Using Self-determination Theory (SDT) to Explain Student STEM Interest and Identity Development

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Abstract

Students' strongly positive STEM interest and identity predict their future study and career choices in a STEM field. STEM education studies addressing multiple disciplines together are insufficient, as they have produced mixed findings and inadequate direction for advancing integrated STEM education. 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 a set of proposed teacher needs-supportive strategies on student STEM interest and identity development during a proposed 12-week SDT-based STEM program. Three hundred forty-two ninth grade students were randomly assigned to SDT and non-SDT groups during the program. 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—integrated STEM interest and identity—and presenting more evidence on how the teacher's needs-supportive strategies 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 compulsory education.

Keywords: STEM education, interest, identity, self-determination theory (SDT), needs satisfaction, K-12 Education, teacher support

Introduction

In meeting socioeconomic challenges with the future workforce, we must improve the recruitment and retention of tertiary 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. STEM interest is a relatively enduring preference for certain topics, subject areas, and activities (Hidi, 1990; Renninger & Hidi, 2011; Schiefele, 1991); and STEM identity refers to 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). A solution to this challenge is integrated STEM education that combines the subject matter of at least two STEM subjects into a joint learning experience (English, 2016; Moore & Smith, 2014), which better develops students' positive interest and identity (Struyf et al., 2019). However, most STEM 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). Student interest and identity development 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 involved in the internalization of student 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 for 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 can foster or suppress student interest and identity. Therefore, this study used SDT to propose teacher needs-supportive strategies 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 student development of STEM interest and identity, thus improving STEM education and policy research strategies.

Literature Review

SDT as a Theoretical Framework 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 basic 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 is 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 defines five types of motivation and forms a motivation continuum. Intrinsic motivation (i) refers to autonomous behaviors undertaken for enjoyment and interest, while extrinsic motivation includes behaviors intended to obtain four distinct outcome categories (Ryan & Deci, 2020), namely, (ii) external, (iii) introjected, (iv) identified, and (v) integrated regulation. 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 about 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 these values and goals. Supporting individuals’ needs is essential to the internalization process. When all the needs are met, 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 to learn by satisfying their needs. Studies that apply SDT to STEM education emphasize its importance in promoting autonomous 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 students' sense of competence (Chiu et al., 2022, 2023; 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, students' 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, 2021, 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 students' psychological need for emotional connections by fostering interpersonal relationships (Chiu et al., 2020). 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.

Perceived Teacher SDT Needs Support 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; 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 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). In summary, motivated students who internalize their learning experiences during STEM activities are more likely to develop a positive STEM interest and identity. In schools, children's and adolescents' interest and identity are still developing, and their motivation is worth studying (Guay, 2022). Teachers are their major learning partners in classrooms, and play a crucial role in fostering their motivation (Allen et al., 2013). Therefore, perceived teacher need support is one of the most important factors. Teachers can enhance STEM interest and identity by encouraging student autonomy, ensuring learning, and being involved interpersonally (Guay, 2022). Science interest and identity can be fostered by teachers in an SDT-based intervention (Moore et al., 2020). Teachers in the intervention can increase autonomy by allowing students to pick a project they are interested in, competency by fostering student knowledge of their subject before the project, and relatedness by making students feel accepted in the classroom through mentoring. This further highlights the advantage of using SDT to increase STEM interest and identity (Moore et al., 2020).

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). Although studies have clearly defined STEM interest in the literature, the development of STEM identity is less clearly defined (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). Therefore, existing studies related to STEM interest and identity have not explained its development in an integrated context. To our knowledge, fewer SDT-based studies have explained the development of STEM interest and identity in integrated STEM education. Moreover, teachers are the major learning partners of school students whose motivation, interest, and identity are still developing. Their needs-supportive strategies can motivate or demotivate STEM learning, which may affect interest and identity development. Accordingly, this study investigates how students' perceived teacher needs for support explain STEM interest and identity in integrated learning.

This Study

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. The following 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.*

In the SDT program, to foster student autonomy, the teachers took the student's perspective: encourage their autonomy during learning activities and use invitational language. The students decided on what subtopics or projects they wanted to investigate, 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 students' need for competence, the teachers explained how they 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 student emotional connections by fostering interpersonal relationships through the formation of student groups by matching the students with similar self-identified subtopics or projects. The teachers also used a collaborative group portfolio to foster an intimate group experience and conducted weekly teacher-student group meetings. In the non-SDT program, the teachers used their normal teaching strategies. They controlled their students' learning experiences by telling them what to do, assigning them specific subtopics and projects, and only allowing them 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 examines the effectiveness of the SDT STEM program on student development of STEM interest and identity, and investigates how student perceived teacher needs support explains STEM interest and identity in integrated learning. See the following research questions.

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

RQ2. What are the interrelationships among teachers' support of students' basic psychological needs and students' subsequent development of integrated STEM interest, identity, and 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): Students' perceived teacher needs for support will have significantly positive effects on their development of STEM interest and identity. H3 (RQ2): Student STEM interest will be associated with their STEM identity before / 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 RQ2 (see Figure 2), where the main regression paths were specified using the student's perceived teacher support of their needs directly related 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 laboratories and have agreed to implement both non-SDT and SDT STEM programs. That is, they offered two lessons (80 minutes) per week for 12 weeks. 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 (total of nine teachers). They also have at least 10 years of teaching experience and have taught in junior and senior forms, i.e., Grade 7 – 12. There were approximately 110 students and three teachers from each school.

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 author, who is an international SDT scholar, 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 measuring all the variables for this study, which is discussed next before the intervention. 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 the same school. They facilitated the student learning with a focus on their own major teaching subject to make sure the students used STEM knowledge to solve their problems. In groups of 4-5 individuals, the student teams solved the STEM problem. Table 1 describes the teaching method in SDT and non-SDT conditions. 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 with similar subtopics or problems 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 at the beginning and were assigned randomly to groups. Every week, these groups learned through the assigned activities and resources, and they discussed their ideas with 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). Moreover, every two weeks, the author observed one lesson of both conditions in all the schools (totaling six lessons every two weeks) and met with the teachers to make sure the intervention and control groups ran as planned. Finally, the students completed the same questionnaire on the day of the presentation. The students were required to explicitly share their STEM knowledge used to solve the problems in the poster presentation. For example, science: how the solar panel works in the design; technology: using low (e.g., any available materials) and high (e.g., micro: bit and husky lens) technology materials; mathematics: prediction, probability, estimation (e.g., estimate / predict the result using equations), shape (e.g., recognize the properties of different shapes), data handling (e.g., organizing and representing statistical data); engineering: engineering thinking: propose various solutions, and choose the best-fit solutions with evidence.

[Add Tables 1 here]

Instruments

The questionnaire comprised the following 5-point Likert-scale self-reported measures. First, perceived teacher needs support was used to measure the teacher facilitation of the student's need for autonomy, competence, and relatedness. Four items for each need were adapted and modified from a study by Chiu (2021), and Standage and colleagues (2005) that was conducted among similarly aged children with acceptable internal reliability. Perceived autonomy support 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.". Perceived competence support was measured using four items with an original α = .84: "My STEM teachers make me feel like I am able to do the activities in class," "I feel that my STEM teachers like us to do well," "my STEM teachers make me feel like I am good at learning," and "my STEM teachers help us to improve." Perceived teacher relatedness support was measured by four items with an original α = .88): "my STEM teachers are interested in me," "my STEM teachers respect me," "my STEM teachers are friendly toward me," and "my STEM teachers support me." STEM identity used four items measuring recognition by others and oneself, which were adapted and modified by Cohen and colleagues (2021). The items measured perceived recognition by others with an original reliability of 0.97: "My family sees me as a STEM person," "my classmates see me as a STEM person," and "my classroom STEM teachers see me as a STEM person.". The 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. STEM interest was measured using four items from a validated instrument by Tyler-Wood and colleagues (2010). 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_STEM_subject) 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 2. 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_STEM_subject*, 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).

Data analyses

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.

To answer RQ2, 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 perceived teacher needs support and student pre-STEM interest and identity contribute to student post-STEM interest and identity, in addition to subject choices.

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: χ^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 3). Accordingly, the data met all the assumptions for further analysis using structural equation modeling for *RQ2* (Kline, 2011).

[Add Tables 2 and 3 here]

Effect of Perceived Teacher Needs Support (*RQ1*)

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_STEM_subject* 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 teacher needs-supportive strategies 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 (RQ2)

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: $\chi^2/df = 1.18$ (< 5.0); TLI = .92 (> .90); CFI = .93 (> .90); RMSEA = .02 (< .08); and SRMR = .04 (< .08) (Hair et al., 2010).

Table 4 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_STEM_subject*. Post-STEM identity (β = .60) had the largest direct and total effects on *num_STEM_subject*. The other six variables had only indirect effects on *num_STEM_subject*: 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, perceived teacher needs support was a significant predictor of post-STEM interest and identity (*H2*), but pre-STEM interest and identity were not. 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 post-STEM interest was a predictor for post-STEM identity (H3).

[Add Table 4 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 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 satisfy the three 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 needs satisfaction fuels student 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). The plausible explanations are, in the SDT 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). Perceived needs satisfaction from teachers support 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). The satisfaction better foster STEM interest and identity development.

The second empirical implication is that the need for satisfaction. The results offer four empirical implications. First, as predicted, the proposed strategies have a significant impact on students' perceived teacher needs support for autonomy, competence, and relatedness in STEM learning activities, which resulted in 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 satisfy the three needs of 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, satisfaction with needs fuels students' 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). The plausible explanations are that in the SDT 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). Perceived needs satisfaction from teacher support 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). The satisfaction will better foster STEM interest and identity development. was strongly associated with STEM interest and identity (H2). Teachers can foster student STEM interest and identity development by supporting their three needs in integrated STEM learning. 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). Moreover, student 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 development was significantly affected by their teacher's motivational behaviors and insignificantly affected by their pre-STEM interest and identity. A plausible explanation for the findings is that the students were early or middle adolescents (Rich & Schachter, 2012), whose STEM interest and identity were still in a developmental stage and in a process of self-discovery, which is affected by their teacher's motivational behaviors. These adolescents are still figuring out who they are, and their identity development is a central feature of their school life. Their development is shaped by many factors, including their teachers, peers, and STEM learning experiences (Verhoeven et al., 2019). In the SDT program, the adolescents were constantly adjusting their beliefs, perceptions, attitudes, and behaviors based on the feedback from their teachers (Verhoeven et al., 2019). Therefore, teacher input could 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 autonomy did (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 seem less important in the context of integrated STEM learning. A plausible explanation is the nature of STEM projects. Students may want to use non-STEM perspectives (e.g., social science, art,psychology) to solve the problems. But they were forced to explicitly use STEM knowledge in solving the problems, resulting in less needs support for autonomy.

Fourth, as predicted, student STEM interest was significantly associated with their STEM 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). They 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 students' future career and study choices in a STEM field (Bieri Buschor et al., 2014; Robinson et al., 2019) (supporting H4). 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 that lead to greater student engagement. Students take control of their learning activities because they are motivated by their genuine interest and excitement (see autonomy in SDT, Ryan & Deci, 2020; Chiu, 2021, 2022).

Theoretical Contribution

This study makes a theoretical contribution to the literature by addressing the knowledge gap in integrated STEM education. As most studies related to STEM interest and identity have 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). Accordingly, our first three empirical findings contribute to the STEM K-12 education literature by using perceived teacher needs support to explain the development of STEM identity in integrated learning activities.

Practical Suggestions

Other than the proposed strategies for teacher support, this study offers three practical suggestions for curriculum designers and teachers to foster student STEM interest and identity development. The first suggestion is to advocate integrated STEM learning in K-12. Our findings demonstrate an effective approach, i.e., SDT, to 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 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 relatedness 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., by asking their students to imagine being a playground designer. Teachers could also use the 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 presences.

Finally, teachers should support students' needs 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 & 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 student skills in creating prototypes supports their competence and helps them develop positive attitudes and values, which better foster their development of STEM interest and identity.

Limitations and Future Directions

This study's findings suggest that to enable students' integrated STEM learning experiences, teachers must support student needs. It had six limitations. First, the proposed teacher needs support strategies were likely to better satisfy students' 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 and middle school adolescents. Different age groups require different levels of needs support, with different subsequent effects. More studies should investigate perceived teacher needs support at the higher education level, i.e., late adolescents. Fifth, 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. Finally, the results are primarily based on self-reported data, which may threaten the validity of the data. Future studies should include teachers' or peers' views on the participants.

Ethical Approval and Funding

- This study got ethical clearance from the author's university, and consents from all the participants
- There is no conflict of interests between the author and participants.
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References

Allen, J., Gregory, A., Mikami, A., Lun, J., Hamre, B., & Pianta, R. (2013). Observations of effective teacher–student interactions in secondary school classrooms: Predicting student achievement with the classroom assessment scoring system—secondary. *School Psychology Review, 42*(1), 76-98.

Bieri Buschor, C., Berweger, S., Keck Frei, A., & Kappler, C. (2014). Majoring in STEM—What accounts for women's career decision making? A mixed methods study. *The Journal of Educational Research, 107*(3), 167-176. https://doi.org/10.1080/00220671.2013.788989

Carlone, H.B., & Johnson, A. (2007). Understanding the science experiences of successful women of color: Science identity as an analytic lens. *Journal of Research in Science Teaching: 44*(8), 1187-1218. https://doi.org/10.1002/tea.20237

Chiu T. K. F. (2022). Applying the Self-determination Theory (SDT) to explain student engagement in online learning during the COVID-19 pandemic. *Journal of Research on Technology in Education, 54*(sup1), 14-30. http://dx.doi.org/10.1080/15391523.2021.1891998

Chiu T. K. F. (2021). Digital support for student engagement in blended learning based on Self-determination Theory. *Computers in Human Behavior, 124*, 106909 http://dx.doi.org/10.1016/j.chb.2021.106909

Chiu T. K. F., Chai C. S., Williams, J, & Lin T. J. (2021). Teacher professional development on Self-determination Theory-based design thinking in STEM education. *Education Technology & Society, 24* (4), 153–165

Chiu, T. K. F., & Churchill, D. (2015). Exploring the characteristics of an optimal design of digital materials for concept learning in mathematics: multimedia learning and variation theory. *Computers & Education, 82*, 280-291. https://doi.org/10.1016/j.compedu.2014.12.001

Chiu, T. K. F., Jong, M, & Mok, I.A.C. (2020). Does learner expertise matter when designing emotional multimedia for learning primary school mathematics?. *Educational Technology Research and Development, 68,* 2305–2320.

Chiu, T. K. F., Moorhouse, B. L., Chai, C. S, & Ismailov M. (2023). Teacher support and student motivation to learn with Artificial Intelligence (AI) chatbot, *Interactive Learning Environments, Advanced online publication,* https://doi.org/10.1080/10494820.2023.2172044

Chiu T. K. F., Sun J. C. Y., & Ismailov M. (2022). Investigating the relationship of technology learning support to digital literacy from the perspective of Self-Determination Theory. *Educational Psychology, 42* (10), 1263-1282, https://doi.org/10.1080/01443410.2022.2074966

Cohen, S. M., Hazari, Z., Mahadeo, J., Sonnert, G., & Sadler, P. M. (2021). Examining the effect of early STEM experiences as a form of STEM capital and identity capital on STEM identity: A gender study. *Science Education, 105*(6), 1126-1150. https://doi.org/10.1002/sce.21670

De Meyer, J., Tallir, I. B., Soenens, B., Vansteenkiste, M., Aelterman, N., Van den Berghe, L., ... & Haerens, L. (2014). Does observed controlling teaching behavior relate to students' motivation in physical education?. *Journal of Educational Psychology, 106*(2), 541. https://doi.org/10.1037/a0034399

Dyrberg, N. R., & Holmegaard, H. T. (2019). Motivational patterns in STEM education: a self-determination perspective on first year courses. *Research in Science & Technological Education, 37*(1), 90-109. https://doi.org/10.1080/02635143.2017.1421529

English, L. D. (2016). STEM education K-12: Perspectives on integration. *International Journal of STEM Education, 3*(1), 3. https://doi.org/10.1186/s40594-016-0036-1

Guay, F. (2022). Applying self-determination theory to education: regulations types, psychological needs, and autonomy supporting behaviors. *Canadian Journal of School Psychology, 37*(1), 75-92. https://doi.org/10.1177/08295735211055355

Garrison, D. R., Anderson, T., & Archer, W. (2001). Critical thinking, cognitive presence, and computer conferencing in distance education. *American Journal of Distance Education, 15*(1), 7-23. https://doi.org/10.1080/08923640109527071

Godwin, A., Potvin, G., Hazari, Z., & Lock, R. (2016). Identity, critical agency, and engineering: An affective model for predicting engineering as a career choice. *Journal of Engineering Education*, *105*(2), 312-340. https://doi.org/10.1002/jee.20118

Goos, M., & Bennison, A. (2019). A zone theory approach to analysing identity formation in mathematics education. *ZDM, 51*(3), 405-418. https://doi.org/10.1007/s11858-018-1011-8

Hidi, S. (1990). Interest and its contribution as a mental resource for learning. *Review of Educational Research, 60*(4), 549-571. https://doi.org/10.3102/00346543060004549

Hidi, S., & Ainley, M. (2008). Interest and self-regulation: Relationships between two variables that influence learning. In D. H. Schunk & B. J. Zimmerman (Eds.), *Motivation and Self-Regulated Learning: Theory, Research, and Applications* (pp. 77-109). Mahwah, NJ, US: Lawrence Erlbaum Associates Publishers.

Hill, P. L., Allemand, M., & Burrow, A. L. (2010). Identity development and forgivingness: Tests of basic relations and mediational pathways. *Personality and Individual Differences*, *49*(5), 497-501. https://doi.org/10.1016/j.paid.2010.05.011

Honey, M., Pearson, G., & Schweingruber, H. (Eds.). (2014). *STEM integration in K-12 education: Status, prospects, and an agenda for research (Vol. 500)*. Washington, DC: National Academies Press.

Katz, I. (2017). In the eye of the beholder: Motivational effects of gender differences in perceptions of teachers. *The Journal of Experimental Education, 85*(1), 73-86. https://doi.org/10.1080/00220973.2015.1101533

Kim, M. (2018). Understanding children's science identity through classroom interactions. *International Journal of Science Education, 40*(1), 24-45. https://doi.org/10.1080/09500693.2017.1395925

Kim, A.Y., Sinatra, G. M., & Seyranian, V. (2018). Developing a STEM identity among young women: a social identity perspective. *Review of Educational Research, 88*(4), 589-625. https://doi.org/10.3102/0034654318779957

La Guardia, J. G. (2009). Developing who I am: A self-determination theory approach to the establishment of healthy identities. *Educational Psychologist, 44*(2), 90-104. https://doi.org/10.1080/00461520902832350

León, J., Núñez, J. L., & Liew, J. (2015). Self-determination and STEM education: Effects of autonomy, motivation, and self-regulated learning on high school math achievement. *Learning and Individual Differences, 43*, 156-163. https://doi.org/10.1016/j.lindif.2015.08.017

Lietaert, S., Roorda, D., Laevers, F., Verschueren, K., & De Fraine, B. (2015). The gender gap in student engagement: The role of teachers' autonomy support, structure, and involvement. *British Journal of Educational Psychology, 85*(4), 498-518. https://doi.org/10.1111/bjep.12095

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

Moore, M. E., Vega, D. M., Wiens, K. M., & Caporale, N. (2020). Connecting theory to practice: Using self-determination theory to better understand inclusion in STEM. *Journal of Microbiology & Biology Education, 21*(1), 05. https://doi.org/10.1128/jmbe.v21i1.1955

Niemiec, C. P., & Ryan, R. M. (2009). Autonomy, competence, and relatedness in the classroom: Applying self-determination theory to educational practice. *Theory and Research in Education, 7*(2), 133-144. https://doi.org/10.1177/1477878509104318

Renninger, K. A., & Hidi, S. (2011). Revisiting the conceptualization, measurement, and generation of interest. *Educational Psychologist, 46*(3), 168-184. https://doi.org/10.1080/00461520.2011.587723

Rich, Y., & Schachter, E. P. (2012). High school identity climate and student identity development. *Contemporary Educational Psychology, 37*(3), 218-228. https://doi.org/10.1016/j.cedpsych.2011.06.002

Robnett, R. D., & Leaper, C. (2013). Friendship groups, personal motivation, and gender in relation to high school students' STEM career interest. *Journal of Research on Adolescence, 23*(4), 652-664. https://doi.org/10.1111/jora.12013

Robinson, K. A., Perez, T., Carmel, J. H., & Linnenbrink-Garcia, L. (2019). Science identity development trajectories in a gateway college chemistry course: Predictors and relations to achievement and STEM pursuit. *Contemporary Educational Psychology, 56*, 180-192. https://doi.org/10.1016/j.cedpsych.2019.01.004

Ryan, R. M., & Deci, E. L. (2003). On assimilating identities to the self: A self-determination theory perspective on internalization and integrity within cultures. In M. R. Leary & J. P. Tangney (Eds.), *Handbook of self and identity* (pp. 253–272). New York: Guilford.

Ryan, R. M., & Deci, E. L. (2017). *Self-determination theory: Basic psychological needs in motivation development and wellness.* New York, NY: Guilford Press.

Ryan, R. M., & Deci, E. L. (2020). Intrinsic and extrinsic motivation from a self-determination theory perspective: Definitions, theory, practices, and future directions. *Contemporary Educational Psychology*, *61*, 101860. https://doi.org/10.1016/j.cedpsych.2020.101860

Ryan, R. M., Lynch, M. F., Vansteenkiste, M., & Deci, E. L. (2011). Motivation and autonomy in counseling, psychotherapy, and behavior change: A look at theory and practice 1ψ7. *The Counseling Psychologist, 39*(2), 193-260. https://doi.org/10.1177/0011000009359313

Schiefele, U. (1991). Interest, learning, and motivation. *Educational Psychologist*, *26*(3-4), 299-323. https://doi.org/10.1080/00461520.1991.9653136

Standage, M., Duda, J. L., & Ntoumanis, N. (2005). A test of self-determination theory in school physical education. *British Journal of Educational Psychology*, *75*(3), 411-433. https://doi.org/10.1348/000709904X22359

Struyf, A., De Loof, H., Boeve-de Pauw, J., & Van Petegem, P. (2019). Students' engagement in different STEM learning environments: integrated STEM education as promising practice?. *International Journal of Science Education, 41*(10), 1387-1407. https://doi.org/10.1080/09500693.2019.1607983

Skinner, E., Saxton, E., Currie, C., & Shusterman, G. (2017). A motivational account of the undergraduate experience in science: brief measures of students' self-system appraisals, engagement in coursework, and identity as a scientist. *International Journal of Science Education, 39*(17), 2433-2459. https://doi.org/10.1080/09500693.2017.1387946

Tyler-Wood, T., Knezek, G., & Christensen, R. (2010). Instruments for assessing interest in STEM content and careers. *Journal of Technology and Teacher Education*, *18*(2), 345-368.

Verhoeven, M., Poorthuis, A. M., & Volman, M. (2019). The role of school in adolescents' identity development. A literature review. *Educational Psychology Review*, *31*(1), 35-63. https://doi.org/10.1007/s10648-018-9457-3

Vincent-Ruz, P., & Schunn, C. D. (2018). The nature of science identity and its role as the driver of student choices. *International Journal of STEM Education*, *5*(1), 48. https://doi.org/10.1186/s40594-018-0140-5

Weng X. J., Chiu T. K. F., & Jong, M. S. Y. (2022). Applying relatedness to explain learning outcomes of STEM maker activities, *Frontiers in Psychology*, 800569 https://doi.org/10.3389/fpsyg.2021.800569

Perceived needs	SDT-condition	non-SDT condition
Autonomy	• the students performed their own research and then chose the subtopic and problem that they wanted to continue to study.	• the students received the STEM subtopic in the beginning
Competency	• every week, the student groups met to learn using their preferred activities and resources. • the students are encouraged to share their individual ideas and reflect on their learning experiences every week	• every week, the student groups learned through the assigned activities and resources • the students are not encouraged to share their individual ideas and reflect on their learning experiences every week
Relatedness	• the students within the similar subtopic/problem were assigned to the same group • the students discussed their ideas as a group during lessons and in consultation meetings with teachers	• the students were assigned randomly to groups • the students discussed their ideas in the whole class • no collaborative group portfolio was used.

	• the students used collaborative group portfolio during learning

Table 1 describes the teaching method in SDT and non-SDT condition

Table 2. Descriptive statistics.

Variables	Mean	SD	Skewness	Kurtosis
Perceived Autonomy	3.40	1.36	0.36	1.33
Perceived Competence	3.70	1.04	0.64	0.63
Perceived Relatedness	3.74	1.01	0.78	0.22
Pre_STEM_interest	3.17	1.07	0.26	0.79
Post_STEM_interest	3.73	1.05	0.73	0.19
Pre_STEM_identity	3.27	1.05	0.16	0.86
Post_STEM_identity	3.75	1.05	0.73	0.22
Number of STEM subjects chosen	1.83	0.93	0.42	0.68

Table 3. Correlation among latent variables.

Latent variables	1	2	3	4	5	6	7
1. Perceived Autonomy	-						
2. Perceived Competence	.62**	-					
3. Perceived Relatedness	.54**	.64**	-				
4. Pre_STEM_interest	.13*	.12*	.11*	-			
5. Post_STEM_interest	.53**	.66**	.61**	.17**	-		
6. Pre_STEM_identity	.12*	.11*	.14*	.32**	.18**	-	
7. Post_STEM_identity	.59**	.70**	.69**	.11*	.67**	.15*	-

*Notes: ** p<0.01; * p<0.05*

Table 4: Hypothesis tests, and the direct, indirect and total effects

Endogenous variable	Exogenous variable	Direct effect	Indirect effect	Total effect	R^2	Hypothesis
Post-STEM interest	Autonomy	.14	-	.14	.56	Supported (p = .01)
	Competence	.40	-	.40		Supported (p < .001)
	Relatedness	.29	-	.29		Supported (p < .001)
	Pre-STEM interest	.08	-	.08		Unsupported(p = .052)
Post-STEM identity	Autonomy	.15	.03	.18	.65	Supported (p < .001)
	Competence	.28	.08	.36		Supported (p = .002)
	Relatedness	.30	.06	.36		Supported (p < .001)
	Pre-STEM interest	-	.02	.02		-
	Post-STEM interest	.21	-	.21		Supported (p < .001)
	Pre-STEM identity	.01	-	.01		Unsupported (p = .69)
Number of STEM subject students chosen	Autonomy	-	.11	.11	.36	-
	Competence	-	.22	.22		-
	Relatedness	-	.22	.22		-
	Pre- STEM interest	-	.14	.14		-
	Post- STEM interest	-	.13	.13		-
	Pre- STEM Identity	-	.01	.01		-
	Post- STEM Identity	.60	-	.60		Supported (p < .001)
Pre-STEM identity	Pre-STEM interest	.38	-	.38	.15	Supported (p < .001)

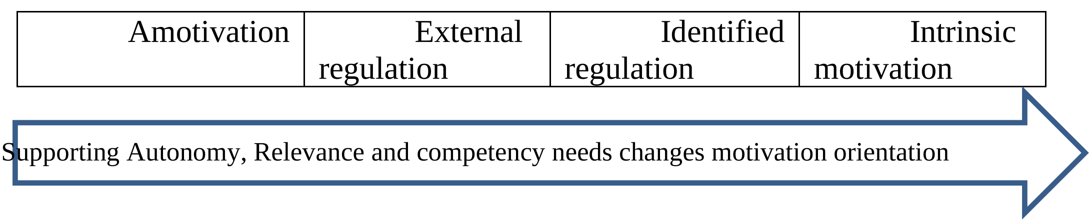

Figure 1. Students' motivational orientation

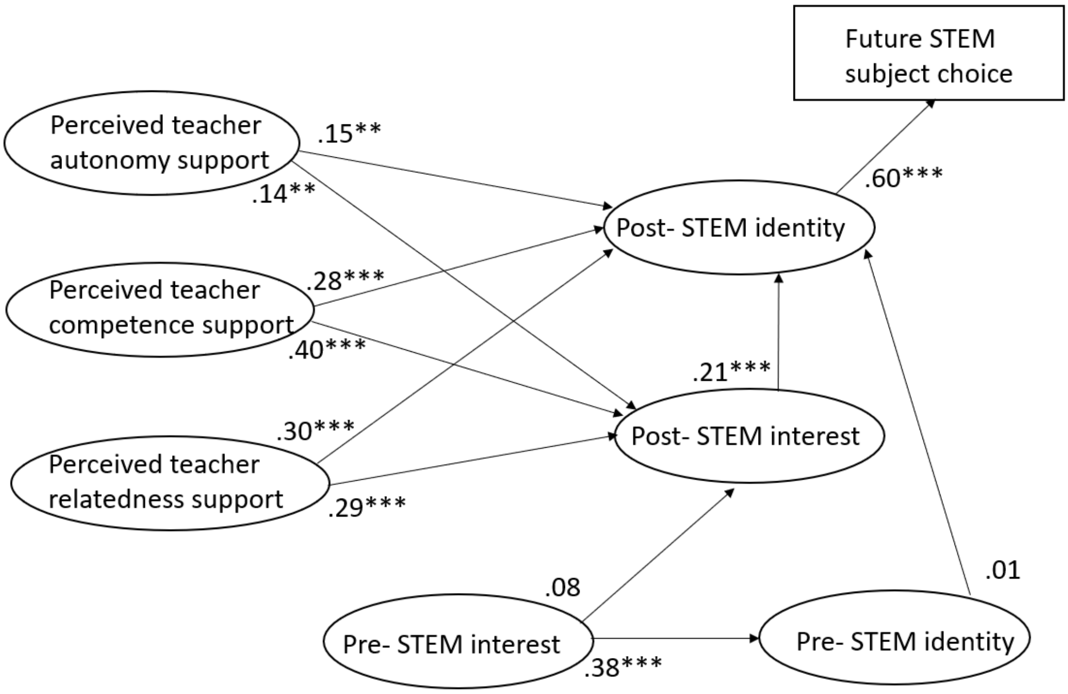

Figure 2. The proposed research model and its analyses

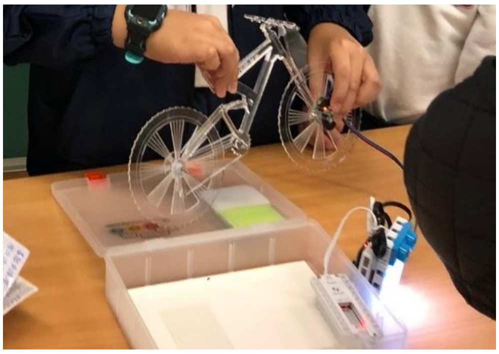

Figure 3. Photos of student presentation in SDT-based program.