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Digital support for student engagement in blended learning based on self-determination theory☆

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A R T I C L E I N F O

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A B S T R A C T

Student engagement in a blended learning environment is very different from that in a traditional classroom environment, and is fostered by satisfying three innate needs identified in self-determination theory (SDT): autonomy, relatedness, and competence. Related studies have emphasized teacher support to satisfy the three students' need, but not digital support. The founders of SDT recently stated that SDT-based research should focus on problems associated with learning technologies. Accordingly, this study proposed digital support designs to fulfill the three abovementioned needs, examined their effectiveness, and investigated how the developed forms of digital support and teacher support contributed to student engagement. The study adopted a sequential explanatory mixed methods research design and involved 426 Grade 11 students. The findings were as follows. (i) Compared with teacher support, digital support better engaged students in blended learning by satisfying their needs. (ii) Teacher support was closely related to student engagement. (iii) The relationship between digital support and student engagement varied. Possible explanations are the benefits of offering multiple modalities, considering learning expertise, and applying emotional designs. The findings contribute to SDT by adding a new perspective, namely digital support, and thereby proposing a new framework for needs support in blended learning.

Blended learning is the thoughtful fusion of face-to-face and online learning experiences (Garrison & Vaughan, 2008). It integrates technology and online learning materials with traditional face-to-face classroom activities. Despite involving both teachers and students, it requires students some control over learning time, place, path, or pace in technological environments (Garrison & Vaughan, 2008). Building strong student engagement in both face-to-face and technological environments is critical for the delivery of effective blended learning, because student engagement is a prerequisite for successful learning (Lam et al., 2018). However, the means of fostering student engagement in the two environments are very different, and sustaining student engagement in learning with technology is challenging (Henrie et al., 2015). Accordingly, student engagement has become an important topic of research on blended learning and learning technologies (Bergdahl et al., 2020; Ryan & Deci, 2020).

Student engagement is energized by motivation (Reeve, 2013) and fostered by various contextual factors (e.g., teacher, peer, and environmental support) (Fredricks, 2011; Lam et al., 2012), as explained by self-determination theory (SDT; Ryan & Deci, 2017, 2020). The theoretical framework of SDT postulates that individuals are motivated to grow and change by fulfilling three innate psychological needs: the need for autonomy (feeling self-endorsed and self-governed), the need for relatedness (feeling loved and connected), and the need for competence (feeling effective and capable). During a learning task, these three innate needs must be satisfied to ensure students' motivation (Chiu, 2021a, 2021b). Accordingly, to support student engagement, technological learning environments should be designed to fulfill these three needs. SDT has been widely applied to motivate engagement and optimize student learning with a focus on teacher–student interaction (particularly teacher support), because teachers play an important role in supporting students' learning needs in schools (Allen et al., 2013; Chiu 2021a, 2021b; Roorda et al., 2011). SDT identifies three teacher support dimensions of classroom practice in both face-to-face and technological environments: autonomy, involvement (relatedness), and

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structure (competence) (Bedenlier et al., 2020; Chiu 2021a, 2021b; Roorda et al., 2011). However, how technological design supports the fulfillment of these three needs has largely been overlooked. Indeed, Ryan and Deci (2020), the founders of SDT, recently suggested that future SDT research should focus on the design of learning technology to motivate engagement and learning. Responding to this call, this study proposed a set of technological learning environment designs, referred to here as *digit*al support designs, to support the innate needs identified in SDT. The study also examined whether the proposed digital support better engaged students in blended learning than teacher support did, and investigated how different types of digital support related to student engagement.

1. Theoretical framework

1.1. Four types of student engagement

Student engagement refers to the degree of attention, effort, participation curiosity, interest, and passion shown by students when they are learning or being taught (Reschly & Christenson, 2012). It relates to students' investment in learning and commitment to achieving learning goals (Marks, 2000) and their persistence in and satisfaction with learning (Fredricks et al., 2004). It predicts how well students will learn in terms of academic achievement and well-being (Christenson et al., 2012) and affords teachers the opportunity to receive regular feedback for designing more effective instruction (Reeve, 2013). Student engagement is a multi-dimensional concept generally considered to include behavioral, emotional, cognitive, and agentic components (Chiu, 2021a, 2021b; Fredricks, 2011; Reeve, 2013).

Behavioral engagement refers to students' participation and involvement in learning activities inside and outside the classroom (Fredricks et al., 2004). Students show greater behavioral engagement when they are proactive in pursuing learning opportunities and take responsibility for their own learning. Emotional engagement comprises students' affective reactions to their classmates, teachers, learning activities, and school, especially discrete emotions such as happiness, excitement, boredom, and anxiety (Fredricks et al., 2004). Students with high levels of emotional engagement feel at home, safe, and interested. Cognitive engagement is defined in terms of students' mental effort to complete tasks using a deep, self-regulated, and strategic approach to learning, rather than superficial learning strategies (Chiu, 2021a). Students with greater cognitive engagement are interested in learning about and exploring the tasks being taught and see the purpose of learning activities. Agentic engagement refers to proactive efforts to constructively contribute to learning and teaching (Reeve, 2013; Reeve & Tseng, 2011). Students with greater agentic engagement seek to express to their teachers what they need for learning. These four dimensions are intercorrelated but operationalized and conceptualized as distinct (Christenson et al., 2012; Reeve, 2013; Chiu 2021a, 2021b). Behavioral, emotional, cognitive and agentic engagement are energized by intrinsic motivation, understood as a prerequisite for students to engage in learning (Reeve, 2013); therefore, they can be explained by SDT (Losier et al., 2001; Ryan & Deci, 2017, 2020).

1.1.1. SDT on student engagement

SDT as a theory of motivation systematically explicates the dynamics of human needs, motivation, and well-being within a social and cultural context (Ryan & Deci, 2017, 2020). This theory suggests that all individuals have three innate needs: the need for autonomy (feeling in control of our own behaviors and goals), the need for relatedness (interacting with, being connected to, and caring for others or activities), and the need for competence (feeling capable, effective, and challenged by tasks). Individuals have greater motivation and engagement in activities when their needs are better supported and satisfied, i.e., moving their motivational orientation from amotivation to extrinsic motivation to intrinsic motivation (Ryan & Deci, 2017, 2020).

SDT-based research has assessed the four dimensions of engagement (Reeve, 2013; Skinner et al., 2009; Vansteenkiste et al., 2005). Skinner et al. (2009) revealed that intrinsic motivation fostered behavioral and emotional engagement. Vansteenkiste et al. (2005) showed that intrinsic motivation led to sophisticated, rather than superficial, learning (cognitive engagement). Reeve (2013) showed that intrinsic motivation enhanced agentic engagement, but did not investigate this aspect extensively. Accordingly, it seems that satisfying the three needs identified by SDT can contribute to the four types of student engagement. In schools, teachers can support student engagement by satisfying their need for autonomy, relatedness, and competence in classrooms and virtual learning environments (Bedenlier et al., 2020; Chiu 2021a, 2021b; Lietaert et al., 2015; Vansteenkiste et al., 2009; Vollet et al., 2017).

1.2. Teacher and digital support as factors explaining student engagement in blended learning

Student engagement in blended learning is influenced by various factors, such as teacher and digital support (Bombaerts & Nickel, 2017, pp. 1089–1092; Chiu, 2021a; Chiu & Hew 2017). Teacher support plays a critical role in motivating student engagement in school. Teachers can accomplish this by endorsing positive learning behavior, providing appropriate resources for learning, and becoming interpersonally involved (Lietaert et al., 2015). Echoing this, SDT-based research has suggested three teacher support dimensions: autonomy, structure (competence), and involvement (relatedness) (Lietaert et al., 2015; Vansteenkiste et al., 2009; Vollet et al., 2017). These dimensions have been applied in different learning environments, such as classrooms, playgrounds, online discussion forums, distance learning, and massive open online courses (Bedenlier et al., 2020; Hartnett, 2015; Chiu et al., 2021; Vansteenkiste et al., 2009; Xie et al., 2006, 2011, p. 2011). Autonomy-supportive teachers facilitate rapport by identifying and nurturing students' needs, interests, and preferences and creating learning opportunities in which these needs, interests, and preferences guide students' behavior (Reeve et al., 2004). For example, teachers can give students choices in terms of learning in an online discussion forum (Xie et al., 2006), allow for self-paced learning, and avoid setting deadlines for online learning tasks (Alamri et al., 2020). With teachers' autonomy support, students are more attentive and show better time management (behavioral engagement; Vansteenkiste et al., 2005), enjoy their lessons more (emotional engagement; Skinner et al., 2008), and better communicate their learning agenda to teachers (agentic engagement; Reeve, 2013). Autonomy allows students more scope and freedom to choose their learning goals, which might result in more cognitive engagement. However, this has not been examined extensively (Bedenlier et al., 2020). Relatedness-supportive teachers provide students with emotional and motivational support, such as involvement, closeness, caring, assistance, and approval (Vollet et al., 2017), by, for example, encouraging interaction between course participants and adopting a warm, friendly approach in online course communications (Bombaerts & Nickel, 2017, pp. 1089–1092; Chiu, 2021a) With teachers' relatedness support, students who have good relationships with teachers feel connected to course activity participation (behavioral engagement), find lesson activities more positive (emotional engagement), are confident in completing challenging tasks (cognitive engagement), and feel comfortable speaking up regarding their learning needs (agentic engagement) (Furrer & Skinner, 2003; Reeve, 2013; Ruzek et al., 2016; Vollet et al., 2017). Competence-supportive teachers communicate clear expectations to students in online learning (Lietaert et al., 2015) by, for example, providing supportive information and clear task expectations, positive and constructive feedback, and unexpected rewards (Chiu, 2021a; Chiu & Hew, 2018). They also tend to use a scaffolding approach to apply technology in teaching (Chiu & Lim, 2020). Under teachers' relatedness support, students feel competent and challenged during learning (cognitive engagement; Skinner et al., 2008), which encourages them to actively participate in lesson activities (behavioral engagement; Reeve, 2013) and, subsequently, to feel positively about the lesson (emotional engagement; Reeve, 2013). Some studies have investigated the relationship between competence support and agentic engagement (Reeve, 2013), but not systematically. In sum, teachers who can satisfy the three needs identified in SDT are more likely to behaviorally, emotionally, cognitively, and agentically engage students in blended learning. However, such teacher support relies on teacher delivery and execution. Very few SDT-based studies have considered non-teacher support, such as digital support, and its role in motivating student engagement.

Digital support here refers to the design of technological learning environments to support students' innate needs. Digital autonomy support can be designed to use multiple modalities (Schnotz & Bannert, 2003). Presenting learning content in multiple modalities is advantageous for students, as it encourages them to actively process such content (Chiu & Churchill, 2015; Schnotz & Bannert, 2003); offering just one modality is less encouraging and stimulating. In environments with multiple resources (modalities), students are free to choose their preferred resources to learn with. Offering only one resource is likely to restrict student choices by encouraging the false assumption that this resource is the key to and covers all the learning content. Moreover, digital relatedness support can use an emotional design (Chiu et al., 2020; Mayer & Estrella, 2014; Park et al., 2015), which uses appealing and interesting design features to invoke learner emotions and facilitate learning in technological environments (Mayer & Estrella, 2014; Park et al., 2015). By creating an enjoyable experience, emotional design can motivate students to exert more effort in processing multimedia information (Knörzer et al., 2016; Mayer & Estrella, 2014). Digital competence support should also consider learner expertise (Chiu et al., 2021; Chiu & Lim, 2020; Chiu & Mok, 2017; Kalyuga, 2014). It is necessary to understand how different instructional formats support different levels of student expertise for different orders of thinking skills in technological learning environments, particularly in multimedia. For example, scaffolding designs such as level-up exercises can offer students clear expectations of lesson activities and flexible learning pathways in technological environments (Chiu, 2021a).

1.3. Research gaps

As discussed, SDT has been widely applied to motivate student engagement in both face-to-face and technological environments (e.g., Ruzzek et al., 2016; Ryan & Deci, 2017, 2020; Standage et al., 2005). However, related studies have emphasized the need for teacher execution and delivery (i.e., teacher support) to satisfy students' need for autonomy, competence, and relatedness; very few SDT studies have investigated how to design technological environments. The process by which a technological design (i.e., digital support) satisfies students' psychological needs to foster student engagement has been seriously understudied. Ryan and Deci (2020) recently stated that current SDT-based research should further consider the promise and problems associated with learning with technology. They also suggested that more SDT-based studies are needed to understand how technology itself can support the need for better motivation, resulting in better engagement and learning.

2. The present study

Student engagement can be fostered through technological design as well as teacher support. Therefore, this study proposed the following digital support designs to satisfy the three innate needs identified by SDT, i.e., perceived learning support from a learning management system (LMS).

- Autonomy: offer and recommend various digital resources for the same learning unit while indicating their relevance to students, e.g., videos, text-based notes, slides, and URLs (Chiu, 2021a)
- Relatedness: use personal and emotional designs for LMS design and communications to promote a positive atmosphere (Chiu, 2021a; Chiu et al., 2020), e.g., uploaded pictures of class members, face-shaped designs
- Competence: offer five level-up exercises and well-designed interactive learning materials in a cognitively demanding technological learning environment, e.g., levels 1 and 5 indicate basic and most advanced exercises (Hong Kong public examination results use five levels); apply multimedia learning principles to the design of digital materials (Chiu et al., 2020; Chiu & & Churchill, 2015; Chiu & Chai, 2020) (see Fig. 1)

This study aimed to (i) examine how well the proposed digital support satisfied the students' needs and motivated engagement, (ii) examine how perceived teacher and digital support related to the four dimensions of student engagement (see Fig. 2), and (iii) investigate which features in the proposed digital support motivated student engagement. Hence, the three research questions were as follows:

RQ1. Does the proposed digital support (compared with teacher support) better meet students' perceived needs and promote their engagement?

RQ2. To what extent does the perceived teacher and digital support predict the four types of student engagement?

RQ3. Which features of the proposed digital support impact student engagement?

Accordingly, the following research hypotheses were proposed.

- H1 (RQ1): Students with digital support will report significantly greater perceived needs support and greater engagement than those without.
- H2 (RQ2): Perceived teacher support will have significant positive effects on the four dimensions of student engagement.
- H3 (RQ2): Perceived digital support will have significant positive effects on the four dimensions of student engagement.

3. Method

3.1. Participants

This study was part of a partnership project that aimed to enrich teacher knowledge of blended learning. It the project, the teachers and schools used blended learning as main instructional approach. The participants were 426 Grade 11 students and four teachers drawn from four Hong Kong high schools with similar academic performance standards. The schools are from middle banding of student academic achievement (Remark: secondary schools in Hong Kong are categorized into three bandings based on student academic achievement). There were approximately 100 students and one teacher from each school. The teachers had an average of 10 years' teaching experience. The students ranged in age from 16 to 18 years (52% female, 48% male). Moreover, the result of A-priori Sample Size Calculator for Structural Equation Models (Soper, 2020) recommended minimum sample size for RQ2 is 200 when the numbers of latent and observed variables are 10 and 30, respectively, and the power level = 0.8. Therefore, the sample size was good for this study.

3.2. Research design and procedure

This case study adopted a sequential explanatory mixed method, and quasi-experimental design with deductive reasoning. The quantitative

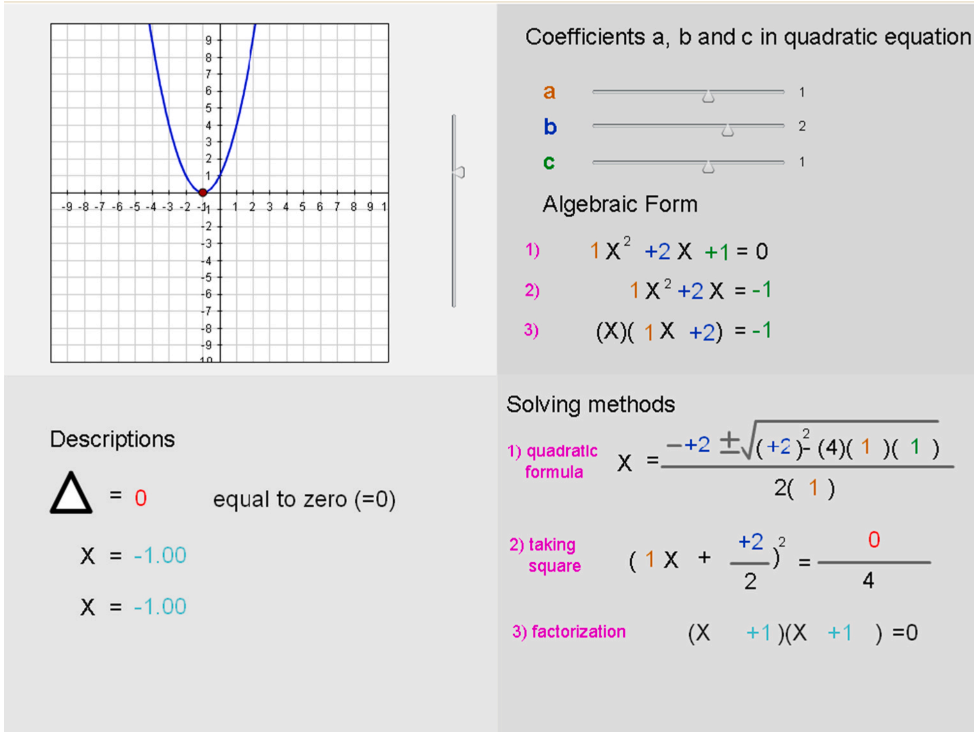


Fig. 1. Sample of Interactive learning material (adapted from Author, 2015).

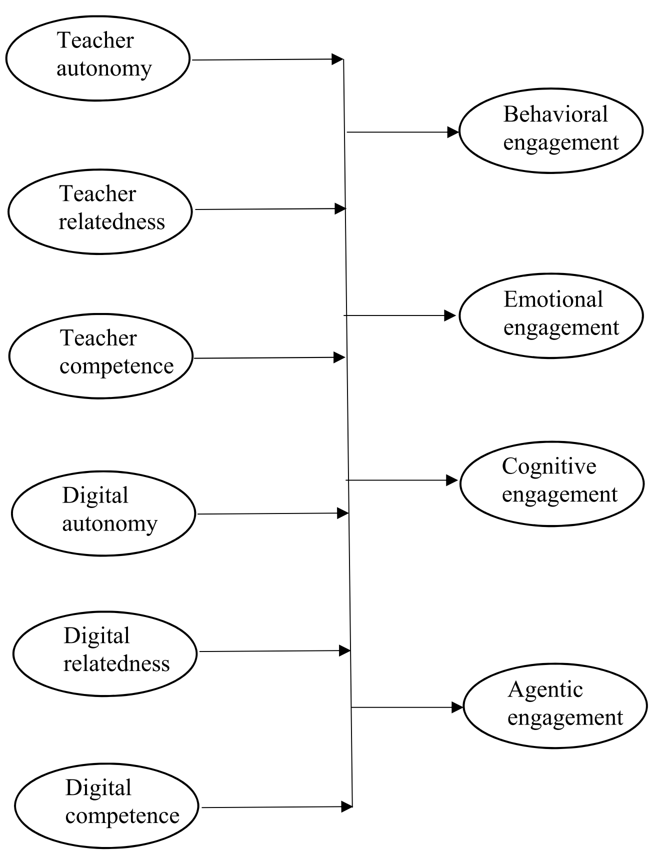


Fig. 2. The research model in this study.

method in the first stage yielded the objective statistical findings (RQ1-2) of the experiment. The two experimental conditions were digital support and a control. The control involved no digital support, i.e., only one resource for the learning unit and level 5 exercises were uploaded to the LMS, and no interactive learning materials or personal/emotional designs were provided or adopted. In the second stage, semi-structured interviews were used to discover the participants' subjective responses and explain phenomena in the quantitative data (RQ3) that could not be described by numbers (Fries, 2009). The author collaborated with two teachers who had extensive experience in teaching with technology to use SDT develop a semi-structured interview protocol. This protocol aimed to facilitate open discussions and prompt to collect in-depth perspectives. The interviews explored how to technological designs support autonomy, competence and relatedness (see the three needs in SDT, Ryan & Deci, 2017).

Ethical approval from the author's institution was obtained, and consent was received from all of the participants. A pilot study was conducted two months before the main study with two groups of 15 students each, and confirmed that the digital support group had stronger perceived need support and greater engagement. This pilot study was intended to check for modifications that needed to be made to the main research study. The students in the pilot study did not participate in the main study.

In the main study, each school was randomly assigned to one of the two experimental groups, resulting in 215 and 211 students in the digital support group and control group, respectively. The students learned a mathematics topic in the blended mode for 10 consecutive school days. Every school day, they completed pre-lesson activities and resources provided in the LMS at home, then discussed what they had learned using both physical and digital communication in 1-h face-to-face lessons. After the lessons, they extended their learning through post-lesson activities in the LMS. In the last lesson, they completed a self-reported questionnaire on their perceived teacher and digital support and engagement in blended learning.

3.3. Instruments

Apart from demographic data, the questionnaire assessed the two categories of perceived support and student engagement using 10 constructs. Each construct comprised five 5-point Likert scale items. The items were checked by four experienced teachers to ensure that the wording and language were understandable.

3.3.1. Perceived teacher and digital support

To assess the students' perceptions of the support they received from teachers and the technological design of the LMS, we adapted the validated questionnaire items proposed by Furrer and Skinner (2003), Standage et al. (2005), and Hew and colleagues (2016). Each construct included three items.

Perceived teacher support was used to measure the students' perceptions of autonomy, relatedness, and competence as facilitated by their teachers. All of the items were adapted from Standage et al. (2005) and modified. The three items for perceived teacher autonomy support, with an original reliability of $\alpha = 0.92$, were "My teacher encourages us to ask questions," "My teacher answers my questions fully and carefully, " and "My teacher makes sure I really understand the goals of the lesson and what I need to do." The three items for perceived teacher relatedness support, with an original reliability of $\alpha = 0.88$, were "My teacher supports me," "My teacher is interested in me," and "My teacher is friendly toward us." In addition, the three items for perceived teacher competence support, with an original reliability of $\alpha = 0.84$, were "My teacher makes me feel like I am good at learning," "I feel that my teacher likes us to do well," and "My teacher makes me feel like I am able to do the activities in class."

Perceived digital support was used to measure the students' perception of autonomy, relatedness, and competence as facilitated by their teachers. All of the items for digital autonomy and competence support were adapted from Hew et al. (2016). The three items for perceived teacher autonomy support, with an original reliability of $\alpha = 0.82$, were "I feel like I can make a lot of input in deciding how I use LMS in learning," "I feel a sense of freedom when using the LMS in my learning," and "I have many opportunities with the LMS to decide for myself how to learn.". The three items for perceived digital competence support, with an original reliability of $\alpha = 0.71$, were "I think I am pretty good at learning using the LMS," "I have been able to learn interesting new knowledge with the LMS," and "I feel a sense of accomplishment from learning with the LMS." All of the items for digital relatedness support were adapted from Furrer and Skinner (2003), with an original reliability of $\alpha = 0.86$: "When I interact with the LMS, I feel supported (changed to comfortable/important)."

3.3.2. Student engagement dimensions

Behavioral and emotional engagement in learning with technology were each measured using three items adapted from Skinner et al. (2009). The items for behavioral engagement were "I try hard to do well in all of the learning activities," "In the blended learning, I work as hard as I can," and "In the blended learning, I participate in all the learning activities." The items for emotional engagement were "In the blended learning, I feel interested (Changed to good)" and "I find blended learning fun."

Cognitive engagement was measured using three items adapted from Wang et al. (2016). They validated and verified items to measure high school students' cognitive engagement in science and mathematics. The items fitted our participants' education level and subject domains. They were as follows: "I go through the learning activities to make sure my work is right," "I think about different ways to solve a problem," and "I try to connect what I am learning to things I have learned before."

To measure the students' agentic engagement, we adapted three items from Reeve (2013), who proposed the concept of agentic engagement. They were "I let my teacher know what I need and want during blended learning," "I let my teacher know what I am interested in during blended learning," and "During blended learning, I express my preferences and opinions."

3.4. Research analytic approach

Independent t-tests were used to answer RQ1 by comparing the means of perceived teacher and digital support between the two experimental conditions in the questionnaire. To answer RQ2, path analyses within the proposed research models were used to assess the contributions of perceived teacher and digital support to each of the four dimensions of student engagement in the questionnaire, i.e., structural regression paths between latent variables. To answer RQ3, two research assistants transcribed and translated the interview data to English, and used the three needs identified by SDT as a framework to analyze the interview data to understand how the digital support designs motivated student engagement. They adopted data triangulation approach to analyze data from different participants. The author acted as the mediator of any differences in interpretation.

4. Results

4.1. Descriptive statistics

The descriptive statistics for all of the latent variables are presented in Table 1. All of the variables were internally reliable, as all of the α values ranged from 0.93 to 0.97 (where good > 0.80) and had sufficiently normal distributions (i.e., skewness less than 2.3, Lei & Lomax, 2005; kurtosis less than 7.0, Byrne, 2010). All the factor loadings ranged from 0.91 to 0.99.

Regarding the goodness-of-fit of the measurement model, the fitness indices of the measured items indicated a good model fit: $\chi^2/df = 2.77$ (<5.0); RMSEA = 0.07 (< .08); SRMR = 0.02 (< .05); TLI = 0.96 (> .90); CFI = 0.97 (> .90) (Hair et al., 2010). The positive correlations between all of the variables were significant, with $p < .01$ (Table 2). This suggested that all of the assumptions required to conduct path analysis for RQ2 were met.

4.2. Effects of the proposed digital support

The independent t-tests showed that the digital group reported significantly greater support for perceived autonomy (M = 3.95, SD = 1.00), competence (M = 3.78, SD = 0.83), and relatedness (M = 3.73, SD = 0.93) from the LMS than the control group did (autonomy: M = 3.63, SD = 1.21, competence: M = 3.51, SD = 0.99, and relatedness: M = 3.01, SD = 1.19), with t(424) = 2.96 (p = .003), t(424) = 3.01 (p = .003), and t(424) = 6.92 (p < .001), respectively. The tests further showed there were no differences in perceived autonomy, competence,

Table 1
Descriptive statistics.

Variables	Mean	SD	Skewness	kurtosis
PTAS	3.70	1.24	0.82	0.40
PTCS	3.57	0.94	0.12	0.84
PTRS	3.64	1.09	0.62	0.31
PDAS	3.79	1.12	0.99	0.21
PDCS	3.64	0.92	0.86	0.76
PDRS	3.38	1.13	0.39	0.55
PBE	3.90	1.19	0.96	0.21
PCE	3.99	0.99	0.84	0.12
PEE	3.92	1.23	1.05	0.03
PAE	3.61	1.23	0.64	0.56

Notes: PTAS: Perceived teacher autonomy support; PTCS: Perceived teacher competence support; PTRS: Perceived teacher relatedness support; PDAS: Perceived digital competence support; PDCS: Perceived digital relatedness support; PBE: Perceived behavioral engagement; PCE: Perceived cognitive engagement; PEE: Perceived emotional engagement; PAE: Perceived agentic engagement.

Table 2
Correlation among latent variables.

Independent variables	1	2	3	4	5	6	7	8	9	10
1. PTAS	–									
2. PTCS	.39**	–								
3. PTRS	.38**	.39**	–							
4. PDAS	.35**	.27**	.31**	–						
5. PDCS	.20**	.25**	.23**	.24**	–					
6. PDRS	.11**	.23**	.20**	.16**	.11**	–				
7. PBE	.40**	.42**	.38**	.35**	.26**	.17**	–			
8. PCE	.44**	.44**	.45**	.39**	.45**	.15**	.38**	–		
9. PEE	42.**	.39**	.38**	.27**	.11**	.27**	.38**	.24**	–	
10. PAE	.44**	.39**	.36**	.36**	.21**	.14**	.31**	.32**	.47**	–

Notes: **p < .01; PTAS: Perceived teacher autonomy support; PTCS: Perceived teacher competence support; PTRS: Perceived teacher relatedness support; PDAS: Perceived digital competence support; PDCS: Perceived digital relatedness support; PBE: Perceived behavioral engagement; PCE: Perceived cognitive engagement; PEE: Perceived emotional engagement; PAE: Perceived agentic engagement.

and relatedness support from teachers between the digital and control groups, with t(424) = 0.007 (p = .99), t(424) = 0.020 (p = .98), and t (424) = 0.880 (p = .38), respectively. The tests also revealed that the digital group showed significantly greater perceived behavioral (M = 4.04, SD = 1.06), cognitive (M = 4.11, SD = 0.88), and agentic (M = 3.78, SD = 0.1.13) engagement than the control group (behavioral M = 3.76, SD = 1.30, cognitive M = 3.87, SD = 1.08, and agentic M = 3.44, SD = 1.30), with t(424) = 2.49 (p = .013), t(424) = 2.57 (p = .010), and t(424) = 2.86 (p = .004), respectively. The two groups showed no significant differences in emotional engagement, with t(424) = 1.78 (p = .08). These results showed that the proposed digital support strategies increased the students' sense of autonomy, competence, and relatedness support from the LMS and led to better behavioral, cognitive, and agentic engagement.

4.3. Relationships between teacher and digital support and student engagement

The path analysis revealed the quality of the model by estimating path coefficients and R-squared values (R^2). The path coefficients and R^2 showed the strength of the relationships and the amount of variance of the endogenous latent variables explained by the exogenous latent variables, respectively. This analysis helped to explain how teacher and digital support contribute to student engagement.

In the research model, regression paths were specified from the six exogenous latent variables (perceived support, i.e., autonomy, competence, and relatedness from the teacher and LMS) directly to the four endogenous latent variables (student engagement, i.e., behavioral, cognitive, emotional, and agentic). The model showed a good fit to the data: χ^2/df = 2.85 (<5.0); RMSEA = 0.07 (< .08); SRMR = 0.03 (< .05); TLI = 0.96 (> .90); CFI = 0.97 (> .90) (Hair et al., 2010).

As shown in Table 3, four of the exogenous variables explained 32% of the variance in the endogenous variable of behavioral engagement. Perceived teacher autonomy, competence, relatedness, and digital autonomy support had similar effects: β = 0.19, β = 0.22, β = 0.16, and β = 0.17, respectively. Moreover, five of the exogenous variables explained 45% of the variance in cognitive engagement. Perceived digital competence support had the largest effect (β = 0.30), followed by teacher autonomy (β = 0.19), teacher relatedness (β = 0.19), teacher competence (β = 0.18), and digital autonomy (β = 0.16) support. Perceived teacher autonomy support (β = 0.26) had a stronger relationship with emotional engagement than did perceived teacher autonomy (β = .19) and competence (β = 0.19) and digital relatedness (β = 0.16) support. These four variables explained 33% of the variance in emotional engagement. In addition, four of the exogenous variables explained 31% of the variance in agentic engagement. Perceived teacher autonomy support had the largest effect (β = 0.24), followed by teacher competence (β = 0.20), digital autonomy (β = 0.18), and teacher relatedness (β = 0.12) support.

Table 3
Results of hypothesis tests.

			Path coefficient	S. E.	C.R.	P	Results
PBE	<—	PTAS	.19	.05	3.92	<.001	Supported
PBE	<—	PTCS	.22	.07	4.53	<.001	Supported
PBE	<—	PTRS	.16	.05	3.27	.001	Supported
PBE	<—	PDAS	.17	.05	3.66	<.001	Supported
PBE	<—	PDCS	.07	.06	1.61	.11	Unsupported
PBE	<—	PDRS	.04	.05	0.85	.40	Unsupported
PCE	<—	PTAS	.19	.04	4.07	<.001	Supported
PCE	<—	PTCS	.18	.05	4.15	<.001	Supported
PCE	<—	PTRS	.19	.04	4.34	<.001	Supported
PCE	<—	PDAS	.16	.04	3.72	<.001	Supported
PCE	<—	PDCS	.30	.05	7.24	<.001	Supported
PCE	<—	PDRS	.01	.04	.24	.81	Unsupported
PEE	<—	PTAS	.26	.05	5.40	<.001	Supported
PEE	<—	PTCS	.19	.07	3.94	<.001	Supported
PEE	<—	PTRS	.19	.06	4.03	<.001	Supported
PEE	<—	PDAS	.06	.05	1.36	.17	Unsupported
PEE	<—	PDCS	.08	.07	1.61	.11	Unsupported
PEE	<—	PDRS	.16	.05	3.70	<.001	Supported
PAE	<—	PTAS	.24	.05	5.02	<.001	Supported
PAE	<—	PTCS	.20	.07	4.05	<.001	Supported
PAE	<—	PTRS	.12	.06	2.58	.01	Supported
PAE	<—	PDAS	.18	.05	3.99	<.001	Supported
PAE	<—	PDCS	.03	.06	.75	.46	Unsupported
PAE	<—	PDRS	.01	,05	.11	.92	Unsupported

Notes: **p < .01; PTAS: Perceived teacher autonomy support; PTCS: Perceived teacher competence support; PTRS: Perceived teacher relatedness support; PDAS: Perceived digital competence support; PDCS: Perceived digital relatedness support; PBE: Perceived behavioral engagement; PCE: Perceived cognitive engagement; PEE: Perceived emotional engagement; PAE: Perceived agentic engagement.

Overall, the three types of perceived teacher support were significant predictors of the four student engagement dimensions. Perceived digital autonomy support was a significant predictor of behavioral, cognitive, and agentic engagement, and perceived digital cognitive support and relatedness support significantly predicted cognitive and emotional engagement, respectively.

4.4. Features of the LMS satisfying student innate needs

This study used semi-structured interviews to collect student views on learning support from the LMS and used the three innate needs identified by SDT as a framework for analysis. The analysis showed that the students' ideas about how the LMS design facilitated their blended learning were very consistent. Moreover, all of the proposed digital support designs satisfied the students' need for autonomy, competence, and relatedness.

4.4.1. Perceived digital autonomy support

The interview data showed that the various learning resources provided in the LMS offered the students the opportunity to select their preferred materials for preparing classroom activities in blended learning. All of the students described the LMS as a learning resource bank from which to choose materials, and they felt stimulated and free, as shown by the following excerpts.

Student 1: I like first reading the PowerPoint slides, followed by watching the videos when doing the pre-lesson tasks.

Student 2: The description of each resource was very clear, which helped me choose the most relevant materials.

Student 3: I consulted several websites with excellent learning resources listed in the LMS.

Student 4: I achieved deeper learning from articles left for us to read. I obtained brief insights from watching videos.

4.4.2. Perceived digital competence support

Furthermore, the data revealed that the two support designs—five level-up exercises and well-designed interactive materials—made the students feel competent in finishing the pre-lesson and classroom tasks for blended learning. During the interviews, all of the students described feeling more confident because the level-up exercises scaffolded their learning by building up their knowledge to answer the most challenging questions. The interviews also showed that the students better understood the content after interacting with/manipulating the materials when they had difficulty learning the topics. This was because they were able to get an immediate response from the materials. The following excerpts illustrate how the two support designs worked.

Student 5: I found that the lower-level exercises guided me to complete the level 5 tasks. It was much easier.

Student 6: I felt that I could finish the pre-lesson and classroom exercises when I saw the 5 levels exercises.

Student 7: I could see what the corresponding graph [interactive learning material] looked like when I input the values.

Student 8: I could use the graph [interactive learning material] to get an idea when having difficulty.

4.4.3. Perceived digital relatedness support

In addition, the data showed that the digital support made the students feel that the LMS belonged to them or their class. The following are excerpts from the students' discussion of how the digital designs supported relatedness.

Student 9: I liked seeing our pictures on the headline [background of LMS] of the course room. I saw my face in the pictures.

Student 10: I found the classroom to be our class learning environment.

Student 11: The emotional design was fun and interesting.

Student 12: I will go back to the classroom to see if we have any updated pictures.

5. Discussions and conclusions

The current study examined and explained how the three types of perceived support from both teachers (teacher support) and an LMS (digital support) contributed to student engagement. Accordingly, this paper has three major empirical implications, makes three theoretical contributions, and offers three practical suggestions for instructional designers and teachers.

5.1. Empirical implications

The first empirical implication is that the proposed digital support had a significant impact on the perceived autonomy, competence, and relatedness support received from the LMS, resulting in stronger student engagement (RQ1). This implies that the proposed support designs were able to satisfy the students' three innate needs when learning with resources and/or completing tasks online for blended learning. Students' innate learning needs in online/virtual learning environments are the same as those in face-to-face classrooms (Ryan & Deci, 2020). Accordingly, an online environment design that supports a stronger sense of autonomy, competence, and relatedness is critical for blended learning. As the findings for RQ1 and RQ3 show, an effective digital support design (i) offers various learning resources with descriptions that indicate their relevance to students (Bedenlier et al., 2020; Hartnett, 2015), (ii) provides scaffolding exercises, such as level-up exercises, that help students build their confidence and knowledge to tackle more challenging exercises, (iii) applies multimedia learning principles to the design of digital learning materials (Chiu & Churchill, 2015; Ng & Chiu, 2017), and (iv) makes the technological environment more personal and fun, such as by using personal images and emotional designs for course room designs. Such proposed digital support designs are effective in satisfying students' autonomy, competence, and relatedness, echoing findings regarding the application of teacher support in classroom teaching (Lietaert et al., 2015; Roorda et al., 2011).

Second, as predicted, the perceived autonomy, competence, and relatedness support received by the students from the teachers was strongly associated with the four dimensions of student engagement (see perceived teacher support in RQ2). Teachers who were able to satisfy the students' three needs were more likely to foster student learning in blended environments. These results are aligned with most SDT-related studies conducted in face-to-face settings, such as classrooms and playgrounds (Lietaert et al., 2015; Vansteenkiste et al., 2009; Vollet et al., 2017). When students' efforts to satisfy their needs are supported by teachers, they are intrinsically motivated to continue to perform the given learning tasks (Losier et al., 2001; Ryan & Deci, 2017, 2020). This intrinsic motivation resembles a "fuel" or energy that encourages students to behaviorally, cognitively, emotionally, and agentically engage in blended learning (Reeve, 2013).

The final empirical implication is that the perceived digital support received by the students from the LMS related in different ways to the four dimensions of student engagement. Perceived digital autonomy support had close relationships with behavioral, cognitive, and agentic engagement. Perceived digital competence support and relatedness support were strongly associated with cognitive and emotional engagement, respectively. This seems to imply that, in terms of the LMS, perceived autonomy support was more important than perceived competence or relatedness. These results are aligned with the majority of SDT-related studies, which have given primacy to autonomy support and emphasized its importance in promoting intrinsic motivation to learn in face-to-face settings (Ruzek et al., 2016). The finding related to autonomy can be explained by the use of multiple modalities (Schnotz & Bannert, 2003): presenting multiple types of learning content resources (modalities) benefited students by encouraging them to actively process such content (Chiu & Churchill, 2015; Chiu et al., 2020; Schnotz & Bannert, 2003); offering just one modality would have been ineffective. In an environment with multiple resources (modalities), the students felt they had choices, were competent, and were able to ask their teachers for more resources or modalities. For example, for an online pre-lesson task lacking the teacher's immediate aid but requiring extra learning support, the students could choose their preferred resource to learn with first, followed by learning with other resources to complete the explanation of the given learning content. They also could ask for or look for more resources with which to complete the task.

A plausible explanation for the finding related to competence in the final implication is that digital competence support played a scaffolding role in the tasks. Scaffolding supported the students by limiting the complexities of the learning content and providing the right amount of structure in the online learning environment (Dabbagh, 2003). Therefore, the students felt that they were capable of completing the tasks. The finding concerning relatedness support may be due to the influence of affective processes on motivation (Chiu, 2021a, 2021b; Ng & Chiu, 2017; Park et al., 2015; Plass & Kalyuga, 2019). Appealing and interesting designs can evoke a positive emotional state in students (Heidig et al., 2015) and motivate learning through the creation of an enjoyable experience (Chiu et al., 2020; Knörzer et al., 2016).

5.2. Theoretical contributions

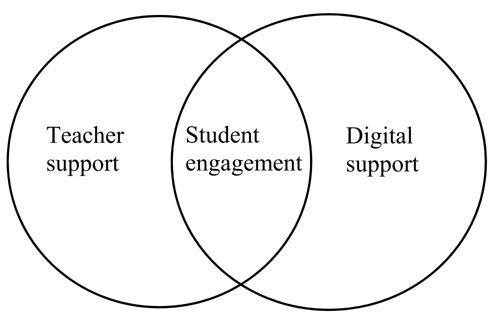
The first and second empirical implications contribute to SDT by adding the dimension of technological design and presenting evidence of how technological design relates to student engagement. The majority of SDT-related studies of support for the three innate needs have concerned the application of teacher support in online and face-to-face contexts (Bedenlier et al., 2020; Chiu, 2021a; Hartnett, 2015; Lietaert et al., 2015; Roorda et al., 2011). These studies have suggested that teachers should use different strategies, such as respecting and accepting students' individual interests, organizing peer moderation to allow students to share information with peers, and fostering the development of trust relationships among students in collaborative learning environments, to intrinsically motivate student engagement. In these studies, teacher support—how teachers should act while teaching— has been the core idea, not technological design. In the present study, the digital support did not involve the teachers; the students interacted only with the LMS. Accordingly, the technological environment was deemed to satisfy the three innate needs in SDT, demonstrating that it was as important as teacher support.

The second theoretical contribution, driven by the second empirical implication, concerns the differences in the impact of teacher and digital support on student engagement in blended learning. The findings show that teacher and digital support had different effects on different dimensions of student engagement in face-to-face and technological (LMS) contexts.

As the findings suggest the importance of supporting motivation using teacher and digital support, this paper proposes a framework for supporting student psychological needs—autonomy, competence, and relatedness—in blended learning (see Fig. 3). This framework aims to guide teachers in facilitating students' motivational disposition toward blended learning. Instead of relying on teachers' actions and efforts to satisfy student needs through an LMS, this framework suggests that classrooms (teacher support) and an LMS (digital support) should be designed separately and independently to satisfy students' needs. These two designs are interrelated, but they are operationalized and conceptualized as distinct. It is necessary to design a more supportive blended learning environment (e.g., greater autonomy support, more valued activities, a more connected system) to meet students' needs in both physical and virtual learning environments. Compared with digital support, teacher support has been better studied (see autonomy support, structure, and involvement; Lietaert et al., 2015; Vansteenkiste et al., 2009; Vollet et al., 2017). In terms of digital support, multiple modalities, Mayer's multimedia learning, and emotional multimedia designs can be used to support autonomy, competence, and relatedness, respectively.

5.3. Practical suggestions

This study offers instructional designers and teachers three practical suggestions for satisfying the three needs for greater engagement in blended learning environments. The first practical suggestion is to design learning resources that promote autonomy. These learning resources should emphasize the sensory channel and/or modality of the representations (i.e., either auditory/visual or textual/pictorial) (Ainsworth, 2006). They should complement one another but differ in terms



Teacher support
Autonomy: Teachers consider student perspectives, allow for choices around learning, give a rationale when choice is constrained, and avoid the use of controlling language.
Relatedness: Teachers provide students with emotional and motivational support, such as pedagogical caring, involvement, closeness, acceptance, and help.
Competence: Teachers provide effective guidance during lessons, create boundaries in learning activities, give competence-relevant feedback, and express confidence in students' abilities.

Digital support
Autonomy: The technological environment offers and recommends various digital resources for the same learning unit and indicates their relevance to students.
Relatedness: The environment includes personal and emotional designs and communication to promote a positive atmosphere.
Competence: The environment offers five level-up exercises and well-designed interactive learning materials in a cognitively demanding technological learning environment.

Student engagement
Behavioral engagement: students' participation and involvement in learning activities.
Emotional engagement: students' affective reactions to their classmates, teachers, learning activities, and school.
Cognitive engagement: students' mental effort to complete tasks using a deep, self-regulated, and strategic approach to learning.
Agentic engagement: students' proactive efforts to constructively contribute to learning and teaching.

Fig. 3. The proposed framework for needs support for blended learning.

of either the learning process they support or the content they contain (Chiu & Churchill, 2015, 2016). Students need to choose appropriate representations but need not understand the relation between them. Accordingly, students can benefit from the autonomy support provided by the resources.

The second suggestion is to design the technological learning environment, including the LMS and learning resources, to address learners' expertise and cognitive load. In designing and developing the environment, Mayer's multimedia learning principles and Kalyuga's expertise reversal effect should be used as guidance for creating effective multimedia and catering to learner diversity (Chiu & Mok, 2017; Kalyuga, 2014; Mayer, 2009). Students will feel more competent if the design of the environment considers cognitive load (in working memory) with its multiple, modality-specific limited capacity.

The last suggestion is to design positive and emotional technological learning environments. The optimization of positive emotions has been shown to enhance learning processes (Chiu et al., 2020; Park et al., 2015). Appealing and interesting designs with warm colors and round shapes should be considered when designing the environment because they can facilitate learning outcomes by inducing positive emotions and creating an enjoyable experience (Chiu et al., 2020; Knörzer et al., 2016; Plass & Kalyuga, 2019).

6. Limitations and future directions

This study suggests that for effective blended learning, students must be supported and engaged in both face-to-face and technological settings. Four limitations of this study are noted here. First, the proposed digital support designs seemed to better satisfy students' innate needs than teacher support did, but more experiments using other new digital support designs are required to validate the findings. Second, this study was conducted in high school sector. The effects of digital support vary according to educational level. More studies should be done in elementary school or higher education sectors. Third, this was a short-term study and might not reveal the full effect of support for relatedness, because an emotional design may only work for a brief period (Chiu et al., 2020). Therefore, future studies should adopt a longitudinal research design to track how student engagement can be fostered. Finally, the current study used self-reported questionnaires to measure engagement; therefore, future studies using objective measures, such as the number of resources and exercises students watched/read/completed, are needed to validate the findings.

Author contributions

Thomas K.F. Chiu: Conceptualization, Methodology, Validation, Formal analysis, Writing – original draft, Writing – review & editing, Supervision, Project administration

Declaration of competing interest

- When the readers would like to access the data presented in this paper but who have no participant identification, they can send a request through Faculty of Education, the Chinese University of Hong Kong, Hong Kong.
- There is no conflict of interests between the author and participants.

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