Fostering Student STEM Interest and Identity Using Self-determination Theory

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Research Article

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Abstract

Background

Student strongly positive (Science, Technology, Engineering, and Mathematics) STEM interest and identity predict their future study and career choices in a STEM field. Integrated STEM programs provide a solution to the challenge of instilling students with an interest in the STEM field. However, STEM education studies addressing multiple disciplines are insufficient, as they have produced mixed findings and inadequate direction for advancing integrated STEM education. The literature suggests that self-determination theory (SDT) provides an understanding of motivational processes that influence the development of STEM interest and identity. This study investigated the effectiveness of teacher needs support on student STEM interest and identity development during a proposed 12-week SDT-based STEM program. Three hundred forty-two grade 9 students were randomly assigned to SDT and non-SDT groups during the program.

Results

Compared with the non-SDT group, the students in the SDT-based group demonstrated significantly stronger autonomy, competence, relatedness, and STEM interest and identity, in addition to greater intentions to choose elective STEM subjects. Moreover, structural equation modeling showed that the student perceived teacher needs support was a significant predictor of their development of STEM interest and identity. Perceived support for competence and relatedness were the strongest predictors. STEM identity was a predictor for the number of elective STEM subjects chosen.

Conclusion

The results support the application of SDT in integrated STEM learning, and explain how supporting student needs affects their STEM interest and identity, which is crucial in interdisciplinary learning and the development of adolescent interest and identity in K-12. Moreover, the results contribute to SDT by adding a new dimension — STEM interest and identity — and presenting more evidence on how teacher needs support foster this dimension. These results have practical implications for advancing integrated STEM education in addition to new opportunities for using fewer resources to effectively foster student interest and identity in universal education.

Background

In meeting socioeconomic challenges with the future workforce, we must improve the recruitment and retention of students with elective STEM majors in education and the job market. Students' STEM interest and identity predict their choices of future studies and careers in STEM fields. A solution to this challenge is quality learning through integrated STEM education (English, 2016; Moore & Smith, 2014), which better develops student positive interest and identity (Struyf et al., 2019). However, the related studies addressing multiple disciplines are insufficient, as they have produced mixed findings and inadequate direction for advancing integrated STEM education (Kim, 2018; Robinson et al., 2019; Vincent-Ruz & Schunn, 2018). We still have little understanding of how students develop their STEM interest and identity through integrated learning activities. Students' development of interest and identity can be explained by their motivation to internalize STEM learning experiences. The more that students internalize their STEM learning experiences, the more joy and value they find in these activities. Self-determination theory (SDT) provides an understanding of the motivational processes in students' internalization of their learning experiences, which influences their development (Ryan & Deci, 2020). SDT proposes that all people have three basic psychological needs, namely, autonomy, competence, and relatedness. Teacher support of these needs is essential for effective learning and well-being. In K-12, teachers are the main supporters of early and middle adolescent students' needs in the development of their interest and identity (Rich & Schachter, 2012). Teacher motivational behaviors will foster and suppress their student interest and identity. Therefore, this study used SDT to propose strategies for teacher needs support within an integrated STEM program and to investigate their effectiveness on student development of STEM interest and identity. The findings contribute to our understanding of how teacher support fosters their student development of STEM interest and identity, thus improving STEM education and policy research strategies.

Literature Review

In this literature review, SDT is used as the main theoretical framework to explain how it can develop student STEM interest and identity. In addition, we identify knowledge gaps in the literature.

SDT as a Theoretical Framework in STEM Education

In STEM education, SDT provides a theoretical framework for student motivation with strong implications for both classroom practice and educational reform policies (Ryan & Deci, 2017, 2020). The theory posits that all individuals have three fundamental psychological needs—autonomy, competence, and relatedness—which determine their motivation to act or not act. Autonomy refers to individuals' sense that they can control their own choices and experience the desire to progress in whatever way they think best. Competence refers to individuals' sense that they know what they are doing, can perform a task, and have the necessary knowledge and skills to succeed. Relatedness refers to the sense that individuals feel connected within a community and share similar goals. SDT includes intrinsic and extrinsic motivation. Intrinsic motivation refers to behaviors undertaken for enjoyment and interest, while extrinsic motivation includes behaviors intended to obtain four distinct outcome categories (Ryan & Deci, 2020), namely, external, introjected, identified, and integrated regulation, which are considered to fall along an internalization continuum. The more internalized individuals' extrinsic motivation, the more autonomous their planned behaviors. Therefore, extrinsic motivation varies based on individuals' internalization of how they value, perceive, and feel their activities. Enhancing internalization induces individuals to partially or deeply adopt the values and goals of their activities, and forestalling internalization induces them to resist and resist these values and goals. According to SDT, supporting individuals' needs is essential to the internalization process. When all three SDT needs are supported, student motivational orientation can move through a motivation continuum from amotivation to extrinsic motivation to intrinsic motivation (see Figure 1), in which students increasingly internalize their motivation until something intrinsic about the activity begins to drive their desire to obtain knowledge (Ryan & Deci, 2017, 2020). Therefore, the students become motivated to sustain their own personal growth and well-being, which potentially enhances their learning outcomes, such as the development of their STEM interest and identity. Accordingly, STEM teachers can intrinsically motivate their students using any motivation orientation to learn by satisfying their need for autonomy, competence, and relatedness.

Studies that apply SDT to STEM education emphasize its importance in promoting intrinsic motivations for teaching and learning. In an autonomy-supportive environment, teachers should consider student perspectives, allow for choices around STEM learning, and adopt endorsing rather than controlling strategies (Chiu, 2021; Dyrberg & Holmegaard, 2019; Skinner et al., 2017). For example, in STEM project-based learning, students should choose topics, products, and learning resources and processes to fit their personal abilities, interests, and goals (Chiu et al., 2021). Students can take ownership and feel empowered in their learning because it reflects their own voice and original ideas (León et al., 2015; Moore et al., 2020). This autonomy-supportive environment may satisfy student sense of competence (Chiu, 2022; Niemiec & Ryan, 2009; Ryan & Deci, 2020). Students who feel capable will enhance their motivation to act, while students who feel ineffective may not persist because of their reduced motivation. Accordingly, student needs for competence and autonomy are interrelated in the internalization of their learning experiences. To support student competence in STEM project-based learning, teachers can structure learning activities by communicating their clear expectations for the project, providing competence-specific feedback at different milestones, and offering step-by-step guidance in making STEM products (Chiu, 2022; Dyrberg & Holmegaard, 2019; León et al., 2015). Relatedness is often discussed in terms of group experiences and teacher involvement (Niemiec & Ryan, 2009). Relatedness-supportive STEM learning environments should nurture student psychological need for emotional connections by fostering interpersonal relationships (Chiu et al., 2020; Weng et al., 2022). Teachers can encourage their students to build personal relationships in attempts to solve social problems relevant to them, such as neighborhood issues (e.g., designing masks in a pandemic) or hot global issues (e.g., climate change). Thus, the students can feel relevant and connected to their problems and subjects, and can develop a strong sense of self-determination to study these problems, design appropriate solutions, and execute their designs.

The following section discusses how SDT can explain the development of student STEM interest and identity, and then identifies knowledge gaps in STEM education.

SDT to Explain Student STEM Interest and Identity Development

Interest is a relatively enduring preference for certain topics, subject areas, and activities (Hidi, 1990; Renninger & Hidi, 2011; Schiefele, 1991), and it includes both feeling- and value-related components (Schiefele, 1991). Feeling-related components refer to the feelings associated with a subject, object, or topic, such as feelings of enjoyment and involvement. Value-related components refer to the personal significance of an object. For example, research objects may contribute to an individual's personality development, competence, or understanding of important issues. These two types of components are highly correlated. Interest develops over time from curiosity (i.e., attention before voluntary engagement) to persistence and then to resourcefulness (Renninger & Hidi, 2011). The presence of interest positively affects learners' attention, goals, and levels of learning. Interest has a strong relationship with self-efficacy. Students with more strongly developed interests will subsequently have stronger feelings of self-efficacy and can better self-regulate their behaviors in persevering with challenging tasks (Hidi & Ainley, 2008). Thus, students with great interest in STEM activities will enjoy STEM subjects, which will foster the development of their STEM identity (Verhoeven et al., 2019).

Identity has been discussed by researchers from different theoretical perspectives, including psychological, sociocultural, and post-structural. However, this paper focuses on the development of student identity in STEM education rather than discussing the concept of identity. Studies of identity development in STEM disciplines have referred to identity as "how individuals know and name themselves, who one is or wants to be, as well as to how one is recognized by others" (Carlone & Johnson, 2007; Goos & Bennison, 2019; Honey et al., 2014; Kim, 2018). Student STEM identities are developed in stages over time, socially constructed with others, and built by internalizing their learning experiences (Hill et al., 2010; Martin-Hansen, 2018; Vincent-Ruz & Schunn, 2018), which can be framed by the SDT concept of three basic psychological needs.

According to SDT, the internalization of activities and pursuits valued by others is as a basic process in developing interests and identity. Student need for autonomy, competence, and relatedness actively fuels their sustained motivation to integrate new knowledge through personal experiences (Ryan & Deci, 2003; La Guardia, 2009). To drive the development of STEM interest and identity in classrooms, learning experiences should allow students to (i) engage with important relationship partners, such as teachers, and share their abiding interests, goals, values, and behaviors (i.e., relatedness); (ii) develop competencies to capitalize on new opportunities for growth and mastery, and to express their success (i.e., competence); and (iii) more flexibly consider their own choices, interests, thoughts, and feelings in engaging with real-world challenges through the transformation of their values, goals, and behaviors from being externally imposed to personally owned (i.e., autonomy) (La Guardia, 2009; Ryan & Deci, 2003; Skinner et al., 2017; Vincent-Ruz & Schunn, 2019; Vongkulluksn et al., 2018). In summary, motivated students who internalize their learning experiences during STEM activities are more likely to develop a positive STEM interest and identity.

Research Gaps in STEM Interest and Identity

STEM education studies that explore the development of student interest and identity in multiple disciplines are insufficient, as they provide mixed findings and inadequate direction for advancing integrated STEM education (Honey et al., 2014; Kim, 2018; Kim et al., 2018; Skinner et al., 2017). Therefore, scholars have examined various issues related to integrated STEM education in schools. The development of student STEM interest and identity considerably influences their choice to enroll in STEM programs and their career aspirations, which are extremely important in promoting integrated STEM education (Honey et al., 2014; Robnett & Leaper, 2012; Weng et al., 2022). Although scholars have clearly defined STEM interest in the literature, the formation of STEM identity is less clearly defined (Martin-Hansen, 2018; Vincent-Ruz & Schunn, 2018). Studies exploring the development of STEM interest and identity have (i) ignored the integrated nature of STEM education and focused on multiple disciplines, namely, science, technology, mathematics, or engineering (e.g., Carlone & Johnson, 2007; Godwin et al., 2016; Kim, 2018; Kim et al., 2018; Robinson et al., 2019; Vincent-Ruz & Schunn, 2018); (ii) focused on student equality in the context of underrepresentation of genders, ethnicities, and languages (Carlone & Johnson, 2007; Cohen et al., 2021; Godwin et al., 2016; Kim et al., 2018); (iii) examined the effect of role models and mentors on the development of STEM interest and identity (Weng et al., 2022); and (iv) highlighted the importance of the early development of STEM interest and identity (Cohen et al., 2021). These findings are echoed by a comprehensive report on the research agenda of STEM integration in K-12 education (Honey et al., 2014). Honey and colleagues (2014) collaborated with many scholars from different disciplines, such as STEM education, teacher education, and learning sciences, in reviewing large-scale studies and found that most identity studies adopted a case-based or qualitative approach and lacked experimental methods. Studies related to STEM interest and identity have not explained its development in an integrated context. To our knowledge, no SDT-based study has explained the development of STEM interest and identity in STEM integrated education. Therefore, this study investigated how students' perceived teacher support of their needs from a SDT perspective explains their development in STEM integrated learning.

This Study

This paper reported the primary findings of a school–university STEM education project funded by a competitive research grant scheme in Hong Kong. This study redesigned a 12-week non-SDT STEM program using a real-world topic, "Sustainable City," to enable the teachers to support their students' three SDT needs. Three different science, technology, and mathematics teachers designed the STEM problem. An engineering teacher was not included because there are none at the K-12 level in Hong Kong. These three teachers collaborated in teaching the STEM problem to ensure that their students applied their knowledge from all four STEM disciplines during their learning activities. The following STEM problem was used as an example learning activity:

There are some real challenges ahead for city planners and architects as increasingly more people in the world live in urban areas. … How can you redesign Hong Kong as a sustainable city? … The five subtopics are energy, food, nature, transport, and waste. … To create solutions, please write down how your group can use your science, mathematics, and technology knowledge to develop and explain your solutions, and how your group can use engineering designs to create a prototype sustainable city.

To foster student autonomy in the SDT program, the teachers took the student perspectives - encourage their autonomy during learning activities, and use invitational language. The students decided on the subtopic they wanted to study and began their own projects. The student groups also decided what forms their prototype would take (e.g., paper, video, and/or physical) and what materials to use in creating their solutions. To support their student need for competence, the teachers explained how their students could make progress and achieve their desired outcomes by structuring the learning activities. The teachers communicated their clear expectations, offered step-by-step guidance, and gave competence-related feedback to their students. To support relatedness, the teachers supported their students' emotional connections by fostering interpersonal relationships through forming student groups by matching the students with similar self-identified subtopics/projects. The teachers also used a collaborative group portfolio to foster an intimate group experience and conducted weekly teacher–student group meetings.

The teachers used their normal teaching strategies in the non-SDT program. That is, they controlled their students' learning experiences by telling them what to do, assigned specific subtopics and projects, and only allowed the students to use the BBC micro:bit tool to build their physical prototypes (i.e., less autonomy). They explained their expectations and offered one-off guidance to students in the first lesson only (i.e., less competence). Finally, they randomly assigned the students into groups, used no collaborative group portfolio, and conducted weekly meetings with the whole class (i.e., less relatedness).

This study investigated the effectiveness of the SDT STEM program on student development of STEM interest and identity. Therefore, to understand how the teacher needs support fostered student STEM interest and identity development, the following research questions were designed:

RQ1. Will the SDT program better foster student development of STEM interest and identity and support their needs than the non-SDT program?

RQ2. How does teachers' support of the students' needs relate to their subsequent development of STEM interest and identity, and their choice of future studies?

Accordingly, the following research hypotheses were proposed.

H1 (*RQ1*): Students in the SDT program will report significantly more positive STEM interest and identity than those in the non-SDT program.

H2 (*RQ2*): Student perceived teacher needs support will have significantly positive effects on their development of STEM interest and identity.

H3 (*RQ2*): Student STEM interest and identity before the programs will be associated with their educational development after the programs.

H4 (*RQ2)*: Student STEM interest and identity after the programs will be associated with their choice of future subjects.

A two-group intervention (i.e., SDT and non-SDT) was used to answer *RQ1*. A research model was proposed to answer *RQ1* (see Figure 2), where the main regression paths were specified using the student perceived teacher support of their needs directly to their development of post-STEM interest and identity. Three other pathways were specified: (i) from pre-STEM interest directly to pre-STEM identity and post-STEM interest; (ii) from pre-STEM identity and post-STEM interest directly to post-STEM identity; and (iii) from post-STEM identity directly to STEM subject choices.

Method

Participants

Hong Kong students choose their elective subjects for Grade 10 while in Grade 9. Therefore, the participants were 342 Grade 9 students from three schools who ranged in age from 14 to 16 years (51% female, 49% male). Schools with similar student academic achievement were selected from a completed research project in which the non-SDT program was developed. The schools have their own STEM laboratory and agreed to implement both non-SDT and SDT STEM programs. That is, they offered two lessons (80 minutes) per week for this project. In each school, the teacher participants included three mathematics, science, and technology teachers with experience teaching the non-SDT program to ensure consistent program delivery. There were approximately 110 students and 3 teachers from each school. The recommended minimum sample size for *RQ2* is 94 when the numbers of observed and latent variables are 29 and 7, respectively, according to the A-priori Sample Size Calculator for Structural Equation Models software (Soper, 2020). Hence, the sample size was appropriate for this study.

Research Procedure

Ethical approval for this study was obtained from the grantee's university, and informed consent was then obtained from the students and their parents. Before performing the main study, the project team ran three 3-hour workshops for the teacher participants to enhance their knowledge and skills about the SDT approach, in addition to conducting a trial of the SDT program with two small student groups to refine the SDT instructional design. The students also completed a 30-minute online prequestionnaire.

The main study used two intervention conditions (i.e., SDT and non-SDT) in each school. The students were randomly assigned to one of these two conditions. Three different subject teachers (i.e., science, mathematics, and technology) collaborated in teaching both conditions. In groups of 4-5 individuals, the student teams solved the STEM problem. These teams met with their teachers every 2 weeks to make sure that the programs ran appropriately. In the SDT condition, after the introduction of the STEM problem, the individual students performed their own research and then chose the subtopic and problem that they wanted to continue to study. Students within the similar subtopic/problem were assigned to the same group. Every week, the groups met to learn using their preferred activities and resources. They discussed their ideas as a group during lessons and in consultation meetings with teachers, and they shared their individual ideas and reflected on their learning experiences during the collaborative group portfolio. In the non-SDT condition, the students received the STEM subtopic in the beginning and were assigned randomly to groups. Every week, these groups learned through the assigned activities and resources, and they discussed their ideas in the whole class. In both conditions, the groups prepared their poster presentations to share their solutions with their peers, and they discussed further improvements with the teachers and all of the students in the last week, see Figure 3. The students completed a 30-minute postquestionnaire on the day of the presentation.

Moreover, the student teams conducted a read-through with two teachers to confirm that the questionnaire format and wording were understandable. Other than questions about personal characteristics, the questionnaire comprised the following 5-point Likert-scale self-reported measures (i.e., the student perceived teacher needs support, and STEM identity and interest).

The student perceived teacher needs support was used to measure the teacher facilitation of the student need for autonomy, competence, and relatedness. Four items for each need were adapted and modified from a study by Standage and colleagues (2005) that was conducted among similarly aged children with acceptable internal reliability. Chiu (2021) tested these items. The perceived teacher support of student autonomy was measured using four items with an original reliability of Cronbach's alpha (α = .92): "my STEM teachers provide us with choices and options," "my STEM teachers encourage us to ask questions," "my STEM teachers answer my questions fully and carefully," and "my STEM teachers make sure I really understand the goals of the lesson and what I need to do.". The perceived teacher support of student competence was measured using four items with an original Cronbach's alpha (α = .84): "my STEM teachers make me feel like I am good at learning," "I feel that my STEM teachers like us to do well," "my STEM teachers make me feel like I am able to do the activities in class," and "my STEM teachers help us to improve." The perceived teacher support of student relatedness was measured by four items with an original Cronbach's alpha ($\alpha = .88$): "my STEM teachers support me," "my STEM teacher is interested in me," "my STEM teachers are friendly toward me," and "my STEM teachers respect me."

The measurement of student STEM identity uses four items measuring recognition by peers and self, which were adapted and modified by Cohen and colleagues (2021). Four of the items measured perceived recognition by peers with an original reliability of 0.97: "my family sees me as a STEM person," "my friends see me as a STEM person," "my classmates see me as a STEM person," and "my classroom STEM teachers see me as a STEM person." One item measured self-recognition: "I see myself as a STEM person." These items were tested among similar age groups by Weng and colleagues (2022) with an original reliability of .90.

The measurement of STEM interest used four items from a validated instrument by Tyler-Wood and colleagues (2010) to measure middle and high school student STEM interest. The items were confirmed by Weng and colleagues (2022) with an original reliability of .88: "I find STEM fascinating," "I find STEM exciting," "I find STEM interesting," and "I find STEM means a lot."

The number of STEM subjects (*num_subj*) was measured using the number of STEM subject(s) that the student participants chose for Grade 10.

Results

Descriptive Statistics

The descriptive statistics for all of the variables are reported in Table 1. All mean values for the latent variables were higher than 3.00 (maximum value is 5) and was 1.8 for the observed variable (i.e., *num_subj*, where the maximum value is 3). This analysis suggested that the latent variables were internally reliable because the Cronbach's alpha values ranged from .94 to .97 (where good > .80). The values for skewness (i.e., < 2.3) and kurtosis (i.e., < 7.0) of all of the latent and observed variables were acceptable for data normality (Garson, 2012).

Measurement Model

For acceptable internal reliability, the factor loadings of all of the latent variables ranged from .82 to .97 (> .70) (Fornell & Lacker, 1981). Moreover, the fitness indices of the measured items indicated a good model fit: $\chi^2/df = 1.19$ (< 5.0); Tucker–Lewis index (TLI) = .93 (> .90); comparative fit index (CFI) = .94 (> .90); root means square error of approximation (RMSEA) = .02 (< .08); and standardized root mean squared residual (SRMR) = .03 (< .08) (Hair et al., 2010). The correlations between all of the latent variables were significant ($p < .05$) (Table 2). Accordingly, the data met all the assumptions for further analysis using structural equation modeling for *RQ2* (Kline, 2011).

[Add Tables 1 and 2 here]

Effect of Perceived Teacher Needs Support (*RQ1*)

Regarding *RQ1*, none of the averages for the latent and observed variables in each of the programs passed Levene's test; therefore, nonparametric analysis of variance (ANOVA) and analysis of covariance (ANCOVA) were used to assess whether there were significant differences between the SDT and non-SDT programs in all of the variables.

The Kruskal–Wallis test and nonparametric ANOVA showed that the students in the SDT program perceived significantly higher autonomy ($H(1) = 229.15$, $p < .001$), competence ($H(1) = 133.98$, $p < .001$), and relatedness ($H(1) = 108.01$, $p < .001$) than students in the non-SDT program. These findings also served as manipulation checks and demonstrated that the proposed SDT strategies were effective in this study.

The Kruskal–Wallis test also revealed insignificant differences between the two programs in the student pre-STEM interest ($H(1) = .12$, $p = .73$) and pre-STEM identity ($H(1) = 1.76$, $p = .18$). These findings indicated that the random assignment within the schools was successful with equal levels of student STEM interest and identity before the intervention. Quade's test and nonparametric (rank) ANCOVA showed that the students in the SDT program had significantly stronger post-STEM interest ($F(1, 341) = 1129.94$, $p < .001$) and identity ($F(1, 341) = 141.69$, $p < .001$) than those in the non-SDT program with their pre-STEM interest and identity used as covariates.

Finally, a Kruskal–Wallis test indicated that *num_subj* in the SDT program was significantly higher than that in the non-SDT program ($H(1) = 31.14$, $p < .001$).

Overall, these results showed that the proposed strategies for teacher needs support increased the student sense of autonomy, competence, and relatedness and led to the development of stronger STEM interest and identity, in addition to stronger behavior to choose STEM subjects (supporting *H1*).

Hypothesis Testing in the Research Model

Structural equation modeling also showed how well fitted the model was by estimating the path coefficients and R-squared values (R^2). The path coefficients and R^2 indicated that exogenous variables explain the strength of the relationships and the amount of variance in endogenous variables, respectively. These analyses aim to understand how teacher needs support and student pre-STEM interest and identity contribute to student post-STEM interest and identity, in addition to subject choices.

The main regression paths in the research model are specified using the three exogenous variables, namely, perceived teacher autonomy, competence, and relatedness support, which lead directly to the two endogenous variables, namely student post-STEM interest and identity. The other paths are (i) from the exogenous variable of pre-STEM interest directly to the two endogenous variables of pre-STEM identity and post-STEM interest; (ii) from the two exogenous variables of pre-STEM identity and post-STEM interest directly to the endogenous variable of post-STEM identity; and (iii) from the exogenous variable of post-STEM identity directly to the endogenous variable of STEM subject choice. The model showed a good fit to the data: χ^2/df = 1.18 (< 5.0); TLI = .92 (> .90); CFI = .93 (> .90); RMSEA = .02 (< .08); and SRMR = .04 (< .08) (Hair et al., 2010).

Table 3 shows the results for all of the hypotheses in addition to the standardized direct, indirect, and total effects for each path. Moreover, Figure 2 shows the results of the path coefficients in the research model. All of the hypothesized paths in the research model were significantly supported (all *p* values < .05) except for two: pre-STEM interest to post-STEM interest and post-STEM identity to post-STEM identity.

Four exogenous variables explained 56% of the variance in post-STEM interest. Competence had the largest direct and total effect on post-STEM interest (β = .40), followed by relatedness (β = .29), autonomy (β = .14), and pre-STEM interest (β = .08). Moreover, six variables explained 65% of the variance in post-STEM identity. Competence (β = .36) and relatedness (β = .36) had the largest total effects on post-STEM identity, followed by post-STEM interest (β = .21), autonomy (β = .21), pre-STEM interest (β = .02), and pre-STEM identity (β = .01). Furthermore, seven variables explained 36% of the variance in *num_subj*. Post-STEM identity (β = .60) had the largest direct and total effects on *num_subj*. The other six variables had only indirect effects on *num_subj*: competence (β = .22), relatedness (β = .22), pre-STEM interest (β = .14), post-STEM interest (β = .13), autonomy (β = .11), and pre-STEM identity (β = .01). Finally, pre-STEM interest explained 15% of the variance in pre-STEM identity (β = .38).

Overall, students' perceived teacher needs support was a significant predictor of their post-STEM interest and identity (*H2*), but pre-STEM interest and identity were not (*H3*). Student perceived teacher support for competence and relatedness were the strongest predictors. Post-STEM identity was a predictor for the number of STEM subjects (*H4*), while pre-STEM interest was a predictor for pre-STEM identity (*H3*).

[Add Table 3 here]

Discussion

Empirical Implications

The results offer four empirical implications. First, as predicted, the proposed strategies have a significant impact on student perceived teacher needs support for autonomy, competence, and relatedness in STEM learning activities, which resulted in the student stronger STEM interest and identity, in addition to greater intentions to choose STEM subjects for elective study (*H1*). These results imply that these strategies would better support the student three SDT needs in STEM learning activities. According to SDT, the internalization of activities and pursuits valued by oneself and/or one's peers is regarded as a basic process in the development of STEM interest and identity. In addition, the students' needs for autonomy, competence, and relatedness fuels their active, sustained, persistent, and motivated activity (La Guardia, 2009; Ryan & Deci, 2020). The more the students internalize their learning experiences in integrated STEM education, the more joy, value, content, and proficiency they have, in addition to greater autonomous motivation (Chiu et al., 2022; Ryan & Deci, 2020). These STEM learning experiences with perceived teacher needs support drove the student stronger STEM interest and identity in the SDT program. In this program, the students felt (i) more competent to learn and create for their own growth (i.e., competence); (ii) more access and engagement with teachers and peers to share their learning interests, values, behaviors, and goals (i.e., relatedness); and (iii) greater ownership of learning (i.e., autonomy) (Chiu, et al., 2021; Godwin et al., 2016; Kim et al., 2018). In the non-SDT program, the students who did not master the BBC micro:bit tool felt frustrated and controlled, and they did not finish their prototypes. Thus, the students (i) found that the STEM learning activities including problems, learning approaches, and ideas/solutions were more relevant and fun. In addition, they (ii) felt that their skills and knowledge were recognized more by themselves, their peers, and their teachers. This perceived teacher support of their needs led to autonomous motivation, which provided high-quality energy and encouraged the students to think about their strengths and interests regarding STEM learning activities (Chiu et al., 2021), which led to a stronger development of STEM interest and identity.

The second empirical implication is that the students' perceived teacher support for their autonomy, competence, and relatedness was strongly associated with their STEM interest and identity (*H2*). Teachers can foster student development of STEM interest and identity by supporting student three needs through integrated STEM learning problems. These results are aligned with studies related to SDT-based teacher motivational behaviors (De Meyer et al., 2014; Moore et al., 2020; Weng et al., 2022). However, students' STEM interest and identity before the intervention were not associated with their STEM interest and identity after the intervention (*H3*). This result implies that in this study, the student development of STEM interest and identity was significantly affected by their teacher motivational behaviors and insignificantly affected by their pre-STEM interest and identity. A plausible explanation for this finding is that the student participants in this study were early or middle adolescents (Rich & Schachter, 2012), whose STEM interest and identity were still in a developmental stage (i.e., their brains are still developing) and in a process of self-discovery, which is affected by their teacher motivational behaviors. These adolescents are still figuring out who they are, and their identity development is a central feature of their school life. The development of these student STEM interest and identity is shaped by many factors, including their teachers, peers, and STEM learning experiences (Verhoeven et al., 2019). In STEM learning activities, these adolescent students are actively taking steps and making choices that reflect how they see themselves. The students in the SDT program selected their own learning problems and approaches, in addition to the teachers and students they want to be associated with. These students were constantly adjusting their beliefs, perceptions, attitudes, and behaviors based on the feedback from their teachers and peers (Verhoeven et al., 2019). The adolescents consider all these factors while working out their identity through integrated STEM learning activities to shape their STEM interest and identity.

The third implication is that among the three SDT needs, competence and relatedness had larger effects on student STEM interest and identity than did autonomy (*H2*). This result implies that the way the teachers structured and scaffolded integrated STEM learning activities and students' good relationships with their teachers and peers play an extremely important role in STEM learning activities when the learning goal is to develop their STEM interest and identity. These results differ from many empirical studies advocating the universal functional importance of student autonomy (León et al., 2015; Ryan et al., 2011). Teacher autonomy support is still one of the most influential factors in school learning; however, its effects were diminished in the context of integrated STEM learning.

Fourth, as predicted, students' STEM interest and identity before the intervention were strongly associated with their STEM interest and identity after the intervention (*H3*). These results follow most studies exploring the strong relationship between interest and identity. Students with more developed interests have greater self-efficacy and can better self-regulate their behavior to persevere with challenging tasks (Hidi & Ainley 2008). These students will enjoy the STEM learning activities and consider themselves as having a STEM identity (Verhoeven et al., 2019).

This final implication reflects the importance of STEM identity, which is an important predictor of student future career and study choices in a STEM field (Bieri Buschor et al., 2014; Robinson et al., 2019) (supporting *H4*). The student development of a STEM identity increases the likelihood that these students will work toward developing STEM literacy or even pursue a STEM-related career. The powerful influence of a STEM identity necessitates that researchers and teachers pursue a better understanding of the underlying mechanism. Modeling a STEM identity in teaching activities is effective because it creates a set of positive expectations leading to greater student engagement. That is, students and teachers take control of their learning and working activities because they are motivated by their genuine interest and excitement (see autonomy in SDT, Ryan & Deci, 2020; Chiu, 2022).

Theoretical Contributions

This study makes two theoretical contributions to the literature. There are no SDT-based empirical studies that explore the development of an integrated STEM interest and identity in both K-12 and higher education. Very few SDT-based studies have explored factors in student choice of STEM majors and careers to improve science education in higher education (Skinner et al., 2017). These findings encourage educators, researchers, and interventionists to improve the quality of undergraduate science learning and teaching (i.e., developing a scientist identity) by focusing on student motivational experiences. Therefore, our first two empirical implications contribute to SDT by adding a new dimension, namely, STEM interest and identity, and present more evidence for how students' perceived teacher support of their needs fosters the development of integrated STEM interest and identity.

The second contribution of this study is to address the knowledge gap in integrated STEM education, as most studies related to STEM interest and identity have (i) ignored its integrated nature, focused on multiple disciplines (e.g., Godwin et al., 2016; Skinner et al., 2017), and examined STEM education using role models and mentors to foster stronger STEM identity among underrepresented groups (Carlone & Johnson, 2007; Kim et al., 2018). These studies have advocated how to teach single STEM subjects that foster the development of STEM identity but have not integrated STEM interest and identity. In addition, mentoring requires many resources and may not be workable in universal K-12 education. Accordingly, our first three empirical findings contribute to the STEM K-12 education literature by using student perceived teacher needs support to foster the development of STEM identity in integrated learning activities. The third finding further suggests that teacher support of student competence and relatedness is more important than their support of autonomy in integrated learning activities because integrated learning often offers more choices to students.

Practical Suggestions

Other than the proposed strategies for teacher support, this study offers three practical suggestions for curriculum designers and teachers to foster their students' STEM interest and identity by satisfying their three needs in integrated STEM learning. The first suggestion is to advocate integrated STEM learning in K-12, which can be implemented with approaches using a single discipline or the integration of more disciplines. Most STEM education programs focus on science. However, recent studies advocate for integrated STEM learning (Moore & Smith, 2014; Struyf et al., 2019). Our findings demonstrate an effective approach, i.e., SDT, in developing student STEM interest and identity through integrated instruction. The results suggest that teachers should focus on supporting student needs instead of providing disciplined instruction in this interdisciplinary context by focusing on disciplinary knowledge development in during individual subject lesson times. Moreover, most studies have used mentors and role models to stimulate student development of greater STEM interest and stronger identity. The practical suggestions from this study offer an alternative instructional approach that requires fewer resources to achieve the same outcomes.

The second suggestion is to foster relatedness in integrated STEM learning. Curriculum designers and teachers should design learning environments or contexts for more relevant and authentic learning (e.g., supporting student relatedness need in the second empirical finding). For example, teachers can ask their students to analyze a neighborhood-based problem by talking with members of the students' community. In addition, the teachers can design STEM problems using a career approach, e.g., asking their students to imagine being a playground designer. Teachers could also use a community of inquiry model (Garrison et al., 2001) to build a learning community by engaging students with the same interests and goals from different schools in their STEM learning activities. This learning experience occurs at the intersection of social, cognitive, and teaching presence.

Finally, teachers should support student need for competence in integrated STEM learning activities, where STEM problems could be solved in many different ways. For example, some students may use a scientific perspective to tackle fundamental issues, some students may use mathematical skills to predict the effectiveness of their ideas, and other students may use engineering and technology solutions to build and test their prototypes before understanding the underlying scientific reasoning. Curriculum designers and teachers should produce various skill-based self-learning videos or infographics to support student learning needs (Chiu, 2022; Chiu & Churchill, 2015). Multimedia activities could allow the students to choose the skills they need to work through their ideas and solutions, in addition to learning or mastering the skills that they are not familiar with (Chiu 2021). Enhancing students' skills in creating prototypes supports their competence and helps them to develop positive attitudes and values, which better fosters their development of STEM interest and identity.

Limitations and Future Directions

The study's findings suggest that to enable students' integrated STEM learning experiences that are more abstract and complicated than multidisciplinary STEM learning activities, teachers must support their students' needs. This study had five limitations. First, the proposed teacher needs support strategies were likely to better satisfy student innate needs. However, more experiments using new motivational behaviors are required to validate these findings. For example, how teachers can use digital and emerging technologies to provide students with immediate feedback (Chiu, 2021, 2022). Second, this paper did not examine the gender difference in supporting student needs because girls are more likely to perceive their teachers as being more supportive than boys (Katz, 2017; Lietaert et al., 2015). Future studies should use different strategies to explore how different genders perceive teacher support. Third, this study used a more integrated approach to measure student STEM interest and identity. These support strategies for student needs may not work in individual disciplines, such as science identity or mathematics interest. The findings of this study should be extended by exploring these strategies in science/mathematics or multiple STEM learning activities. Fourth, this study was conducted at the middle school level with early/middle adolescents. Different age groups require different levels of needs support, with subsequent different effects. More studies should investigate teachers' support of their students' needs in higher education level, i.e., late adolescents. Finally, student interest and identity develop and change over time and 12 weeks may not be long enough to reveal this development. Therefore, longitudinal studies are recommended to track how student STEM interest and identity can be fostered over time.

Overall, this study supports the application of SDT in integrated STEM learning and explains how teacher needs support affects student development of STEM interest and identity. Therefore, teachers' support of their students' needs is crucial in interdisciplinary learning, namely, STEM education, and it effectively fosters adolescents' STEM interest and identity in K-12.

Declarations

Declaration of interest statement

- The datasets used for the current study are available from the corresponding author on reasonable request.
- There is no conflict of interests between the author and participants.

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Figures

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