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Teacher Professional Development on Self-Determination Theory–Based Design Thinking in STEM Education

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ABSTRACT: Design thinking has become increasingly important in the context of the current movement toward integrated STEM education. Allied teaching practices often take the form of project-based learning, which represents a major shift in the teaching and learning process and poses challenges for many teachers during implementation. Many professional development programmes for STEM teachers focus on the development of teacher beliefs and content or technological knowledge. Teachers may not have enough opportunities to gain sufficient knowledge of how to foster students' intrinsic motivation for project-based learning. The teacher-support dimensions – autonomy, structure and involvement – distinguished in self-determination theory (SDT) can foster student motivation, and the teaching experience can allow for feedback and reflection. Accordingly, this study aimed to investigate how to design a PD programme consisting of a workshop and actual teaching experience as a way of using SDT-based design thinking in teaching STEM project-based learning. Specifically, the study comprised two interventions designed to examine how teacher/student learning is affected by workshops alone and actual teaching experience, respectively. The participants were 60 teachers and 358 secondary school students. The findings revealed that it is beneficial for teachers to apply what they learned from workshops in classroom teaching and that SDT-based design thinking benefits students more than non-SDT-based design thinking. Hence, this study suggests that professional development should occur over a sustained period, enhance teacher capacity to support students' needs, and offer multiple opportunities for feedback and reflection. Consequently, a model of pedagogical design thinking for professional development programmes is proposed.

Keywords: Teacher professional development, STEM education, Self-Determination theory, Motivation, Design thinking

1. Introduction

In the current movement to develop and implement integrated Science, Technology, Engineering and Mathematics (STEM) education, design thinking has become a focus for students to traverse disciplinary boundaries and draw on knowledge from various disciplines to synthesise and apply new knowledge (Henriksen et al., 2020; Li et al., 2019). Many integrated STEM teaching practices implicitly aim to promote design thinking in the form of project-based learning (e.g., Chai et al., 2020; English, 2019). A design-thinking framework that is being increasingly frequently adopted for many STEM education projects is Innovation Design Engineering Organization (IDEO, 2020), which is based on the five stages of empathize, define, ideate, prototype and test. This movement involves a major shift in the teaching and learning process and poses challenges for teachers (Henriksen et al., 2020; Retna, 2016). Many recent professional development (PD) programmes have focused on training teachers to teach STEM in an integrated context (Chai et al., 2020; English, 2019; Honey et al., 2014; Ring et al., 2017). However, many of them have focused on the development of teacher beliefs, content knowledge, new pedagogy, technological skills and curriculum design (Al Salami et al., 2017; Chai, 2019; Chiu & Churchill, 2016; Ring et al., 2017; Thibaut et al., 2018). Teachers, therefore, may not have been provided with enough opportunities to gain sufficient knowledge of how to foster students' intrinsic motivation for design thinking through project-based learning (Kim & Cho, 2014; Ryan & Deci, 2017, 2020). Given that design thinking usually involves students solving ill-defined problems that are complex and cognitively challenging (Johansson-Sköldberg et al., 2013), it seems important for teachers to provide students with adequate support by developing relevant design-thinking competencies, as well as fostering the intrinsic motivation to undertake complex tasks. Although a number of studies have addressed some of the complex issues in the field of STEM education, the specific question of how to adapt motivational theory appropriately to design effective and sustainable pedagogy and learning in an interdisciplinary context is relatively under-investigated (Chiu & Chai, 2020; Li et al., 2019). Moreover, Van Haneghan et al. (2015) reported that some teachers did not possess sufficient confidence to foster intrinsic motivation among students.

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Student motivation and engagement in a prolonged project may go through ups and downs (IDEO, 2020). The students may initially feel excited, but then get demotivated by obstacles such as the inability to consolidate and/or implement ideas in the middle of the journey, at which time they need stimuli to gain energy and confidence to move towards project completion. Teachers play an important role in fostering students' intrinsic motivation (Lam et al., 2009; Lam et al., 2010; Lietaert et al., 2015; Sierens et al., 2009). Self-determination theory (SDT) posits that learning environments should support the individual's innate needs for autonomy, competence and relatedness. Such environments can intrinsically motivate student engagement in activities and enhance performance, persistence and creativity (Ryan & Deci, 2017). In addition, the theory posits that environments that do not support these three psychological needs within a social context will have a detrimental impact on learning. The three dimensions of teacher support identified in SDT for classroom practice – autonomy support, structure and involvement (Lietaert et al., 2015; Roorda et al., 2011) – can be used to motivate and engage students effectively in classroom learning.

In addition, the literature on teacher PD has highlighted another challenge. Without the opportunity to apply teaching ideas and obtain and reflect on feedback, the intended outcomes of PD may not be sufficiently integrated into the teacher repertoire to genuinely change practice (Al Salami et al., 2017; Desimone, 2009; Fore et al., 2015). For example, Fore et al. (2015) highlighted how teacher beliefs filter the information they receive during PD and shape their responses to a new curriculum. Thus, although teachers' knowledge is changed, the knowledge may not be converted into practice. In other words, teacher PD is incomplete if it does not involve the teachers in implementing the newly designed lessons and observing students' changes as feedback for reflective refinement (Chai, 2019). Concomitantly, research on teacher PD should provide evidence of students' changes to ascertain the effects of the PD. There have, however, been relatively few studies that have addressed both teachers' and students' concurrent outcomes from PD.

To address the above challenges, this experimental study compared the perceptual outcomes of two groups of teachers and students who experienced learning to design in the context of STEM education with (SDT) and without (non-SDT) the incorporation of the three teacher-support dimensions. In other words, it is important to note here that three contexts for design were involved in this study. The first was that the teachers attended the workshops designed by the researchers; the second was that the teachers taught the students STEM projects using design thinking; and the third was that the students created artefacts related to the STEM projects.

2. Literature review

In this section, we start by discussing the two challenges of design thinking in integrated STEM education, followed by a discussion of SDT-based teacher support that may help students to negotiate the challenges. We then provide an overview of previous studies on PD programmes for STEM teachers. This section culminates with a discussion of how these factors could be incorporated into the designed intervention to address the two challenges.

2.1. Design thinking in STEM-integrated education

Design thinking is one of the key competencies that students need to develop as an outcome of STEM education (Chai et al., 2020). It refers to the cognitive skills and approaches that designers use to address problems (Cross, 2001). The meaning of design thinking is open to diverse interpretations in different professional fields (Li et al., 2019; Johansson-Sköldberg et al., 2013). For example, it means careful thinking and planning for creativity in business management and can be seen as routine actions for innovation in engineering (Johansson-Sköldberg et al., 2013). Design thinking was popularised by David Kelley, the founder of the IDEO design consulting company and Stanford's d.school in the business and education context (McCullagh, 2010). He advocates for design thinking as a human-centric way to provide a solution-based approach to solving complex problems. It is based on understanding human needs and framing the problems to address those needs by creating many ideas in brainstorming sessions and adopting a hands-on approach to prototyping and testing (Stanford d.school, 2009). This method encourages designers to get to know the users and define their needs through different stages. The user-centeredness inspires designers to present innovative ideas using prototypes. Subsequently, the designers conduct testing to improve the ideas. To apply design thinking in education, Stanford's d.school has further suggested five stages of the design-thinking process for addressing complex and ill-defined design problems. The stages are *empathize*: conduct research to develop an understanding of users' needs; *define*: combine the research and articulate where the users' problems lie; *ideate*: generate a range of creative ideas; *prototype*: build real and tactile representations of selected ideas; *test*: present the prototype to users for feedback. These procedures may be useful for informing teachers and students as to how to go about designing real-world projects and resolving problems (Stanford d.school, 2009).

Design thinking that is usually implemented in a project-based approach can have a significant impact on the curriculum and on instruction (Dym et al., 2005; Li et al., 2019). For example, engineering education has evolved from being largely about engineering solutions and models to including reflective practices that are often characterised by project-based learning (Dym et al., 2005). Mathematics is often perceived as a non-experimental subject, and researchers have advocated including more design activities and project-based learning in mathematics education (Li et al., 2019). Nonetheless, design is a complex and ill-structured task, and student rates of progress may not be consistent. When students are engaged in long-term projects involving design thinking, their commitment may go through ups and downs (IDEO, 2020). For example, the students may initially feel excited, but then get demotivated by obstacles such as the inability to consolidate and/or implement ideas in the middle of the journey, at which time they need support to gain energy and confidence to move towards design resolution. Teachers thus play an important role in fostering intrinsic motivation in students (Lam et al., 2009; Lam et al., 2010; Lietaert et al., 2015; Sierens et al., 2009). Without effective support, students may lack the confidence and skills to complete a project. Thus, one major challenge of conducting a project-based approach is fostering students' persistence and motivation (Lam et al., 2009; Lam et al., 2010). To this end, teacher PD associated with designing STEM projects should include strategies to enhance and maintain students' intrinsic motivation over a prolonged learning time.

Design thinking encourages diverse perspectives in viewing and solving problems, which is vital to creativity and innovation. It has become increasingly important in the current movement to develop and implement integrated STEM education (Honey et al., 2014; Li et al., 2019). The research literature suggests that using design thinking as the main pedagogical method benefits students in learning about STEM. For example, practising design thinking significantly improved academic performance in Physics for female and male students (Simeon et al., 2020). English (2019) reported a longitudinal study of Grade 4 students solving a shoe design problem and found that the students were more aware of the STEM knowledge they needed to use and were able to use the knowledge to make decisions and give explanations. Kelley and Sung (2017) revealed that using a design approach fostered students' computational thinking and significantly improved their science knowledge. Although design thinking seems to enhance students' STEM learning, design problems are ill-structured, cognitively challenging and require multiple forms of knowledge to resolve (Johansson-Sköldberg et al., 2013). The demands on both teachers' and students' knowledge, skills and resilience are high, and thus both teachers and students need support. However, there has been little investigation of how teachers implement these innovative practices to foster design thinking in STEM education (Retna, 2016). There are also, apparently, few studies of whether teachers' efforts to sustain students' motivation for STEM education are successful.

In sum, project-based learning requires teachers to support students' psychological needs to maintain their intrinsic motivation. Teacher PD in integrated STEM project-based learning involving design thinking should pay attention to the question of how to foster students' intrinsic motivation over a period of time.

2.2. Student intrinsic motivation and Self-Determination Theory

Multiple theories of motivation have been developed to account for people's behaviour, including expectancy-value theory (Eccles, 2005), social cognitive theory (Bandura, 1994; Zimmerman, 2000) and SDT (Deci & Ryan, 2017, 2020). The first two theories focus mainly on people's efficacy to learn and achieve their goals as the factors influencing their choices and efforts. SDT, however, focuses on intrinsic motivation directed towards the satisfaction of one's interests or desire for mastery. For the long-term development of students, developing intrinsic motivation is arguably the most important factor in learning.

Enhancing and maintaining students' intrinsic motivation is very important for implementing design thinking. Intrinsic motivation can be explained by SDT, proposed by Deci and Ryan (2017, 2020). This theory aims to explicate the dynamics of human needs and motivation within a social context. It suggests that satisfying individuals' three basic psychological needs – autonomy, competence and relatedness – can foster their intrinsic motivation. Autonomy refers to the desire to self-initiate and self-regulate one's own behaviour; competence refers to the desire to feel effective in attaining valued outcomes; and relatedness refers to the desire to feel connected to others and organisations. This theory is widely applied in educational contexts. Learning environments that support individual experiences of autonomy, competence and relatedness can foster high-quality forms of motivation and engagement for activities, including enhanced performance, persistence and creativity (Ryan & Deci, 2017, 2020).

In line with SDT, teacher practices may be analysed based on the dimensions of autonomy support (autonomy), structure (competence) and involvement (relatedness) (Lietaert et al., 2015; Sierens et al., 2009; Vansteenkiste et al., 2009; Chiu, 2021a; Chiu, 2021b). Autonomy-supportive teachers allow for choices around learning, provide explanations when choice is constrained, avoid the use of controlling language and reduce unnecessary stress and demands on students (Katz & Assor, 2007; Chiu, 2021a, 2021b). Students are encouraged to choose and decide their personal goals based on their self-efficacy and to seek assistance when needed, which helps them to feel empowered in their learning (Chiu, 2021a; Chiu, 2021b). Structure involves the communication of clear expectations with respect to student behaviour (Sierens et al., 2009). Teachers who focus on structure will provide good guidance during lessons (Jang et al., 2010), give competence-relevant feedback (Chiu 2021a; Chiu, 2021b) and assemble effective learning materials for achieving desired outcomes. Involved teachers provide students with emotional and motivational support such as pedagogical caring, involvement closeness, acceptance and help (Chiu, 2021a, 2021b). Such teacher practices make students feel welcome, safe, efficacious and autonomous; they internalise the positive experiences and evince engagement (Ryan & Deci, 2017, 2020).

One of the effective STEM instructional approaches is design thinking, which usually adopts a project-based learning approach (Li et al., 2019). Whereas students need teachers' guidance in STEM learning, teachers need to support and foster students' intrinsic motivation throughout the learning process. Teachers who are capable of intrinsically motivating students in project-based learning are more likely to provide students with integrated experiences (Lietaert et al., 2015; Sierens et al., 2009; Vansteenkiste et al., 2009). Although the teacher-support dimensions have been widely applied to optimise student learning in some other contexts (e.g., Ryan & Deci, 2020; Standage et al., 2005), they have largely been overlooked in project-based learning.

2.3. Teaching experience and teacher professional development programmes

The literature on teacher PD programmes for STEM education has focused on the development of teacher beliefs, self-efficacy, content knowledge, pedagogical content knowledge, technological skills and curriculum design (Al Salami et al., 2017; Chiu, 2017; Chiu & Churchill, 2016; Nadelson et al., 2012; Ring et al., 2017). These programmes aim to prepare teachers to teach STEM in an integrated context by enhancing their science, technology, engineering and/or mathematics subject knowledge, introducing innovative teaching methods for interdisciplinary learning and scaffolding learning outcomes. These STEM-related teacher PD programmes are generally successful in the aforementioned aspects. However, PD for teachers is generally episodic and fragmented and does not afford the time necessary for learning that is rigorous and cumulative (Chai, 2019; Darling-Hammond et al., 2017). A handful of researchers (Chai, 2019; Desimone, 2009) have argued that there is a need to require teachers to apply what they have learned in practice when designing effective teacher PD programmes for integrated STEM teaching.

Accordingly, contemporary programmes should offer opportunities for feedback and reflection and be of sustained duration (Darling-Hammond et al., 2017; Desimone, 2009). Feedback and reflection are powerful tools in designing effective PD because they are critical components of adult learning theory (Thurlings et al., 2013; van Diggelen et al., 2013). Both elements are essential for STEM PD, as STEM teaching methods and content knowledge are likely to be novel to the student. Testing the ideas in classrooms and receiving feedback from the students allows teachers to reflect on their current practice, which is essential for teacher growth. Moreover, meaningful PD requires time and high-quality implementation (Darling-Hammond et al., 2017). Teacher PD programmes should be sustained and offer multiple opportunities for teachers to engage in learning. One-off workshops are more likely to fail if their main goal is to change practice. In sum, effective teacher PD programmes for integrated STEM teaching should carefully consider both student motivation in project-based learning and feedback and reflection on innovative practices.

3. The Present study

As discussed, actual teaching experience affords opportunities for feedback and reflection that enhance teacher competence; the teacher-support dimensions based on SDT can foster students' intrinsic motivation, which is important for project-based learning. This experimental study investigated how to design a PD programme for applying SDT-based design thinking in teaching STEM project-based learning. Specifically, two interventions were conducted to examine how a workshop alone and how actual teaching experience affect teacher/student learning, see Figure 1. There were two groups in each of the interventions. That is, the SDT teacher group received training on design thinking with the three teacher-support dimensions, whereas the non-SDT teacher group received training without the dimensions. The SDT and non-SDT student groups were taught by SDT and non-SDT teacher groups, respectively. Intervention 1 aimed to test the effect of the enhancement of the dimensions given from the workshop on teachers' perceived competence and intrinsic motivation towards design thinking; Intervention 2 was intended to examine whether applying the dimensions in design thinking affected (i) teachers' perceived competence and intrinsic motivation towards design thinking, and (ii) students' perceived competence and intrinsic motivation towards design thinking and cognitive engagement in integrated STEM learning.

Accordingly, the three research questions were as follows:

- RQ1: Will the SDT teacher group perceive stronger gains in their learning about design thinking than the non-SDT teacher group from the workshops? (Intervention 1)
- RQ2: Will the SDT teacher group perceive stronger gains in their learning about design thinking than the non-SDT teacher group after classroom teaching? (Intervention 2)
- RQ3: Will the SDT student group perceive stronger gains in their learning about design thinking and in their integrated STEM learning experiences than the non-SDT students after classroom teaching? (Intervention 2)

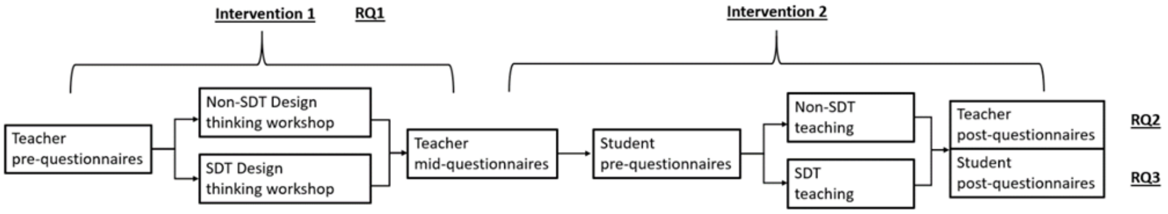

Figure 1. The flow of the interventions in the PD programme

Therefore, we examined three hypotheses:

- (H1) The SDT teacher group will not perceive a significantly stronger sense of competence and intrinsic motivation towards design thinking than the non-SDT teacher group after the workshop (Ring et al., 2017; RQ1);
- (H2) The SDT teacher group will perceive a significantly stronger sense of competence and intrinsic motivation towards design thinking than the non-SDT teacher group after the implementation (Al Salami et al., 2017; Chiu & Churchill, 2016; RQ2); and
- (H3) The SDT student group will perceive a significantly stronger sense of competence and intrinsic motivation towards design thinking, as well as engaging more cognitively in interdisciplinary STEM learning than the non-SDT student group (Chiu, 2021a, 2021b; Chiu & Mok, 2017; Chiu & Lim, 2020; RQ3)

4. Method

4.1. Participants

The participants were 60 teachers and their 358 Secondary Three–level (Grade 9) students from six schools in Hong Kong. The schools were located in different districts and varied in terms of socioeconomic backgrounds and academic standards. The data were collected during a 6-month teacher PD programme. Of the 60 teachers who participated in this study, 60% were male and 40% were female. They were, on average, 33.5 years old (*SD* = 5.4) and had been teaching for an average of 10.5 years (*SD* = 4.8). The student sample was randomly selected and comprised 53% boys and 47% girls. Their mean age was 14.4 years (*SD* = 0.5). The teacher and student participants had not previously taught or learned about design thinking in any subject.

4.2. Procedures

Institutional ethical clearance was followed by participant consent. The study consisted of two interventions – a PD workshop followed by classroom teaching. In Invention 1, the two teacher groups completed an online questionnaire (teacher pre-questionnaire) one week before the workshop and attended four 3-hour PD sessions focused on design thinking over a 2-month period. In the SDT workshop, the roles of three teacher-support dimensions (please see section 2.2 paragraph 3) in design thinking were emphasised, explained and demonstrated, and the teachers explored the SDT pedagogy in STEM teaching. In the first three sessions, a researcher first explained the five stages of design thinking and shared how to teach three STEM topics with design thinking, followed by participant discussions and presentations. In the last session, the researcher discussed with the participants how the three teacher-support dimensions satisfy students' psychological needs in each stage; e.g., avoiding using controlling wordings such as "should or must" to promote autonomy, providing a list of videos that students need for their project, using competence-related feedback to provide a structure that builds students' competence (e.g., advice on what skills and tools are needed for the tasks/ideas) and conducting smaller weekly teacher–student consultation sessions to build relatedness. The teachers created their own support strategies in each stage. In the non-SDT workshops, teacher-support dimensions were not mentioned. We shared and discussed how to use design thinking in teaching STEM in the four sessions. In the last workshop, both groups finished a questionnaire (teacher mid-questionnaire) online. In Intervention 2, the two student groups completed an online questionnaire (student pre-questionnaire) one week before the STEM lessons. The teacher groups applied what they had learned in the workshops to teach their students to take an integrated approach to STEM over 12 weeks. The topic concerned air pollution in Hong Kong. In the final lesson, all of the student and teacher groups finished another online questionnaire (teacher and student post-questionnaire). All of the questionnaires in the interventions were 30 minutes long. All students and teachers were informed that their participation was voluntary and that their answers and identities would remain confidential. They were also informed that their data would be reported collectively and used for research purposes only.

4.3. Instruments

Apart from demographic data, the teacher questionnaire included two variables: perceived competence and intrinsic motivation towards design thinking; the student questionnaire included three variables: perceived competence and intrinsic motivation towards design thinking and cognitive engagement in integrated STEM learning. Each of the variables was measured by five 5-point Likert scale items that had been adapted from previous studies with acceptable reliability and validity (described below). The items were also checked by two experienced teachers to make sure that the wording and language were understandable. Details of the instruments are described below.

Perceived competence toward design thinking was measured using the four items from the perceived competence subscale of the 18-item Intrinsic Motivation Inventory (IMI) (McAuley et al., 1989), with Cronbach's alpha = .80. The items from the competence subscale were: "When I have participated in teaching (for students, teaching is changed to learning) the STEM project, I feel pretty competent with design thinking," "I am pretty skilled at teaching (completing) the STEM project with design thinking," "I am satisfied with my teaching (learning) the STEM project using a design-thinking approach" and "I think I did pretty well at using design thinking in the STEM project." The competence subscale of the IMI showed acceptable reliability with similarly aged groups in a previous study by Standage and colleagues (2005).

Intrinsic motivation towards design thinking was measured using the four items from the perceived competence subscale of the 18-item IMI (McAuley et al., 1989), with Cronbach's alpha = .78. The stem of the items from the intrinsic motivation subscale was modified in this study to ask the question: "When I have participated in teaching (completing) the STEM project." The stem was followed by "because I feel design thinking is fun," "because I enjoy applying design thinking," "because I would describe design thinking as very interesting" and "because design thinking was fun to use." The intrinsic motivation subscale of the IMI showed acceptable reliability with similarly aged groups in two previous studies by Chiu et al. (2020), Chiu and Mok (2017) and Standage and colleagues (2005).

Cognitive engagement was measured using four items adapted from a study by Wang and colleagues (2016), with Cronbach's alpha = .75. They validated and verified items to measure middle and high school students' cognitive engagement in science and mathematics. These items were relevant to our participants and subject domains. For example, "I go through the work for integrated STEM learning and make sure that it's right," "I think about different subjects (science, technology, engineering and mathematics) to solve a problem," "I try to connect what I am learning to things I have learned before" and "I try to understand my mistakes when I get something wrong."

4.4. Research analytic approach

Analysis of covariance (ANCOVA) was used in two observations analyses when assessing the differences in the post-observation means after accounting for the pre-observation values (Bonate, 2000; Chiu & Churchill, 2015). Therefore, we used ANCOVA to analyse the questionnaires to answer the three research questions.

5. Results

5.1. Descriptive statistics

Table 1 presents the descriptive statistics and Cronbach's alpha coefficients (Cronbach, 1951) for all variables. As indicated, the alpha coefficients ranged from .81 to .96, and thus the variables can be considered internally reliable based on the $\alpha = .70$ criterion.

Table 1. Descriptive statistics

Teacher ($N = 60$)	Pre-questionnaire			Mid-questionnaire			Post-questionnaire		
Variables	Mean	*SD*	Cronbach's alpha	Mean	*SD*	Cronbach's alpha	Mean	*SD*	Cronbach's alpha
Perceived competence	3.27	0.44	.82	4.20	0.46	.81	4.17	0.61	.95
Intrinsic motivation	3.37	.47	.94	4.16	.53	.85	4.19	.65	.96

Student ($N = 358$)	Pre-questionnaire			Post-questionnaire		
	Mean	*SD*	Cronbach's alpha	Mean	*SD*	Cronbach's alpha
Perceived competence	3.17	0.43	.90	4.09	0.52	.84
Intrinsic motivation	3.19	0.42	.83	4.14	0.52	.81
Cognitive engagement	3.23	0.42	.84	3.90	0.65	.92

5.2. Analyses of covariance (ANCOVA)

Table 2 shows the ANCOVA results. The analysis of homogeneity of the regression slope showed that (i) the two teacher groups did not differ in perceived competence, $F(1, 56) = 0.16$, $p = .70$, or intrinsic motivation, $F(1, 56) = 1.92$, $p = .17$, on the mid-questionnaire with the pre-questionnaire entered as a covariate; (ii) the two teacher groups did not differ in perceived competence, $F(1, 56) = 2.28$, $p = .14$, or intrinsic motivation, $F(1, 56) = 0.86$, $p = .36$, on the post-questionnaire with the mid-questionnaire entered as a covariate; and (iii) the two student groups did not differ in perceived competence, $F(1, 354) = 0.19$, $p = .17$, intrinsic motivation, $F(1, 354) = 0.55$, $p = .46$, or cognitive engagement, $F(1, 354) = 2.62$, $p = .11$, on the mid-questionnaire with the pre-questionnaire entered as a covariate. These results confirm the homogeneity the data. Next ANCOVAs were conducted to analyse the post-treatment questionnaire scores by excluding the effect of their pre-treatment questionnaire scores.

RQ1 (H1): For the dependent variable perceived competence, there was no significant difference in the mid-questionnaire scores between the SDT ($M = 4.18$, $SD = 0.47$) and non-SDT ($M = 4.23$, $SD = 0.45$) teacher groups, $F(1, 57) = 0.58$, $p = .45$, with a small effect size $\eta^2 = 0.01$. For the dependent variable intrinsic motivation, there was no significant difference in the mid-questionnaire scores between the SDT ($M = 4.25$, $SD = 0.44$) and non-SDT ($M = 4.08$, $SD = 0.60$) teacher groups, $F(1, 57) = 1.66$, $p = .20$, with a small effect size, $\eta^2 = 0.03$.

RQ2 (H2): For the dependent variable perceived competence, the post-questionnaire scores of the SDT teacher group ($M = 4.19$, $SD = 0.49$) were significantly higher than those of the non-SDT teacher group ($M = 3.82$, $SD = 0.57$), $F(1, 57) = 27.51$, $p < .001$, with a large effect size, $\eta^2 =0.33$. For the dependent variable intrinsic motivation, the post-questionnaire scores of the SDT teacher group ($M = 4.57$, $SD = 0.49$) were significantly higher than those of the non-SDT teacher group ($M = 3.82$, $SD = 0.57$), $F(1, 57) = 30.54$, $p < .001$, with a large effect size, $\eta^2 =0.35$.

RQ3 (H3): For the dependent variable perceived competence, the post-questionnaire scores of the SDT student group ($M = 4.36$, $SD = 0.43$) were significantly higher than those of the non-SDT student group ($M = 3.83$, $SD = 0.48$), $F(1, 355) = 259.25$, $p < .001$, with a large effect size, $\eta^2 = 0.42$. For the dependent variable intrinsic motivation (H2), the post-questionnaire scores of the SDT student group ($M = 4.35$, $SD = 0.44$) were significantly higher than those of the non-SDT student group ($M = 3.93$, $SD = 0.52$), $F(1, 355) = 135.69$, $p < .001$, with a large effect size, $\eta^2 = 0.28$. For the dependent variable cognitive engagement (H3), the post-questionnaire scores of the SDT student group ($M = 4.27$, $SD = 0.58$) were significantly higher than those of the non-SDT group ($M = 3.53$, $SD = 0.49$), $F(1, 355) = 221.62$, $p < .001$, with a large effect size, $\eta^2 = 0.38$.

We concluded that including teacher-support dimensions in the teacher PD workshop had no significant effect on teachers' perceived competence or intrinsic motivation towards design thinking, and that classroom teaching had an impact on both teachers' and students' perceived competence and intrinsic motivation towards design thinking, and students' integrated STEM learning experience.

Table 2. ANCOVA results of the teacher and student questionnaires

Variable	Group	*N*	Mean	*SD*	*F*	$\cdot \eta^2$
Teacher (dependent variables: mid-questionnaire; covariate: pre-questionnaire)						
Perceived competence	SDT	30	4.18	0.47	0.58	0.45
	Non-SDT	30	4.23	0.45		
Intrinsic motivation	SDT	30	4.25	0.44	1.66	0.03
	Non-SDT	30	4.08	0.60		
Teacher (dependent variables: post-questionnaire; covariate: mid-questionnaire)						
Perceived competence	SDT	30	4.19	0.49	27.51^{***}	0.33
	Non-SDT	30	3.82	0.57		
Intrinsic motivation	SDT	30	4.57	0.49	30.54^{***}	0.35
	Non-SDT	30	3.82	0.57		
Student (dependent variables: pre-questionnaire; covariate: post-questionnaire)						
Perceived competence	SDT	178	4.36	0.43	259.25^{***}	0.42
	Non-SDT	180	3.83	0.48		
Intrinsic motivation	SDT	178	4.35	0.44	135.69^{***}	0.28
	Non-SDT	180	3.93	0.52		
Cognitive engagement	SDT	178	4.27	0.58	221.62^{***}	0.38
	Non-SDT	180	3.53	0.49		

Note. $^{*} p < .05$; $^{**} p < .01$; $^{***}p < .001$.

6. Discussion

The main goal of this study was to investigate how incorporating the three teacher-support dimensions in a STEM teacher PD programme about design thinking affects teacher learning and to determine its implementations for teacher and student learning. The findings afford three major empirical implications and make one theoretical contribution. We offer three practical suggestions for teacher PD programmes.

6.1. Empirical implication

The first implication is that the workshops alone did not result in significant differences among the SDT and non-SDT groups with regard to the participants' perceived competence or intrinsic motivation for SDT-based design thinking (H1). This is not surprising, as such differences move beyond influences on declarative knowledge (Chai, 2019). Insignificant differences may only be evident after teachers have been able to test the ideas in the classroom (Al Salami et al., 2017). This is discussed next for the second implication.

The second implication, as hypothesised in H2, was that after applying what they learned from the workshops in classroom teaching, the SDT group perceived themselves as having a significantly stronger sense of competence and intrinsic motivation towards design thinking than the non-SDT group. This implies that the application of the dimensions boosted the SDT teachers' perceived competence and intrinsic motivation towards design thinking in STEM project-based learning, whereas the non-SDT teachers may not have been able to support project-based learning effectively. These results are aligned with the teacher training research that highlights the importance of teaching experience and practice in changing teacher self-efficacy and attitude. Implementation through experiential teaching is fundamental in preparing teachers to accept new pedagogies (Darling-Hammond et al., 2017; Fore et al., 2015). A plausible explanation for these findings is that while both groups facilitated design thinking, the attention towards the motivational factors may have created a qualitatively different experience for teachers and students. As the teachers in the SDT group were more involved with the students, they would have had a more direct understanding of the students' progress. As they encouraged students' autonomy and provided them with structure, the students were more likely to have been motivated and performed better, which is reflected in the next implication. Significant changes in teachers' perceived design capacity for the motivational design of STEM projects became prominent with a strong effect after actual classroom teaching.

The final implication is that the students in the SDT group reported perceiving themselves as having a stronger sense of competence and intrinsic motivation towards design thinking, and were significantly more cognitively engaged in STEM project-based learning than the non-SDT group (H3). These results align with studies of satisfying autonomy, competence and relatedness needs for intrinsically motivating student engagement (Ryan & Deci, 2017, 2020; Lietaert et al., 2015; Roorda et al., 2011). This intrinsic motivation is very important in activities that involve learning over a period of time, such as during project-based learning. It is essential to build students' efficacy and competence through a structured environment with teachers' encouragement. Educationally, these are the types of experiences that teachers need to foster through their instructional design for project-based learning. Therefore, the teacher-support dimensions play a very important role in learning, particularly over a longer period of time (Ryan & Deci, 2017, 2020; Vansteenkiste et al., 2009).

6.2. Theoretical contribution

The theoretical contribution of this study lies in enriching the literature on STEM education by connecting it with the well-established SDT framework. The findings demonstrate that attending explicitly to autonomy support, structure and involvement during the PD programme is a required dimension for STEM project-based learning. It is thus desirable for future theorisation of STEM education to consider SDT as a foundation for the motivational design of STEM education (Ryan & Deci, 2017, 2020).

As the findings suggest the importance of supporting motivation in design thinking, we propose a framework for pedagogical design thinking to guide teachers to facilitate students' motivational disposition towards design thinking, as shown in Figure 2. Gaining knowledge of design thinking is different from nurturing a design-thinking mindset (H3). School students need inputs from teachers to change how they think about problem-solving over a sustained period. Therefore, we propose to pedagogise design thinking by emphasising that teachers need support. To successfully nurture a design-thinking mindset in students, teachers need to satisfy students' psychological needs – autonomy, competence and relatedness – if students' knowledge of design thinking is to be transformed into a design-thinking mindset. Instead of routinising STEM learning by getting students to complete tasks and create products, teachers should consider applying motivational design to promote intrinsic motivation. In other words, instead of reducing ill-defined design problems to a set of well-defined classroom procedures, teachers should support students in handling the uncertainties through providing choices, resources and possible directions and discussing the alternatives with students. This is crucial to help students to build design dispositions beyond knowledge acquisition.

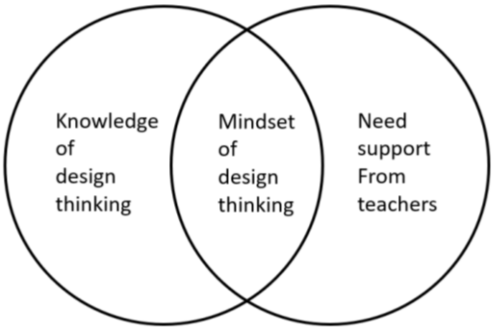

Figure 2. A framework for pedagogical design thinking

6.3. Practical suggestion

This study offers three practical suggestions for teacher PD programmes to enhance teachers' capacity to teach integrated STEM. The first suggestion is that programmes should incorporate time for feedback and reflection (H2 and H3; Darling-Hammond et al., 2017). The programme designers and providers should use co-design, classroom visits and coaching for feedback and reflection, which are critical components of adult learning theory (Thurlings et al., 2013; van Diggelen et al., 2013). They should provide intentional time for teachers to think about, receive input on, and make changes to their new and developing practice.

The second suggestion is that meaningful PD programmes require time for implementation (Darling-Hammond et al., 2017). One-off workshops are more likely to fail if their main purpose is to change practice. Therefore, we suggest that programmes should be held over a sustained period, offering multiple opportunities for teachers to engage in learning a set of concepts or practices in design thinking. Teachers will thus be more likely to transform their teaching practices and student learning (H2 and H3).

Mastering pedagogical practices that facilitate design thinking is crucial to creating positive and empowering learning experiences for students. Because design thinking is often implemented in a project-based approach, enhancing and maintaining students' intrinsic motivation is very important (Lam et al., 2009). In our final practical suggestion, we propose that teacher PD programmes should include teacher-support dimensions – autonomy support, structure and involvement – in design thinking, as shown in Figure 3. It is suggested that teachers develop autonomy support in the first two stages – empathize and define – because students should feel they have the choice to identify problems that are relevant and interesting to them. Teachers are advised to pay attention to structure in the last three stages – ideate, prototype and test. Students need feedback to revise their ideas for feasibility because they may be too abstract or challenging. Teachers should be involved in all stages because students' learning is not just their own responsibility but also that of their teachers.

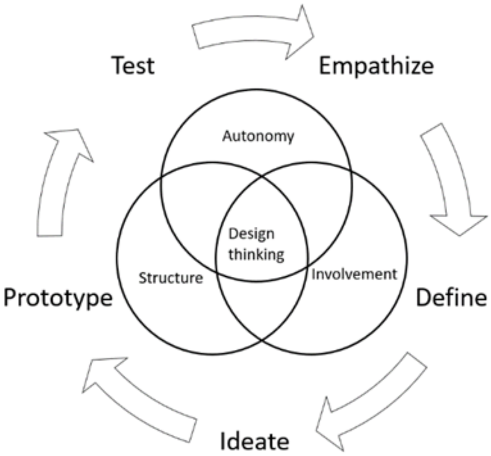

Figure 3. Pedagogical design thinking

7. Conclusion

This study has demonstrated that the integration of SDT elements in STEM education promotes perceived competence and intrinsic motivation towards design thinking. When teachers implement autonomy-supporting strategies, provide enriching structures and relate to students through involvement in group consultations, both students and teachers achieve substantial development. There are two suggested future directions: teacher education and design thinking. First, students' intrinsic motivation over a period of learning time and teaching experience for feedback and reflection should be the focus of teacher PD programmes that aim to change practice (Darling-Hammond et al., 2017). Second, our findings suggest that design thinking, allied with teacher support, could be a viable way to positively foster students' STEM-integrated learning experience.

8. Limitation

Four limitations of this study are noted here. First, while this study appears to support the effects of the teacher-support dimensions on teachers' and students' perceived competence and intrinsic motivation, more studies are needed to validate these findings. The results of the present interventions could be extended by additional studies of other teacher-support strategies (Ryan & Deci, 2017, 2020; Standage et al., 2005). Second, this study did not differentiate between or scrutinise the underlying effect of each stage of the design-thinking process (Stanford d.school, 2009), and future research should be conducted to investigate how teachers support students in each stage. Third, just one cycle of classroom teaching was adopted in this paper, and so the full effects of feedback and reflection may not have been revealed; future studies should adopt iterative cycles. The final limitation is that only intrinsic motivation was used in the interventions, which did not distinguish between different types of motivation. Future studies could adopt questions from the study by Zycinska and Januszek (2019) to measure the self-determination continuum to gain more insights.

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