= 8.29, $p < .01$ for students' engagement and it decreased the amount of explained variance of a learning environment with or without the iSTEM approach (see Table 3). Approximately 41% of the variation in students' engagement was a function of the class group (ICC= 0.41).

Table 3. Relationship between the type of STEM learning environment and students' engagement

	Models	
	I	Π
β iSTEM versus domain-specific STEM	$.71^{+}$	.06
β Student-centredness		.61**

Note: $^{+}p<.10$ $^{*}p<.05$. $^{**}p<.01$. $^{***}p<.001$.

The focus group data make these findings more clear, in the sense that, when students in the focus groups expressed that they were emotionally and behaviourally engaged towards iSTEM, this was mostly associated with the student-centredness within this learning environment. For example, designing, collaborating with others and experiencing ‘freedom’ in these lessons, were mentioned by respondents as engaging aspects. As the next quotes illustrate, respondents in FG1 and FG4 clearly stated that they felt that the iSTEM lessons were generally more student-centred compared to teacher-centred learning environments, which in turn was associated with more expressed engagement.

Melanie:	During working [in iSTEM lesson] she [teacher] comes to look around to see if we are doing it well.
Interviewer:	What happens when you are stuck in a hard exercise?
Melanie	Then we raise our hand and she helps us a little bit further, so we can go on. She doesn’t tell us everything.
	(….)
Bob:	During physics she [same teacher] is just constantly talking and we just have to pay attention.
Nick:	There is a more boring atmosphere in physics, in contrast to iSTEM; it’s a lot more fun there.
Bob:	In iSTEM we are really busy, for example, with that little car. In contrast to physics, there you really have to just sit and listen.
(FG4)	

The following quote illustrates that, besides a generally student-centred approach in iSTEM, also the integration of STEM content can support students’ engagement, if the direct relevance of the subject matter becomes clearer through the integration and application.

Michael:	I find it good [iSTEM] because you can often cooperate and because it often involves projects. You do learn from just opening a book, but I find that a very boring manner of learning. I wrote it all down now and I understand it, but what will I actually get out of it? You have this less with iSTEM, because you really learn how helpful it is for you. You see that you can calculate this and it is handy for that. Then you get a better image of it and you benefit more from it, in my opinion.
Interviewer:	So, you mean that you understand more why you need to know it?
Michael:	Yes, indeed. For physics, they teach us for example hydrostatic pressure. Then you know that there is so much pressure on water, but what will I get out of it?
Interviewer:	Can you give an example of the iSTEM lesson that made you to understand the use?
Michael:	For example, programming this little car. You know how to calculate the velocity and then you can perfectly adapt it. With the formula of velocity as such … ok you know it, but then you don’t have a very good image of it yet.
(FG1)	

The data indicate that also the use of authentic real-world problems, through problem-centred learning, can positively influence students’ engagement. Nevertheless, this was more the case when students experienced this problem as personally relevant and closely related to problems in the ‘real world’. The next quotes from FG4 and FG6 clarify this:

Nick (FG4)	I think I will practise a STEM profession, because I like it. For example, this car we had to make and try out. I liked it and later on you can also really make and develop it, to then later improve it and update it.

Sam:	That's actually why I chose STEM [iSTEM], because you can work on this museum security system. But this car, we will never use it later on, but after all it's nice to know.
Tom:	But sometimes it could be more comprehensive. For example, in this museum security system we only work with lasers. In a real museum security system they will do much more.
(FG6)	

Student-centred principles and students' engagement

Multilevel analysis shows that the scale 'lesson plan & implementation' was not significant at the .05 level, but marginally significant for students' collective engagement [F (1, 20.7)]= 3.73, p = 0.07 (Model IIIa). 'Communicative interactions' (Model IIIb) and 'student/teacher relationships' (Model IIIc) were both significant; [F (1, 20.5)]= 9.44, p < .01 and [F (1, 19.3)]= 11.3, p < .01. More details can be found in Table 4. The ICC in Models IIIa and IIIb was equal to 0.41, which means that 41% of the variation in students' engagement was a function of the class group. In Model IIIc the ICC was equal to 0.39. How students' engagement manifests itself in relation to the various student-centred principles will be discussed below in more detail, illustrated by students' narrative experiences.

Table 4. Relationship between student-centred principles and students' engagement

(1)	Models		
	IIIa	**IIIb**	**IIIc**
β iSTEM versus domain-specific STEM	.24	.02	.16
β Lesson plan & implementation	.44^{+}		
β Communicative interactions		.64**	
β Student-teacher relationships			.64**

Note: ^{+}p<.10 *p<.05. **p<.01. ***p<.001.

Lesson plan and implementation

The quantitative results showed that 'lesson plan and implementation' was marginally significant for students' collective engagement. The results of the focus groups demonstrate in more detail how 'lesson plan and implementation' in the STEM learning environment can promote or thwart students' engagement. Many respondents appreciated and indicated that they were emotionally engaged when the class group would be considered as a learning community. In FG1, for example, students were highly engaged for STEM and mathematics, but indicated that they missed group discussions about the subject matter. While students would enjoy it if the teacher would actively appeal for students’ knowledge and ideas, the teacher would instead directly answer students’ questions. Hence, the teacher did not value alternative modes of investigation or problem solving. This led to frustration for students who were initially intrinsically interested and highly engaged.

Jonas:	It’s a pity that madam [iSTEM and physics teacher] is never open to discussions, also not about the content of the lesson. Although we did this the last two years and I found it pleasant and you also learn from it. Now madam avoids this directly.
Interviewer:	So you have never had group discussions?
Jonas:	No, never!
Interviewer:	What would you like to discuss?
Jonas:	Really everything.
Interviewer:	About which specific subject matter for example?
Jonas:	Sometimes if you interpreted something differently, that you, for example, heard from another teacher; ‘the sun is yellow because there is pigment in it’. But then Madam says: ‘oh no, the sun is yellow because it is a plasma ball’.
Michael:	Maybe this is something for the professionalisation of STEM-teachers, learning to be open to discussions (laughs)

(FG1)

In FG5, students showed interest in sharing knowledge with other pupils, like in a real learning community, when they were asked what they would change about the iSTEM lessons. Mostly they worked alone or in twos, but they saw it as an advantage to make an appeal to each pupil’s knowledge to find a faster solution for complex problems.

Sarah:	I would involve the class more. Because now we are working mostly in twos, but if these two people don’t get along well and such... I would work with more people at the same time, because if you both don’t understand it.
Interviewer:	You would work with the whole class group?
Sarah	With more people and negotiate more, because together we mostly get to a very good answer, but we don’t do it enough. Everyone has ideas. Everyone paid attention to different aspects and together we would have finally figured out a strategy.

(FG5)

The focus group data reveal that not only the fact that students are considered as a learning community can be important for students’ engagement, but also the fact that the focus and direction of the lesson is consequently regularly determined by ideas originating from the students. An example that occurred during one of the observations in an iSTEM lesson, worded by students in FG6, illustrates this finding well. Respondents in this focus group explained that their iSTEM teacher organised a brainstorm to apply students’ ideas regarding the appropriate material for designing a light box. However, the teacher finally imposed the material, which made the students feel disappointed and emotionally disengaged. At the same time, they shared their enthusiasm for design activities about which they had more control.

Ella: Mostly you don’t get anything out of it [brainstorm/ group discussion].

Tom: Finally you know that it will become sir’s [iSTEM teacher] decision! I said ‘no paper’ for the light box and then finally it became a carton.

Interviewer: So finally you don’t decide how it really becomes?

Tom: Mostly not. The previous semester it was allowed more. Then you had to program and you could choose what to program. If you had got the basics, you could attach sirens and so on. You could choose yourself what to do. That was fun. Now, in contrast, you can’t really experiment yourself. It’s just ‘do that’.

(FG6)

In a few focus groups students also expressed interest and enthusiasm about choosing the topic of a project, based on the interests of the class group.

Communicative interactions

Multilevel analysis showed that communicative interactions were significant for students’ collective engagement. Also the qualitative data illustrate the importance of this scale. Students’ engagement level in FG3 was categorised as ‘low’ for physics, which was an exceptional engagement level across the observational data. When students in this focus group described how their physics lessons mostly occurred, they described this as a very teacher-centred learning environment. The teacher would give his Power Point presentation and students only had to listen. Thus, there was nearly no student talk occurring between and among students. Additionally, they stated that the teacher would not always answer students’ questions or remarks, which indicated that the student-centred principle ‘there was a climate of respect for what others had to say’ was also not applicable in these lessons. Obviously, students mentioned that they were both emotionally and behaviourally disengaged in this learning environment and suggested that they would appreciate more ‘action’ in the classroom.

Matthias: I find physics and chemistry – we get it from the same teacher – really boring. I know I speak for all, if I am saying this.

Interviewer: How do these lessons mostly go?

Matthias: The teacher stands in front, we sit and he is just teaching, continuously talking without a pause. Then it is just your course, everything is filled in so you don’t have to do anything. We look at the blackboard, but yes it is quite hard to pay attention.

Do the others feel the same about it?

Interviewer: Me a bit less, but it depends on what it is about, of course, because some things are

John: more interesting for someone else than for the other. It would be nicer if we could fill in the course a bit ourselves. Then we would catch up faster.

(FG7)

The focus group data illustrate that the student-centred principle ‘students were involved in the communication of their ideas to others using a variety of means and media’ was also of importance for students’ engagement. Most respondents found group work, critiquing or brainstorming engaging activities. Most students valued group work because they found it beneficial to find solutions together or to ask other pupils help in understanding the subject matter.

Student-teacher relationships

The quantitative data revealed that student-teacher relationships were significant for students' collective engagement. Importantly, the qualitative data reveal that it is not only important that the teacher acts as a resource person not telling students what to do and how to do it, but also that students experience enough help. In FG5, students shared their experience about a programming lesson. They stated that they simply had to follow directions, while most students actually did not understand the subject matter. Thus, they were 'active' but not actively thinking and making decisions. On the other hand they experienced a lack of help due to the teacher's high expectations of the STEM class. Those experiences made those students feel frustrated and overwhelmed.

Amélie:	They [iSTEM teachers] just can't explain it. They both can do it well, but they are not used to explaining it all to the letter to us, because we all don't understand it very well yet.
Charlotte:	Programming was hell.
Amélie:	They just said 'go ahead'.
Charlotte:	Yes, programming was just retyping. There was an example and we just had to adjust some small things and further just retype.
	(…)
Kim:	In the 12th grade they have to take the matters in their own hands, but we've just come from the 8th grade where they hold our hand the whole time. We have never had any lessons about it.
Amélie:	All these teachers think that we are amazingly clever.
	Then they say 'I expected more of a STEM-class'. I find that horrible.

(FG5)

In contrast to the experiences of these students, students in FG6, who had a high engagement level in the iSTEM lesson, felt more guided by the iSTEM teacher as he was giving, in their opinion, sufficient hints and regularly made an exercise together with the whole class. This was clearly appreciated by the respondents. The fact that the teacher was giving hints, also indicates that the teacher would actively listen to what students were saying and that he showed patience. The quote below does not only illustrate that the teacher was a 'guide on the side', but that he also considered his class as a learning community where everyone could talk about their ideas.

Interviewer:	What happens when you are stuck solving a hard task during the lesson [iSTEM]?
Thomas:	Then we mostly say it all. The whole group participates and everyone talks about their ideas.
Emma:	Or we ask Sir [iSTEM teacher] and then he helps us, but he never helps us too much. We have to keep finding solutions ourselves.
Aurélie:	Then he shows us a part of it.
Thomas:	Or we look on the internet or in the course.
Interviewer:	You say he always shows a part of how to do it?
Aurélie:	Yes, certain things, if it is really too hard, but he never tells us the solution directly.
Emma:	He gives hints.
Aurélie:	But we will also never have to make an exercise about something we have never made exercises about before. He always shows a few, so that's good.

(FG6)

Discussion

The aim of this study was to investigate how students' engagement occurs in different STEM learning environments by applying a mixed-method approach. As engaging students in STEM is an important need in society, research in diverse contexts, making use of different research methods is needed in order to understand how students' engagement in STEM can be promoted. In this study we focused on how a learning environment applying an iSTEM approach and STEM learning environments' student-centredness can play a role in promoting grade 9 students' collective classroom engagement. Furthermore, we investigated which student-centred principles were most significant and meaningful in this regard.

Students' engagement in different STEM learning environments

Based on the observational data, our results suggested that an iSTEM approach initially has a positive impact on students' collective engagement. Students' average engagement in a learning environment with an iSTEM approach was higher compared to students' engagement in a learning environment with a 'domain-specific' approach. Nevertheless, when we took the STEM learning environment's student-centredness into account in our analysis, the explained variance of the iSTEM approach for students' engagement decreased to a non-significant level, and the effect in the model disappeared. This suggests that the initial significance of iSTEM for students' engagement can be explained by a higher degree of student-centredness in this environment, rather than by the specific integrated nature of the learning environment. The results of the focus group data confirm these findings and illustrate that students who experience the iSTEM learning environment as more student-centred, express more emotional and behavioural engagement. This is in line with previous studies that found students to be more engaged in student-centred STEM learning environments (e.g. Gasiewski et al., 2012; Hampden-Thompson & Bennett, 2013; Wu & Huang, 2007).

While our quantitative data suggest that, when taking student-centeredness into account, the iSTEM approach has no significant impact on students' collective engagement, the results from our qualitative analyses show a different picture. These data suggest that the integration of STEM content and the use of authentic real world problems (problem centred learning) is experienced as engaging for students. Our study shows how this was the case if the (in)direct relevance of the subject matter became clearer for students.

Taking the above results into account, we can conclude that applying an iSTEM approach in the STEM learning environment is good practice to promote students' engagement as it seems to facilitate the teachers' implementation of a general student-centred approach. Considering the need to engage and prepare students in STEM, these results are important as previous research highlighted the significance of students' engagement in STEM for other learning outcomes, such as students' achievement, skill development and academic learning (Bathgate & Schunn, 2017; Reeve, 2012; Skinner et al., 2017). However, we highlight, in line with Nadelson and Seifert (2017), the importance of a good implementation of iSTEM education and teachers' professional mind-set. In this study, we found that it is especially important for students' engagement that teachers apply a student-centred approach within iSTEM and adopt a professional mind-set as 'coach' during instruction. In order to facilitate a good implementation, it is important that schools are aware of teachers' attitudes towards iSTEM, as previous research found that these can influence teacher' instructional practices critically (Thibaut, Knipprath, Dehaene, & Depaepe, 2018). Moreover, previous research indicated that the school context and, in particular, the support, guidance and leadership of school principals are vital if teachers are to make major shifts from a teacher-centred to a student-centred approach (Thibaut et al., 2018b).

Student-centred principles and students' engagement

Regarding the specific student-centred principles, the quantitative results show that the overarching student-centred principle 'lesson plan and implementation' was significant for students' collective engagement. The focus group data illustrate that students generally appreciate this and express emotional engagement when they are considered as a learning community. These findings imply that STEM teachers can promote students' engagement by actively appealing for students' knowledge and ideas by, for example, initiating discussions in the class group about scientific ideas or engineering design. Moreover, we found evidence that it is also important for students' engagement that the focus and direction of the lesson is consequently regularly determined by ideas originating from the students themselves. Teachers can therefore support students' autonomy by providing them with a choice (Stroet, Opdenakker, & Minnaert, 2013) on the learning content and approach. Students in one of the focus groups expressed their emotional engagement about the fact that the teacher provided a (limited) degree of freedom about what could be programmed during one of the iSTEM lessons. Another manner to provide students with choice could be, for example, choosing a project based on the interests of the whole class group.

The overarching student-centred principles 'communicative interactions' and 'student-teacher relationships' were both significant for students' collective engagement. Communicative interactions in the classroom are basically an indicator of how the other student-centred principles are implemented in the learning environment. As the other two principles were significant in this study, it is therefore not surprising that communicative interactions were also found to be important. Regarding the principle 'student-teacher relationships', the qualitative data make clear that is not only important that teachers let initiative come from the students, but that they also need to provide them with enough guidance. In one focus group, for example, all students experienced a lack of help due to the teacher's high expectations of the STEM class. This resulted in emotional disengagement. In contrast, respondents who were engaged experienced enough help as the teacher was giving sufficient hints and would show an example of an exercise when students were completely stuck while solving a problem or exercise. Brush and Saye (2000) found similar results in a study evaluating the implementation of a technology-enhanced student-centred unit. Their results showed that students felt lost or overwhelmed when the teacher did not provide enough structure, by acting as a non-participant observer in the classroom instead of a resource and coach for students. Previous research has already highlighted the need for teachers to provide structure, as this has been found to increase students' feelings of competence, which affects, in turn, students' engagement (Reeve, 2012). In the context of the iSTEM approach, this underlines the importance of a good implementation of the iSTEM key principle 'cooperative learning' (Thibaut et al., 2018a), especially for students for whom a student-centred learning environment includes high degrees of novelty. This principle emphasises teachers' guidance, in contrast to 'collaborative learning', where the teacher will not actively monitor the different student groups and will refer all substantive questions back to the group to resolve (Matthews, 1995; Thibaut et al., 2018a). Along the same lines, Baeten et al. (2013) highlight the importance of gradually moving from a teacher-centred approach to a student-centred approach. Thus, students may adjust their role to the new approach (Baeten et al., 2013). Moreover, this could also be important for teachers who lack experience with student-centred teaching. Their role in a student-centred learning environment as a coach and facilitator, instead of a dispenser of knowledge, becomes more complex. Moreover, our data also suggests that teachers might have difficulties with time-related aspects in a student-centred learning environment, and this, in turn, can have an impact on students' engagement. The next quote gives an impression of the challenge teachers might face, of giving students sufficient freedom to work on their project, but, also, finish the instruction of the provided learning material in time.

Emma:	In the first semester it was all a bit chaotic, because some things seemed to be wrong. But now it is better.
Jessica:	Yes now it's much easier.
Emma:	Yes, the first semester was still a bit searching
	(….)
Jessica:	I did not like the project with the car. We also didn't finish it.
Thomas: (FG6)	Yes sometimes it was wrongly estimated. We got two lesson hours to make a lightbox and finally we worked six or seven lesson hours on it. That lasted a long time.

Strong professionalisation programmes to educate STEM teachers for the complex role of coach and facilitator, are therefore needed. An important aspect to focus on in such professionalisation programme is the challenge of balancing the provision of enough autonomy on the one hand and structure on the other hand.

Study strenghts, limitations and future research

The mixed-method approach, using observational data and focus groups, is an added value in this study. Only a few other studies used a mixed-method approach, including qualitative data, to investigate students' engagement in relation to the STEM learning environment (e.g. Gasiewski et al., 2012). Most studies within science education literature measure students' engagement by making use of self-report questionnaires (e.g. Bathgate & Schunn, 2017; Hampden-Thompson & Bennett, 2013; Skinner et al., 2017; Wu & Huang, 2007). Sinatra et al. (2015) argue that each method to measure engagement in science has strengths and weaknesses. The use of observational protocols has the possibility of observer bias, such as seeing what one is looking for. On the other hand, self-report has the problem of retrospection. Combining observations with focus groups to measure students' engagement was therefore an advantage in this study. By using observations we eliminated retrospection, because the observations were made in 'real time' (Sinatra et al., 2015). On the other hand, the focus group data increased the validity of the observational data. Moreover, they gave more insight into these quantitative data by providing a detailed description on how students' engagement occurs in relation to different STEM learning environments.

A limitation of this study is that engagement was measured at the class group level, which did not allow us to compare students' engagement across different student groups, such as low-achieving and high-achieving students (e.g. Wu & Huang, 2007). Further research, investigating the importance of the iSTEM approach for students' engagement could therefore measure students' engagement at the individual level. Future research can additionally map how different STEM learning environments can have an impact on students' long-term engagement. Moreover, it would be valuable to investigate students' engagement and interactions within different STEM learning environments in a culturally different context, as the cultural context in this study was now bound to the specific schools included in this study and compulsory secondary education in a Flemish context. Furthermore, other studies investigating the significance of iSTEM for students' engagement can study the impact of the different key principles of iSTEM (Thibaut et al., 2018a) for students' engagement, as we focused on iSTEM as a general approach and the overarching student-centred principles.

Conclusion

In conclusion, this study shows that grade 9 students express more behavioural and emotional engagement in STEM learning environments including a higher degree of student-centredness. The main finding is that, applying an integrated STEM (iSTEM) approach is a good practice to promote students' engagement in the STEM learning environment, as it facilitates teachers' implementation of a general student-centred approach. These findings are innovative as, to the best of our knowledge; no other studies investigated which role iSTEM education can play in promoting students' engagement.

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References

Anderson, R. D. (2007). Inquiry as an organizing theme for science curricula. In S.K. Abell, & N.G. Lederman (Eds.), *Handbook of research on science education* (pp. 807-830). New Jersey: Lawrence Erlbaum Associates.

Austin, J. D., Hirstein, J., & Walen, S. (1997). Integrated mathematics interfaced with science. *School Science & Mathematics*, 97(1), 45-49.

Baeten, M., Dochy, F., & Struyven, K. (2013). The effects of different learning environments on students' motivation for learning and their achievement. *British Journal of Educational Psychology*, *83*(3), 484-501.

Bathgate, M., & Schunn, C. (2017). The psychological characteristics of experiences that influence science motivation and content knowledge. *International Journal of Science Education*, *39*(17), 2402-2432.

Binkley, M., Erstad, O., Herman, J., Raizen, S., Ripley, M., Miller-Ricci, M., et al., (2012). Defining twenty-first century skills. In P. Griffin, B. McGaw, & E. Care (Eds.), *Assessment and teaching of 21st century skills* (pp. 17–66). Dordrecht: Springer.

Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology*, 3(2), 77–101.

Brush, T., & Saye, J. (2000). Implementation and evaluation of a student-centered learning unit: A case study. *Educational technology research and development*, *48*(3), 79-100.

Gasiewski, J. A., Eagan, M. K., Garcia, G. A., Hurtado, S., & Chang, M. J. (2012). From gatekeeping to engagement: A multicontextual, mixed method study of student academic engagement in introductory STEM courses. *Research in higher education*, *53*(2), 229-261.

Gutherie, J. T., Wigfield, A., & VonSecker, C. (2000). Effects of integrated instruction on motivation and strategy use in reading. *Journal of Educational Psychology*, *92*(2), 331–341.

Hampden-Thompson, G., & Bennett, J. (2013). Science teaching and learning activities and students' engagement in science. *International Journal of Science Education*, *35*(8), 1325-1343.

Honey, M., Pearson, G., & Schweingruber, H. (Eds.). (2014). *STEM integration in K-12 education: Status, prospects, and an agenda for research.* Washington, DC: National Academies Press.

Hurley, M. (2001). Reviewing integrated science and mathematics: The search for evidence and definitions from new perspectives. *School Science & Mathematics*, 101(5), 259-268.

Knipprath, H., Thibaut, L., Buyse, M. P., Ceuppens, S., De Loof, H., De Meester, J., ... & Deprez, J. (2018). STEM education in Flanders: Literacy and a positive attitude towards STEM. *IEEE Instrumentation & Measurement Magazine, 21*(3), 36–40.

Koul, R. B., Fraser, B. J., Maynard, N., & Tade, M. (2017). Evaluation of engineering and technology activities in primary schools in terms of learning environment, attitudes and understanding. *Learning Environments Research*, 1-16.

Loyens, S. M. M., & Rikers, R. M. J. P. (2011). Instruction based on inquiry. In R. Mayer, & P. Alexander (Eds.), *Handbook of research on learning and instruction* (pp. 361-381). New York: Routledge.

Moore, T. J., & Smith, K. A. (2014). Advancing the State of the Art of STEM Integration. *Journal of STEM Education: Innovations and Research*, *15*(1), 5-10.

Mouratidis, A. A., Vansteenkiste, M., Sideridis, G., & Lens, W. (2011). Vitality and interest–enjoyment as a function of class-to-class variation in need-supportive teaching and pupils' autonomous motivation. *Journal of Educational Psychology*, *103*(2), 353.

Mustafa, N., Ismail, Z., Tasir, Z., Said, M., & Haruzuan, M. N. (2016). A meta-analysis on effective strategies for integrated STEM education. *Advanced Science Letters, 22*(12), 4225-4228.

Nadelson, L.S., & Seifert, A.L. (2017). Integrated STEM defined: Contexts, challenges, and the future. *The Journal of Educational Research, 110*(3), 221-223.

Osborne, J., & Collins, S. (2001). Pupil’s views of the role and value of the science curriculum: A focus-group study. *International Journal of Science Educaton, 23*(5), 441-467.

Pritschet, L., Powell, D., & Horne, Z. (2016). Marginally significant effects as evidence for hypotheses: Changing attitudes over four decades. *Psychological Science*, *27*(7), 1036-1042.

Reeve, J. (2012). A self-determination theory perspective on student engagement. In S. L. Christenson, A. L. Reschly, & C. Wylie (Eds.), *Handbook of research on student engagement* (pp. 149-172). New York, NY: Springer.

Reeve, J., Jang, H., Carrell, D., Jeon, S., & Barch, J. (2004). Enhancing students' engagement by increasing teachers' autonomy support. *Motivation and emotion*, *28*(2), 147-169.

Riskowski, J. L., Todd, C. D., Wee, B., Dark, M., & Harbor, J. (2009). Exploring the effectiveness of an interdisciplinary water resources engineering module in an eighth grade science course. *International Journal of Engineering Education, 25*(1), 181–195.

Salonen, A., Hartikainen-Ahia, A., Hense, J., Scheersoi, A., & Keinonen, T. (2017). Secondary school students’ perceptions of working life skills in science-related careers. *International Journal of Science Education, 39*(10), 1339-1352.

Sanders, M. (2009). STEM, STEM education, STEM mania. *The technology teacher, 68*(4), 20–26

Sawada, D., Piburn, M. D., Judson, E., Turley, J., Falconer, K., Benford, R., et al. (2002). Measuring reform practices in science and mathematics classrooms: The reformed teaching observation protocol. *School science and mathematics, 102*(6), 245-253.

Sawada, D. Piburn, M., Turley, J., Falconer, K., Benford, R., Bloom, I., et al. (2000). *Reformed teaching observation protocol (RTOP) training guide*. (ACEPT Technical Report No. IN00-2). Tempe, AZ: Arizona Collaborative for Excellence in the Preparation of Teachers.

Schmid, S., & Bogner, F. X. (2017). How an inquiry-based classroom lesson intervenes in science efficacy, career-orientation and self-determination. *International Journal of Science Education*, *39*(17), 2342-2360.

Sinatra, G. M., Heddy, B. C. & Lombardi, D. (2015). The challenges of defining and measuring student engagement in science. *Educational Psychologist*, *50*(1), 1–13.

Skinner, E., Furrer, C., Marchand, G., & Kindermann, T. (2008). Engagement and disaffection in the classroom: Part of a larger motivational dynamic? *Journal of Educational Psychology*, *100*(4), 765–781.

Skinner, E., Saxton, E., Currie, C., & Shusterman, G. (2017). A motivational account of the undergraduate experience in science: brief measures of students' self-system appraisals, engagement in coursework, and identity as a scientist. *International Journal of Science Education*, *39*(17), 2433-2459.

Stohlmann, M., Moore, T. J., & Roehrig, G. H. (2012). Considerations for teaching integrated STEM education. *Journal of Pre-College Engineering Education Research*, *2*(1), 28-34.

Stroet, K., Opdenakker, M. C. & Minnaert, A. (2013). Effects of need supportive teaching on early adolescents' motivation and engagement: A review of the literature. *Educational Research Review, 9*, 65–87.

Struyf, A., Boeve-de Pauw, J., & Van Petegem, P. (2017). 'Hard science': a career option for socially and societally interested students? Grade 12 students' vocational interest gap explored. *International Journal of Science Education, 39*(17), 2304-2320.

Struyven, K., Dochy, F., & Janssens, S. (2008). Students' likes and dislikes regarding student-activating and lecture-based educational setting: Consequences for students' perceptions of the learning environment, student learning and performance. *European Journal of Psychology of Education, 23*, 295-317.

Thibaut, L., Ceuppens, S., De Loof, H., De Meester, J., Goovaerts, L., Struyf, A., et al. (2018a). Integrated STEM Education: A Systematic Review of Instructional Practices in Secondary Education. *European Journal of STEM Education*, 3(1), 02. https://doi.org/10.20897/ejsteme/85525

Thibaut, L., Knipprath, H., Dehaene, W., & Depaepe, F. (2018b). The influence of teachers' attitudes and school context on instructional practices in integrated STEM education. *Teaching and Teacher Education*, *71*, 190-205.

Wang, H. H., Moore, T. J., Roehrig, G. H., & Park, M. S. (2011). STEM integration: Teacher perceptions and practice. *Journal of Pre-College Engineering Education Research*, 1(2), 1-13.

World Economic Forum. (2017). *Realizing human potential in the fourth industrial revolution: An agenda for leaders to shape the future of education, gender and work.* Switzerland. http://www3.weforum.org/docs/WEF_EGW_Whitepaper.pdf

Wu, H. K., & Huang, Y. L. (2007). Ninth grade student engagement in teacher centered and student centered technology enhanced learning environments. *Science Education*, *91*(5), 727-749.