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RESEARCH

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A model for examining middle school students' STEM integration behavior in a national technology competition

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Abstract

Background: Research on teaching and learning for science, technology, engineering, and mathematics (STEM) subjects has increased, and has demonstrated the importance of integrating interdisciplinary knowledge and skills. Our research model was based on the theory of planned behavior (TPB) and the data were analyzed by partial least squares-structural equation modeling. The present study aims to identify factors that play an important role in students' ability to integrate STEM knowledge and skills.

Results: Data were collected from participants who had won awards in local contests and represented their regions in a national technology competition. The reliability and validity of our instrument, the Students' STEM Integration Scale, were verified. The findings demonstrated that students' intentions to integrate STEM knowledge and skills to solve complex problems can be predicted by their attitude and perceived behavioral control.

Conclusions: This work highlights factors which are associated with students' intentions to integrate interdisciplinary knowledge and skills, and serves as a reference for research on the gap between intentions and actual behavior. The findings could help teachers and instructors design STEM-based activities to enhance students' attitudes, perceived behavioral control, and intentions, to improve their ability to integrate STEM knowledge and skills.

Keywords: Behavioral intention, Behavior, National technology competition, STEM, Interdisciplinary integration

Introduction

The importance of integrating interdisciplinary knowledge and skills to solve complex problems in daily life is widely acknowledged (Bybee, 2013; Lin et al., 2021); however, the OECD (2019) reported that students who perform well in science and mathematics continue to lack confidence when confronted with undefined problems, particularly in Taiwan. The report showed that students who lack practical experience are unable to solve complex problems, even with good knowledge, owing to their lack of familiarity with approaches for integrating science, technology, engineering, and mathematics (STEM) knowledge and skills. Studies on K-12 learners and K-12 learning in STEM subjects have increased significantly in the last decade (Fan et al., 2021; Li et al., 2019; Lin et al. 2020a, 2020b). Research has indicated that students' learning motivation is correlated with their attitudes and perceptions (Brown et al., 2016; Roberts et al., 2018; Tseng et al., 2013); therefore, it is important for teachers to understand the factors associated with students' intentions and behavior with respect to integrating STEM knowledge and skills.

Studies focusing on students' intentions in STEM education are typically limited to one school (Zhang et al., 2019, 2020). Although some studies have included more than one school, the lectures and activities differed (Luan et al., 2020), and studies collecting data from different

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schools are limited overall (Chittum et al., 2017; Miller et al., 2018). Moreover, to the best of our knowledge, no study has investigated factors that may be associated with students' intentions and behavior with respect to integrating STEM knowledge and skills. To address the deficit in studies including students from more than two schools, and the inconsistency in teaching content between participating schools, the present study recruited students from various regions of Taiwan, who then participated in a national competition in which they could integrate their STEM knowledge and skills to solve complex problems.

The present study aims to identify the factors that play an important role in students' intentions and behavior with respect to the integration of STEM knowledge and skills. Our research model was based on the theory of planned behavior (TPB) (Ajzen, 1991), which was deemed more appropriate than other theories due to its applicability for investigating intentions and behaviors (Cheng, 2019; Chu & Chen, 2016). The TPB model hypothesizes that attitude, subjective norm, and perceived behavioral control play important roles in behavioral intention, while perceived behavioral control and behavioral intention are also related to actual behavior. Therefore, the research model used in this study consists of five factors: attitude, subjective norm, perceived behavioral control, behavioral intention, and "STEM integration behavior" (see Table 1 for a definition of each factor).

Attitude

Attitude refers to an individual's evaluation (favorable or unfavorable) of a particular behavior (Ajzen, 1991). In the present study, attitude refers to students' appraisal (positive or negative) of the application of STEM knowledge and skills to the problem-solving process. Earlier studies found attitude to be a significant predictor of students' behavioral intentions, including to engage in e-learning (Park, 2009), use technology (Teo & Zhou, 2014), and use tablet computers in particular (Zheng & Li, 2020). Students' attitudes toward the integration of STEM knowledge and skills are hypothesized to positively relate to their behavioral intentions toward STEM integration behavior (*H1*).

Subjective norm

Subjective norm refers to social pressure that relates to an individual to engage in or refrain from a given behavior (Ajzen, 1991). These social pressures usually originate from the media, family, and schools (Ajzen & Driver, 1991). Empirical research has provided evidence for a positive relationship between an individual's subjective norm and behavioral intention, particularly in studies that attempted to investigate individuals' intentions toward technology use (Chen et al., 2018; Watson & Rockinson-Szapkiw, 2021; Zheng & Li, 2020). However, some studies observed no such relationship (Padilla-Angulo, 2019; Zulfiqar et al., 2019). The present study defines subjective norm as social pressure exerted by important groups, such as society, parents, classmates, and the competition committee, to integrate STEM knowledge and skills. We postulate that students will exhibit strong intentions to integrate their STEM knowledge and skills in response to social pressure (*H2*).

Perceived behavioral control

Ajzen and Fishbein (2000) and Ajzen (1991) defined perceived behavioral control as the perceived ease or difficulty with which an individual engages in a given behavior. Perceived behavioral control can be affected by an individual's experiences and anticipated obstacles. In the abovementioned studies, perceived behavioral control is defined as the perceived ease or difficulty with which students integrate STEM knowledge and skills to solve complex problems with limited resources. Students' perceived behavioral control has been found to be associated with their behavioral intentions, for example to participate in Massive Online Open Courses (MOOCs) (Lung-Guang, 2019) as well as their intentions to use Mobile Web 2.0 while learning (Dalvi-Esfahani et al., 2020). Thus, we hypothesized that students'

Table 1 Definitions of the variables of interest

Variable	Definition	References
Attitude	Students' positive or negative appraisal of integrating STEM knowledge and skills for problem-solving	Ajzen and Fishbein (1980)
Subjective norm	The pressure exerted by important groups, such as society, parents, classmates, and the committee of the competition	Ajzen (1991)
Perceived behavioral control	Students' perceptions of the ease or difficulty of integrating STEM knowledge and skills to solve complex problems with limited resources	Ajzen and Fishbein (2000)
Behavioral intention	The intention of students to integrate STEM knowledge and skills to solve complex problems in their daily lives	Ajzen and Fishbein (1980)
STEM integration behavior	Students' self-evaluations of their integration of STEM knowledge and skills during the competition	Ajzen and Fishbein (1980)

perceived behavioral control with respect to integrating STEM knowledge and skills would positively relate to their behavioral intentions toward STEM integration (*H3*).

Among individuals who hold equally strong intentions to engage in a given behavior, those with greater confidence are more likely than others to persevere (Ajzen, 1991). Therefore, an individual's perceived behavioral control can be used to predict their actual behavior (Cheng, 2019). In this study, STEM integration behavior refers to students' self-evaluations of their success in integrating STEM knowledge and skills during the competition. We hypothesized that students' perceived behavioral control with respect to integrating STEM knowledge and skills plays an important role in their STEM integration behavior (*H4*).

Behavioral intention

Behavioral intention refers to an individual's willingness to engage in a particular behavior (Ajzen, 1991; Fishbein & Ajzen, 1975), and is usually used to predict actual behavior (Chu & Chen, 2016; Lee, 2006; Nie et al., 2020; Tosuntaş et al., 2015; Zhang et al., 2019). In the present study, behavioral intention refers to students' willingness to integrate STEM knowledge and skills when solving complex problems, and is used to predict students' actual STEM integration behavior. It is hypothesized that students' behavioral intentions to integrate STEM knowledge and skills is significantly associated with STEM integration behavior (*H5*).

Research model and hypotheses

This study's purpose is to identify factors related to students' intentions and behavior with respect to integrating STEM knowledge and skills, using a research model based on the TPB (Ajzen, 1991). In addition to the TPB, the technology acceptance model (TAM) has been widely used as a basis for research on individual intention. Some studies have explored intention using the TAM, which focuses on how an individual's perception of a particular technology influences their willingness to use it; it emphasizes the influence of the features of the technology rather than social factors on intention (Chu & Chen, 2016). Social factors, such as peer influence (Hartshorne & Ajjan, 2009) and family support (Zheng & Li, 2020), are important in students' intentions so were considered by our research model. Cheng (2019) observed that TPB provided more comprehensive explanations than TAM, while combining the theories yielded little improvement. In summary, TPB is more powerful than TAM for exploring the influence of social factors on intention, so was used in the present study. Our research model is shown in Fig. 1; the paths therein are in accordance with the abovementioned literature.

H1 Students' attitudes toward integrating STEM knowledge and skills are positively related to their intentions toward STEM integration behavior.

H2 Students' subjective norms with respect to integrating STEM knowledge and skills are positively related to their intentions toward STEM integration behavior.

H3 Students' perceived behavioral control with respect to integrating STEM knowledge and skills is positively related to their intentions toward STEM integration behavior.

H4 Students' perceived behavioral control with respect to integrating STEM knowledge and skills plays an important role in STEM integration behavior.

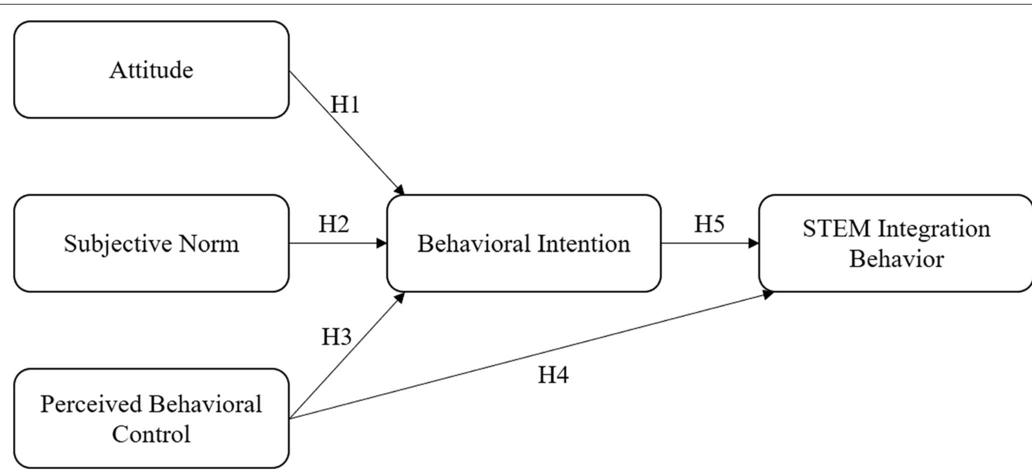

Fig. 1 Research model

H5 Students' behavioral intentions to integrate STEM knowledge and skills are significantly associated with STEM integration behavior.

Methodology

Participants

The present study involved 92 middle school students from eight different regions of Taiwan, who participated in a national technology competition from September to December. Their demographic information is presented in Table 2. Among the participants, 75 (82%) were male and 17 (18%) were female. Regarding the grade distribution, 51 (55%) students were in Grade 8 and 41 (45%) were in Grade 9. As for the distribution of regions, 32 (35%) students came from Taipei City, 6 (7%) are from New Taipei City, 4 (4%) are from Keelung City, 22 (24%) are from Taoyuan City, 3 (3%) are from Taichung City, 5 (5%) are from Kaohsiung City, 13 (14%) are from Yilan City, and 7 (8%) came from Taitung City. The study population consisted of contestants who had won preliminary awards in local contests and represented their regions in a national technology competition. Compared with other contestants, those who win awards are usually regarded to have demonstrated more proficiency in integrating STEM knowledge and skills throughout the competition. Therefore, instead of collecting data from all contestants, analysis only of the winning contestants' data is preferable for understanding intentions and actual behavior with respect to integrating STEM knowledge and skills. No data were collected from 7th grade students, because they were among the contest winners. As students in Grade 7 were only a few months into their technology courses when the competition was held, their understanding of how to integrate STEM knowledge and skills was likely relatively undeveloped.

Table 2 Demographic information of the participants

Demographic characteristic	Subcategories	Number	Percentage (%)
Gender	Male	75	82
	Female	17	18
Grade	Eighth grade	51	55
	Ninth grade	41	45
Region	Taipei City	32	35
	New Taipei City	6	7
	Keelung City	4	4
	Taoyuan City	22	24
	Taichung City	3	3
	Kaohsiung City	5	5
	Yilan City	13	14
	Taitung City	7	8

Procedure

The annual national technology competition included preliminary and final rounds. Preliminary rounds were held in various regions, and the winning teams were eligible to participate in the final. We collected data from the contestants who took part in the final which included students from Grades 7–9 after the whole competition was finished. In the competition, students were asked to complete the tasks independently, without any assistance from their teachers throughout the entire process.

Prior to the competition, the committee issued basic guidelines regarding the theme and rules, as well as a list of necessary materials and tools. Teachers were given time to ensure that their students were capable of solving problems during designing and making activities. To enhance students' competence in terms of thinking, collaborating, and communicating, rather than simply presenting the designs of their teachers, the variables were slightly different in each preliminary round. Therefore, even if the students had received good instruction prior to participating in the competition, they still needed to integrate their STEM knowledge and skills, and make adjustments in accordance with the design variables that the committee announced on the day.

The competition's theme was hydraulic systems, and the main purpose was to provide students with the opportunity to learn about the principles of hydraulics, and apply their knowledge and skills to complete the tasks. The students were asked to design two hydraulic devices, a "hydraulic arm" and a "batting device", using syringes of various sizes (Figs. 2, 3, 4). Each session was 4 min in duration. During the sessions, the students controlled the hydraulic arm to grab balls and shot them with the batting device. The number of shots was unlimited. The target at which the balls were shot was divided into five parts, each worth a different amount of points (20, 40, 60, 80, or 100; Fig. 2). Areas closer to the center of the target were worth more points. The total points corresponded to the final score. The variables in the preliminary rounds were the ball size and positions in which they were initially placed. The students did not know the details of these variables until the day of the competition.

The committee guidelines included several questions prompting students to think and discuss before they began designing their own devices, such as "What kind of chuck on the hydraulic arm is able to grab balls of various sizes?" and "According to Pascal's principle, what is the effect of using different-sized syringes? What can we achieve with the different syringes?" By addressing these questions, students were able to acquire the required knowledge and apply it to the problem-solving process. Moreover, the questions encouraged the students to integrate STEM knowledge and skills to solve complex problems when designing and making their own devices.

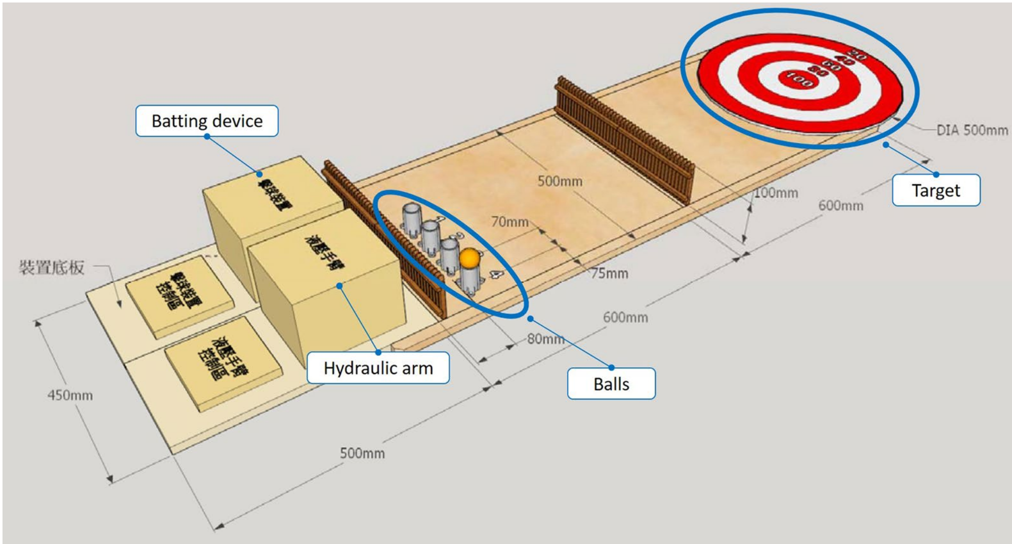

Fig. 2 Schematic diagram of the national technology competition arena

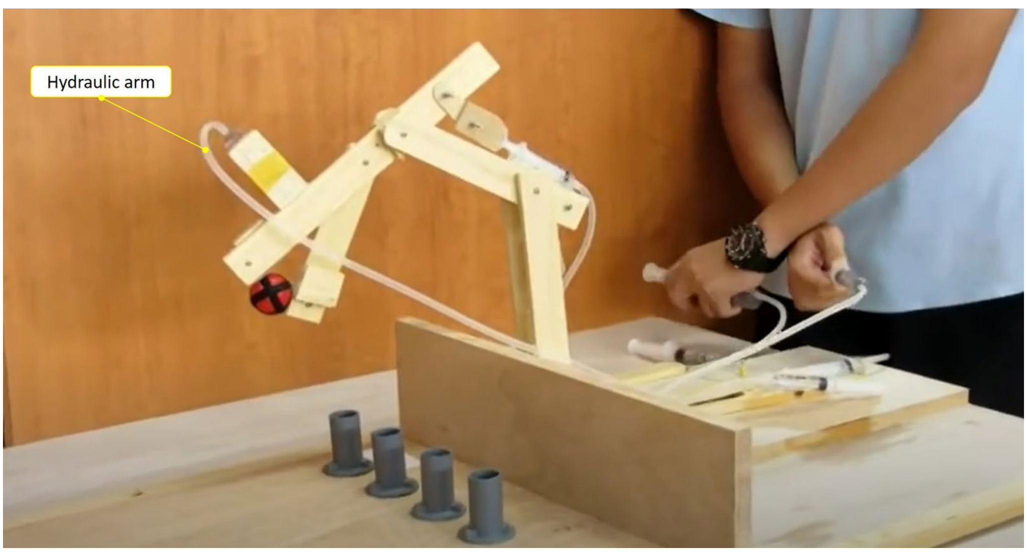

Fig. 3 Use of the hydraulic arm to grab a ball

Study instrument

The study instrument, the Students' STEM Integration Scale, included 30 items relating to five factors, and was based on studies by Ajzen (1991) and Ajzen and Fishbein (1980, 2000). Appendix 1 shows the items used to measure students' attitudes, subjective norms, perceived behavioral control, behavioral intentions, and STEM integration behavior on a 7-point Likert scale (1 = strongly disagree, 7 = strongly agree). To test the reliability and validity of the Students' STEM Integration Scale, three experts in relevant fields were invited to review the contents, and the scale was then revised according to their feedback.

After the initial scale had been compiled, a model ($N = 95$ samples) was built, and the measurement model of partial least squares–structural equation modeling (PLS–SEM) was used to assess its reliability and validity. Cronbach's α values were calculated to check the internal consistency reliability, where values greater than 0.7 are considered acceptable (Fornell & Larcker, 1981). The overall Cronbach's α for the Students' STEM Integration Scale was 0.96, and the Cronbach's α values of all factors were satisfactory

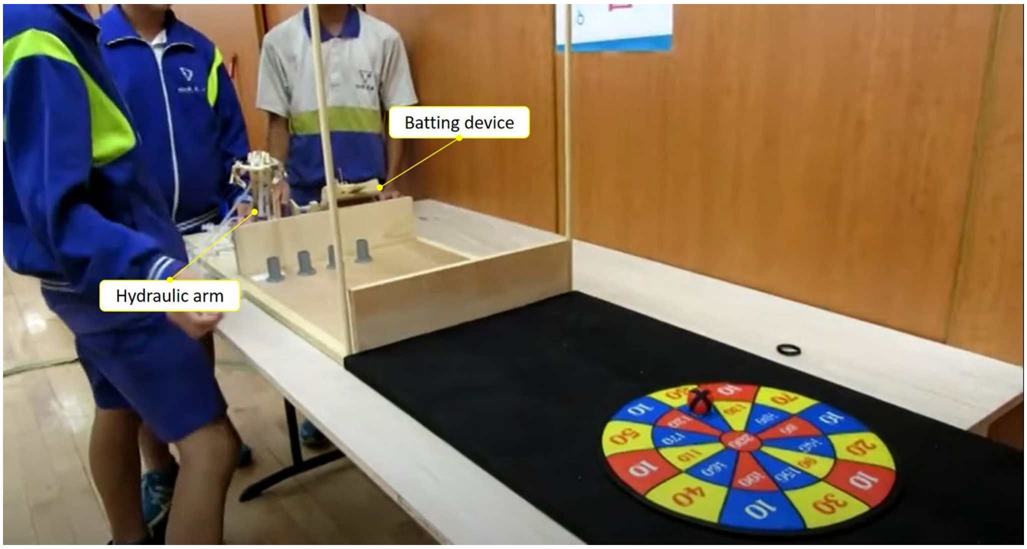

Fig. 4 National technology competition area

(attitude = 0.86, subjective norm = 0.86, perceived behavioral control = 0.91, behavioral intention = 0.95, STEM integration behavior = 0.94). Four items with loadings less than 0.7 were removed (two on attitude, one on subjective norm, and one on perceived behavioral control) (Hair et al., 2021). Ultimately, 26 items (loadings range: 0.70–0.94) were included in the Students' STEM Integration Scale, including 4 on attitude, 5 on subjective norm, 4 on perceived behavioral control, 6 on behavioral intention, and 7 on STEM integration behavior (see Appendix 1).

Data analysis

Partial least squares–structural equation modeling (PLS–SEM) was employed to test the hypothesized model by two steps, including the measurement model and the structural model. All analyses were performed using SmartPLS (version 3.3.2). The measurement model was used to assess the reliability and validity of the Students' STEM Integration Scale, and the structural model was used to explore the relationships among the five factors, and the hypothesized paths, as a means of assessing their relationships with students' intentions and behavior with respect to integrating STEM knowledge and skills. Although the estimated bias issue of using PLS–SEM was discussed, research has shown that there only exists a very low level of difference between PLS–SEM and Covariance-based SEM (CB-SEM) estimates (Reinartz et al., 2009). Besides, in some conditions (e.g., small sample size or non-normal data), PLS–SEM shows greater statistical power than CB-SEM (Hair et al., 2011).

PLS–SEM is originally developed for exploratory research and the main purpose of using the technique in studies is to identify relationships between factors (Hair et al., 2017). In the study, the skewness and kurtosis values of some items did not meet the thresholds of normality (values ranged from −2 to +2 and absolute values lower than 1) (see Appendix 2), indicating a non-normal distribution (Hair et al., 2021). It could be related to the participants in the study who were selected out from the group of preliminary winning students which may lead to the issue of a highly homogeneous sample. To sum up, because the aim of the study is to explore the factors which are able to predict students' STEM integration behavior with the non-normal data, given this rationale, PLS–SEM is recommended as an appropriate technique for examining the proposed model for its ability to identify predictors and analyze non-normal data. Other advantage for the widespread use of PLS–SEM are its ability to explore small sample sizes (Lin et al. 2020a). According to Chin and Newsted (1999), ten times the maximum number of formative indicators is sufficient for PLS; in the present study, the collection of 92 samples was acceptable.

Results and discussion

Measurement model analysis

The results of the measurement model analysis are summarized in Table 3. The findings verified the internal consistency reliability and convergent validity. All of the items' loadings were above the suggested threshold value (0.50) (Fornell & Larcker, 1981). The composite reliability (CR), Cronbach's α, and Rho_A values all exceeded 0.70, indicating that the internal consistency reliability was acceptable

(Dijkstra & Henseler, 2015; Hair et al., 2021; Nunnally, 1994). The average variance extracted (AVE) for each factor was greater than the threshold value of 0.50 (Bagozzi & Yi, 1988), indicating acceptable convergent validity.

To further examine the discriminant validity of the proposed model, the Fornell–Larcker criterion (1981) and Heterotrait–Monotrait (HTMT) ratio was used, as common conservative approaches. Fornell and Larcker (1981) suggest that the square root of the AVE value of each factor should be greater than the latent variable correlations (LVC). As Table 4 illustrates, the root square of AVE values (indicated by the bold values forming a diagonal) were all greater than the LVC (i.e., below the diagonal). The HTMT ratio is also used to confirm that factors are not modeled as common factors (Henseler et al., 2015). The HTMT values must not be close to 1, i.e., higher than a threshold value of 0.90; otherwise, discriminant validity is considered lacking (Gold et al., 2001). Table 4 illustrates that all HTMT values were lower than 0.90 (i.e., above the diagonal), thus confirming good discriminant validity of the factors.

Structural model analysis

Bootstrapping is a commonly applied resampling technique for testing structural models in research with small sample sizes, including the significance of hypothesized paths (Chin & Newsted, 1999); 5000 bootstraps has been suggested for such analyses (Lin et al. 2020a). The beta coefficients (β), significance values of the path coefficients, and corresponding t values are reported in Table 5. All hypothesized paths were supported, except that between subjective norm and behavioral intention ($\beta = -0.04$, $t = 0.33$). In addition to the p values, the Q^2 and f^2 statistics are reported; these reflect model predictive power and the effect size, respectively (Hair

Table 3 Results of the measurement model analysis

Factor	Item	Loading	CR	AVE	Cronbach's α	Rho_A
Attitude			0.90	0.68	0.84	0.84
	ATT 1	0.82				
	ATT 2	0.82				
	ATT 3	0.86				
	ATT 4	0.80				
Subjective norm			0.83	0.50	0.78	0.78
	SN1	0.70				
	SN2	0.75				
	SN3	0.77				
	SN4	0.68				
	SN5	0.64				
Perceived behavioral control			0.91	0.72	0.87	0.87
	PBC1	0.78				
	PBC2	0.89				
	PBC3	0.87				
	PBC4	0.84				
Behavioral intention			0.94	0.72	0.92	0.92
	BI1	0.88				
	BI2	0.89				
	BI3	0.85				
	BI4	0.83				
	BI5	0.81				
	BI6	0.81				
STEM integration behavior			0.93	0.66	0.92	0.92
	STEM-IB1	0.79				
	STEM-IB 2	0.81				
	STEM-IB 3	0.78				
	STEM-IB 4	0.80				
	STEM-IB 5	0.80				
	STEM-IB 6	0.84				
	STEM-IB 7	0.87				

Table 4 Results of the discriminant validity analysis

	Attitude	Subjective norm	PBC	BI	STEM-IB
Attitude	**0.82**	0.65	0.44	0.71	0.60
Subjective Norm	0.62	**0.71**	0.65	0.46	0.55
PBC	0.39	0.54	**0.85**	0.59	0.70
BI	0.63	0.47	0.53	**0.85**	0.71
STEM-IB	0.54	0.52	0.63	0.66	**0.82**

The square root AVE values are in bold; the results for the Fornell–Larcker criterion are below the diagonal and those of the Heterotrait–Monotrait ratio are above the diagonal

PBC perceived behavioral control, *BI* behavioral intention, *STEM-IB* STEM integration behavior

Table 5 Statistics for the paths in the proposed model

Hypothesis	Pathway	β	*t* value	f^2	Outcome
H1	Attitude → BI	0.51	4.98***	0.317	Supported
H2	Subjective Norm → BI	− 0.04	0.33	0.001	Rejected
H3	PBC → BI	0.36	2.97**	0.174	Supported
H4	PBC → STEM-IB	0.39	4.24***	0.237	Supported
H5	BI → STEM-IB	0.45	4.01***	0.316	Supported

PBC perceived behavioral control, *BI* behavioral intention, *STEM-IB* STEM integration behavior

**$p < 0.01$

***$p < 0.001$

et al., 2021). The Q^2 values should be above zero (Hair et al., 2021), and f^2 values of 0.02, 0.15, and 0.35 represent small, moderate, and strong effect sizes, respectively (Cohen, 2013).

In this study, ***H1*** hypothesizes that students' attitudes toward integrating STEM knowledge and skills positively relate to their behavioral intentions toward STEM integration. The results showed that attitude correlated positively with behavioral intention, and the effect size was moderate ($\beta = 0.51$, $t = 4.98$, $p < 0.001$, $f^2 = 0.317$). Thus, hypothesis 1 was supported. This result is consistent with findings reported by Brown et al. (2016), Park (2009), Teo and Zhou (2014), and Zheng and Li (2020), who found that students with positive attitudes tend to exhibit strong intentions to engage in particular behaviors. Our results indicated that students showing a positive attitude toward integrating STEM knowledge and skill while participating in the competition were also willing to do so in their daily lives.

H2 hypothesized that students' subjective norms with respect to integrating STEM knowledge and skills would correlate positively with their behavioral intentions toward STEM integration. However, in contrast to Chen et al. (2018), Watson and Rockinson-Szapkiw (2021), and Zheng and Li (2020), the results of our study indicate that subjective norm had no significant relationship with behavioral intention ($\beta = -0.04$, $t = 0.33$, $p > 0.05$, $f^2 = 0.001$), which aligns with findings reported by several other studies (Padilla-Angulo, 2019; Uzun & Kilis, 2020; Zulfiqar et al., 2019). A possible reason for this finding is that students who participated in the final of the competition integrated STEM knowledge and skills as a requirement to solve complex problems during the designing and making activities, and not because they were under pressure from their peers, families, teachers, or social media. Social influences may have been less important to those students, because they were operating autonomously. Several studies have argued that subjective norms can be multidimensional, where multiple social influences may have different effects on an individual's intentions (Hodgins et al., 1996). This idea was supported by Cheung and Vogel (2013), who found that peer influence exerted a positive effect on intentions, while instructors and media did not.

H3 of this study posited that students' perceived behavioral control with respect to integrating STEM knowledge and skills correlates positively with their behavioral intentions toward STEM integration. Our findings suggest that perceived behavioral control has a significant positive relationship with behavioral intention; the effect size was moderate ($\beta = 0.36$, $t = 2.97$, $p < 0.01$, $f^2 = 0.174$). These findings are similar to those of Dalvi-Esfahani et al. (2020) and Lung-Guang (2019). Students who were particularly interested in STEM subjects (e.g., those who followed related news or took part in relevant activities) were more likely to have strong intentions toward integrating their STEM knowledge and skills.

H4 hypothesized that students' perceived behavioral control with respect to integrating STEM knowledge and skills plays an important role in STEM integration behavior. In line with Ajzen's studies (2012, 2020), which argued for a direct effect of perceived behavioral control on behavior, our study's findings indicated that perceived behavioral control was significantly positively related to STEM integration behavior, with a moderate effect size ($\beta = 0.39$, $t = 4.24$, $p < 0.001$, $f^2 = 0.237$). Therefore, students with greater confidence in their ability to integrate STEM knowledge and skills performed more "dynamically" during the competition. The results also corroborate Wigginton et al.'s (2016) findings, which demonstrated that children's perceived behavioral control was a significant predictor of their actual behavior.

H5 predicts that students' behavioral intentions toward integrating STEM knowledge and skills will be significantly associated with STEM integration behavior. As Table 5 demonstrates, behavioral intention was significantly positively associated with STEM integration behavior, with a moderate effect size ($\beta = 0.45$, $t = 4.01$, $p < 0.001$, $f^2 = 0.316$). Cheng (2019) also observed, the students were more likely to use a particular technology for the group assignment when they showed strong intentions to do so. Zhang et al. (2019) also found that students' intentions were significantly related to their behavior, in the context of obtaining a degree in a STEM subject. Other studies have reported similar findings (Chu & Chen, 2016; Lee, 2006; Nie et al., 2020; Tosuntaş et al., 2015). In our study, students with strong behavioral intentions toward integrating STEM knowledge and skills during designing, making, or revising activities were more likely to engage in STEM integration behavior while participating in the competition.

In correlations analyses, R^2 provides a measure of a model's explanatory power; values of 0.25, 0.5, and 0.7 are used as thresholds for weak, moderate, and strong coefficients, respectively (Hair et al., 2021). In this study, the R^2 of behavioral intention was 0.49, i.e., 49% of the total variance in the proportion of "behavioral intention" was explained by "attitude," "subjective norm," and "perceived behavioral control". Meanwhile, 54% ($R^2 = 0.54$) of the total variance in "STEM integration behavior" was explained by "perceived behavioral control" and "behavioral intention" (Fig. 5). According to Hair et al. (2021), both of these R^2 values reflect moderate explanatory power. The predictive relevance (Q^2) is assessed using the blindfolding procedure, where values greater than zero indicate predictive relevance (Hair et al., 2021). In the present study, the Q^2 values were 0.31 and 0.28 for behavioral intention and STEM integration behavior, respectively, indicating predictive relevance.

Figure 5 shows the results for the paths in the proposed research model.

Our study aimed to identify factors that are associated with students' behavioral intentions and actual behavior with respect to integrating STEM knowledge and skills. According to our research model, which is based on the TPB and was used to test hypotheses generated from a literature review, attitude and perceived behavioral control, but not subjective norm, were positively associated with behavioral intention. This implies that students with favorable attitudes toward, and confidence in, their STEM knowledge and skills integration have greater intentions to apply what they have learned to solve complex problems. The results also revealed that perceived behavioral control and behavioral intention were significantly related to STEM integration behavior: students who believe they are capable of mastering integration of STEM knowledge and skills, and who have a strong intention to do so, are more likely to engage in this behavior.

Implications

Research on teaching and learning in STEM subjects should pay more attention to the factors that might be associated with students' learning. Studies typically apply TPB to explore individuals' intentions without simultaneously examining their behaviors. This may be because actual behavior is difficult to measure and a gap often exists between intention and action. In contrast, this study investigated both intention and actual behavior via a model with a sound theoretical basis (i.e., based on the TPB). The results suggest that students' perceived behavioral control and behavioral intention have a direct effect on their behaviors. Furthermore, our study included students from

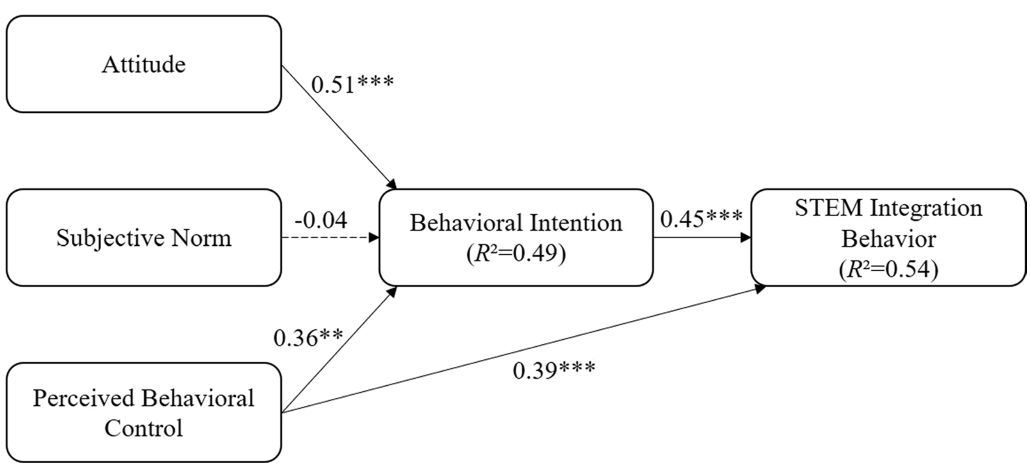

Fig. 5 Results of the hypothesized research model. **$p < 0.01$; ***$p < 0.001$

several regions of Taiwan, all of whom participated in the same competition and received the same information from the competition committee. Thus, there was no asymmetry in information between urban and rural students.

In this study, students' attitudes and perceived behavioral control were identified as two important factors which had significant relationships with their intention to integrate STEM knowledge and skills. Therefore, before teachers begin instructing students regarding how to integrate their knowledge and skills, they must first improve their attitudes and encourage positive appraisals, as well as enhance their confidence in integrating what they have learned. Research has shown that students' attitudes could be effectively improved by encouraging them to participate in related activities (Padilla-Angulo, 2019) or had them believe that a particular ability or tool may enhance their performance (Zheng & Li, 2020). For teachers, it is recommended to design an authentic and student-centered learning context which related to students' life experiences and provide students with opportunities to integrate their knowledge and skills. Besides, the learning activities can be planned as a series of project-based, problem-based, or inquiry-based activities to facilitate students' STEM integration behavior while learning. Implementing an appropriate STEM lesson is suggested to have students experience how and when to integrate their interdisciplinary knowledge and skills, and to realize the importance of STEM integration behavior. By doing so, students can be expected to show a positive and confident attitude regarding STEM integration behavior.

Finally, increasing students' perceived behavioral control and intention makes them more likely to engage in STEM integration behavior. To better enhance students' confidence in integrating STEM knowledge and skills, teachers may manage to create an environment in which students can be supported with imperative assistance while learning, for example, delivering STEM lessons with a sequential teaching process to lecture and demonstrate related knowledge and skills, or preparing necessary equipment, resources, materials, manuals or guidance to facilitate students in their learning process, etc. In addition, it is suggested that teachers have students reflect on their experience, including success or failure experience by asking students to develop a portfolio to record their learning process. In summary, teachers need to improve students' perceived behavioral control by planning their teaching and arranging the learning environment to successfully engage students in STEM integration behavior.

Limitations and suggestions for future research

In addition to the contributions mentioned above, here we acknowledge some of the present study's limitations. First, the sample was limited to students who won preliminary awards and were eligible to participate in the final of the national technology competition. We included these students to ensure that all participants were able to answer the questions precisely, although this meant that the sample was small. Nevertheless, the diversity and uniqueness of our sample constitutes a strength of our research. As mentioned, targeting those outstanding performance students in the competitions helped the study analyzed their STEM integration behaviors; however, due to the targeted sample were selected from elite students, who won preliminary awards in local contests, the generalizability of the findings in the present study may limit. We recommend that future studies enroll participants from international STEM-based competitions, to avoid small samples and thus explore students' perceptions regarding the integration of STEM knowledge and skills in more depth, as well as additional predictors of students' intentions or behavior when confronted with various problems. Together with more data are collected, the findings are possible to be generalized to a more general student population.

Second, subjective norm was not tested as a single factor potentially predicting students' intentions. Although the findings were consistent with several previous studies (Padilla-Angulo, 2019; Uzun & Kilis, 2020; Zulfiqar et al., 2019), they were contrary to the original conception of the TPB. Research has indicated that subjective norms play an important role of individuals' intentions (Chen et al., 2018; Cheng, 2019; Lung-Guang, 2019; Zheng & Li, 2020). Hodgins et al. (1996) and Cheung and Vogel (2013) argued that social factors can be divided into multiple types, including peer influence, family support, media, and teacher influence. Few studies have investigated these social factors individually, which should be a target for future research.

Finally, the data collection method used in this study, namely, self-evaluation, has been questioned in previous research. The aim was to obtain data that were sufficiently powerful to explain the students' STEM integration behavior. The reliability and validity of the Students' STEM Integration Scale used to this end were verified, and its suitability for use in future research was demonstrated.

Conclusions

This study investigated factors which are associated with students' intentions and behavior with respect to integrating STEM knowledge and skills, using a model based on the TPB. Previous studies tended to recruit participants from few schools, and lectures and activities were generally inconsistent among those schools. However, our participants were drawn from multiple schools/regions, so the results generalize to a wider range of students. We confirmed that students' attitudes and perceived behavioral control, but not subjective norms, affected their behavioral intentions. Furthermore, perceived behavioral control and behavioral intentions positively predicted STEM integration behavior. We hope that our findings will lead to more attention being paid to these factors by studies on students' intentions and behavior. Our study could serve as a reference for future investigations of STEM students' behavioral intentions.

Appendix 1. The students' STEM integration scale

Factors and items
Attitude
1. It is helpful for me to refer to relevant scientific principles (e.g., Pascal's principle, the lever principle) when making a hydraulic arm or batting device
2. It is helpful for me to learn how to operate manual and power tools to make a hydraulic arm or batting device
3. It is helpful for me to apply engineering knowledge (e.g., of mechanics) when making a hydraulic arm or batting device
4. It is helpful for me to apply mathematical knowledge (e.g., of measurements, calculations, or geometry) when making a hydraulic arm or batting device
Subjective norm
1. I will integrate STEM knowledge and skills when designing and making the devices requested by my teacher
2. I will integrate STEM knowledge and skills when designing and making devices according to the requests of my peers
3. Based on newspapers, magazines, television, online news, social media, etc.), I will integrate STEM knowledge and skills when designing and making devices
4. I will integrate STEM knowledge and skills when designing and making devices according to requests from my family
5. I will integrate STEM knowledge and skills when designing and making devices according to competition guidelines
Perceived behavioral control
1. I take the initiative when collecting relevant news on science, technology, engineering, and mathematics
2. I like to integrate STEM knowledge and skills into hands-on activities
3. I have the ability to integrate STEM knowledge and skills to design and make a functioning device
4. I am able to take the initiative when collecting information relevant to STEM knowledge and skills to design and make a functional device
Behavioral intention
1. I intend to integrate STEM knowledge and skills into the design process in the future
2. I intend to integrate STEM knowledge and skills into the manufacturing process in the future
3. I intend to integrate STEM knowledge and skills into the testing and revising process in the future
4. I will encourage peers to integrate STEM knowledge and skills to solve problems in the future
5. I intend to acquire more knowledge and skills relevant to STEM
6. After participating in the competition, I intend to solve problems by integrating STEM knowledge and skills
STEM integration behavior
1. I integrated scientific principles (e.g., the lever principle and Pascal's principle) to design and make devices during the competition
2. I integrated technological knowledge (e.g., of problem-solving, materials and tools) to design and make devices during the competition
3. I integrated engineering knowledge (e.g., mechanistic knowledge) to design and make the devices during the competition
4. I integrated mathematics knowledge (e.g., of measurements, calculations, or geometry) to design and manufacture equipment during the competition
5. I integrated STEM knowledge and skills to solve problems during the testing and revising process
6. By integrating STEM knowledge and skills, I was able to design and make devices efficiently during the competition
7. By integrating STEM knowledge and skills during the competition, my practical skills were improved

Appendix 2. Descriptive statistic results of the scale items

	Mean	Standard deviation	Skewness	Kurotsis
ATT1	6.04	0.97	− 0.97	0.42
ATT2	6.22	0.99	− 1.28	1.22
ATT3	6.21	1.02	− 1.19	0.51
ATT4	5.88	1.18	− 0.90	0.23
SN1	6.15	0.97	− 0.90	− 0.24
SN2	5.47	1.30	− 1.23	2.60
SN3	5.21	1.37	− 1.01	1.32
SN4	4.79	1.63	− 0.55	− 0.26
SN5	6.01	1.05	− 1.69	4.91
PBC1	5.25	1.31	− 0.65	0.28
PBC2	5.74	1.30	− 1.31	1.87
PBC3	5.11	1.45	− 0.86	0.59
PBC4	5.36	1.31	− 1.23	1.79
BI1	6.23	0.96	− 1.31	1.52
BI2	6.24	0.98	− 1.37	1.58
BI3	6.34	0.94	− 1.70	2.84
Bi4	6.02	0.99	− 1.00	0.66
BI5	6.18	1.04	− 2.01	5.19
BI6	6.32	0.88	− 1.37	1.83
B1	5.64	1.30	− 1.00	1.05
B2	5.87	1.01	− 0.59	− 0.14
B3	5.53	1.38	− 1.27	2.00
B4	5.55	0.99	− 0.40	0.26
B5	5.88	1.03	− 1.07	1.78
B6	5.85	0.99	− 0.85	0.63
B7	5.89	1.08	− 1.21	1.63

Abbreviations
STEM: Science, Technology, Engineering, and Mathematics; TPB: The theory of planned behavior; TAM: Technology acceptance model; SEM: Structural equation modeling; HTMT: Heterotrait–Monotrait; LVC: Latent variable correlations; AVE: Average variance extracted; CFA: Confirmatory factor analysis; CR: Composite reliability; PBC: Perceived behavioral control; BI: Behavioral intention; STEM-IB: STEM integration behavior.

Authors' contributions
C-JK: the leader of this research, she is in charge of the literature collecting and analyzing, research design, data analysis, and writing the manuscript (contributions to this research: 30%). Y-SH: responsible for research design, conducting questionnaire survey, providing comments to this research and revised the manuscript (contributions to this research: 20%). M-CC: responsible for research design, conducting questionnaire survey, providing comments to this research and revised the manuscript (contributions to this research: 20%). K-YL: responsible for research design, conducting questionnaire survey, collecting the data, and writing the manuscript (contributions to this research: 30%). All authors read and approved the final manuscript.

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Availability of data and materials
Not applicable.

Declarations

Consent for publication
Not applicable.

Competing interests
Not applicable.

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