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THE EFFECTS OF AUTONOMY-SUPPORTIVE AND CONTROLLING TEACHING BEHAVIORS ON PRIMARY STUDENTS' STEM LEARNING PERFORMANCE AND FLOW EXPERIENCE

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Abstract. *Flow experience plays a major role in influencing students' interest of STEM, which is the key to promote STEM talent development. Various teaching behaviors contribute differently to student learning performance and flow experience. Specifically, this research sought to concretely explore the different influences of Autonomy-supportive (AS) teaching behavior and Controlling (C) teaching behavior on students' STEM learning performance and flow experience. The research conducted an experimental exploration of STEM project among primary school students in two groups with two different teaching behaviors (AS and C) respectively. T-test and ANCOVA analysis revealed that both teaching behaviors greatly contributed to improvement of students' learning performance. MANCOVA analysis showed that students in Autonomy-supportive group got slightly significant higher flow experience than those in Control group. Regarding flow constructs, both groups had the similar level of engagement, but students in Autonomy-supportive group had higher enjoyment, and stronger control than those in the other group. In other words, Autonomy-supportive teaching behavior and Controlling teaching behavior both enhanced greatly students' STEM learning performance. While Autonomy-supportive teaching behavior allowed students to be more enjoyable and have a higher level of control in STEM learning.*
Keywords: *autonomy-supportive teaching, controlling teaching, flow experience, learning performance, intrinsic motivation, STEM projec*

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Introduction

With the increasing demand of social development for talents with 21st century skills, STEM (Science, Mathematics, Technology and Engineering) education is getting more and more attention (The committee on STEM education, 2018). It was emphasized in the *Innovation America: Building a Science, Technology, Engineering, and Math Education Agenda,* enacted by National Governors Association, that STEM literacy is significant in talent competition in the area of knowledge economy. Many studies have revealed that increasing students' interest in STEM learning is the key to promote the development of STEM talents (Lindahl, 2007; Osborne et al., 2009; President's Committee of Advisors on Science and Technology [PCAST], 2010). However, students' interest in STEM learning, which is associated with their psychological states, declines with the increase of grades (Zhou et al., 2019).

Students' psychological states in the process of learning, such as flow, motivation, reflection, cognitive interests, and sense of presence, have a positive correlation with their learning outcomes, especially when learning interactions are high-quality implemented (Billinghurst, 2003; Dalgarno & Lee, 2010; Kye & Kim, 2008; Lee et al., 2010). Specifically, flow experience has shown a significant impact on the learning process (Pearce et al., 2005). In addition, it was reported that flow experience was related to the most positive instantaneous patterns (e.g., cognitive, emotional, and motivational functions) (Bassi & Delle Fave, 2012), and was an indicator of functional state (e.g., learning motivation) related to learning outcomes (Engeser et al., 2005). It seems to be a way to enhance student's STEM interest and performance by improving their flow experience.

Previous research has reported that how to enhance students' flow experience remains a main challenge (Ibanez et al., 2014). Specifically, different teaching behaviors may lead to different flow experience and learning outcomes (Shen & Chu, 2014). Number of practices have shown different effects of various teaching behaviors on flow experience. For instance,

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some researchers pointed out that the innovated teaching behaviors led a significant promotion on learners' flow experience, satisfaction and learning performance (Hsieh et al., 2016; Hung et al., 2015; Kiili, 2006; Hwang et al., 2012; Liu, 2014; Wang & Chen, 2010). The present research sought to concretely explore the different influences of Autonomy-supportive teaching behavior and Controlling teaching behavior on students' learning performance and flow experience in STEM-related domain.

Literature Review

Flow experience

Csikszentmihalyi firstly proposed the concept of flow in 1960 and described it as *"the state in which people are so involved in an activity that nothing else seems to matter; the experience itself is so enjoyable that people will do it even at great cost, for the sheer sake of doing it."* (Csikszentmihalyi, 1990, p.4). That is, flow experience refers to a dynamic process of personal feelings (Chen et al., 2000). In the aspect of education, flow experience has been found a significantly positive influence on learning performance (Chang et al., 2017; Pearce et al., 2005; Wang & Hsu, 2014; Yen & Lin, 2020). Specifically, flow experience helps learners ignore irrelevant ideas (Chang et al., 2017), forget the passage of time, and pursue the value of learning itself (Csikszentmihalyi, 1990), so as to increase the continued intention of learning (Wang et al., 2017), the exploratory learning behavior (Skadberg & Kimmel, 2004; Webster et al., 1993), the proactive attitude toward challenges (Sun et al., 2017), and the awareness and application of new solution (Liu et al., 2011).

Based on the fundamental work on flow properties by Csikszentmihalyi (1990), researchers have constantly striven to identify the constructs of flow. Webster et al. (1993) suggested four flow constructs: control, focus of attention, curiosity, and cognitive enjoyment. Ghani and Deshpande (1994) proposed two flow constructs: concentration and enjoyment. On the basis of above work, Pearce et al. (2005) proposed three flow constructs: Enjoyment, Control, and Engagement. Enjoyment, Control, and Engagement respectively refer to the fact that learners enjoy the learning process, possess a sense of control over the learning, and engage in and concentrate on learning activity. It has been suggested that these three constructs were suitable for measuring the flow experience because of its conciseness, concreteness (Chang et al., 2017) and effective presentation (Csikszentmihalyi, 1975).

Intrinsic motivation to flow experience

Self-determination theory refers to the ability of making choices and managing one's own behavior (Deci & Ryan, 1985). As the origin of autonomous engagement and self-determined behavior, intrinsic motivation is the core in self-determination theory (Deci & Ryan, 2000). When a self-determined action is driven by intrinsic motivation, the locus of causality will be perceived in the person's internal, whereas when the behavior is controlled, the locus of causality will be felt in external (deCharms, 1968). Moreover, self-determination theory expounds that intrinsically motivated behaviors will be presented, once three basic psychological needs, including autonomy, competence and relatedness, are fulfilled (Deci & Ryan, 2000). Autonomy involves the awareness of the behaviors' origin (Reeve, 2002) and the self-determination of the actions (Deci et al., 1991). Competence refers to the ability of efficaciously performing the requisite actions and attaining the excepting outcomes (Deci & Ryan, 1985). Relatedness refers to the drive of interaction and integration in social environment (Deci & Ryan, 2000).

Many research studies have resulted that the intrinsic motivation is positively related to flow experience (Bakker et al., 2011; Csikszentmihalyi & LeFevre, 1989; Haworth & Hill, 1992; Kowal & Fortier, 1999; Taylor et al., 2006). Generally, extrinsically motivated activities may deprive the actor of control over one's behavior (Bakker et al., 2011), while intrinsically motivated behavior is the antecedent of flow experience (Taylor et al., 2006).

From the perspective of three basic psychological needs, self-determined behavior is important to students' flow experience. Satisfying students' autonomy is critical to promote their flow experience (Kiili, 2006; Lin & Joe, 2012; Loubris et al., 1995; Reeve & Jang, 2006; Taylor et al., 2006). A high level self-control of the learning content leads to a more pleasant experience (Park et al., 2010; Rogers & Muller, 2006). As well, the optimal experience occurs when the challenge level is suited to pupils' skills (Keller et al., 2011; Nakamura & Csikszentmihalyi, 2002; Shernoff et al., 2003; Tavares et al., 2019). It is indicated that there is a positive link between competence and flow experience (Jackson & Roberts, 1992; Ommundsen & Kvalø, 2007). Moreover, high relatedness is associated with the optimal experience, as the more social interactions take place the higher flow state would be cultivated (Delle

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Fave et al., 2002; Freire et al., 2016; Jose et al., 2012; Mesurado, 2009; Rathunde, 2001; Weinstein, 2006). In a word, the fulfillment of perceived autonomy, competence and relatedness leads to intrinsically motivated behaviors, resulting in a great flow experience.

Teaching behaviors to learning performance, intrinsic motivation, and flow experience

Autonomy-supportive teaching behavior and Controlling teaching behavior are usually exhibited by teachers (Reeve, 2009). Autonomy-supportive teaching behavior refers to cultivate students' intrinsically motivational resources and acknowledge their opinions and feelings by non-controlling instructions (Jang et al., 2010). In contrast, under the Controlling teaching behavior, students' perspectives are easily disregarded due to the coercive information (Deci & Ryan, 1987). Some researchers pointed out that students who received Autonomy-supportive teaching behavior presented a higher learning performance and academic achievement (Boggiano et al., 1993; Cheon et al., 2019; Grolnick & Ryan, 1987; Manninen et al, 2020; Ulstad et al., 2018).

In terms of different levels of self-determination, Ryan and Deci (2000) suggested that autonomy-supportive environment would integrate students' self-determination and promote students' internalization. Many research studies showed that autonomy-supportive instructions fostered students' intrinsic motivation (Basten et al., 2014; Deci et al., 1981; Hagger et al., 2003; Hofferber et al., 2016; Ommundsen & Kvalø, 2007; Pusak et al., 2004), as well as their autonomy (Assor et al., 2005; Mageau & Vallerand, 2003; Reeve & Jang, 2006). However, Controlling teaching behavior would undermine the quality of intrinsic motivation (Hofferber et al., 2016) and hinder the sense of autonomy (Assor et al., 2005).

As for the effect of two teaching behaviors on flow experience, it was found that Autonomy-supportive teaching behavior led to greater flow experience, including sustained positive emotions (Gagne et al., 2003; Grolnick & Ryan, 1987; Ryan & Connell, 1989). Whereas Controlling teaching behavior negatively affected enjoyment (Ommundsen & Kvalø, 2007) and intensive engagement (Assor et al., 2005). Hofferber et al. (2016) reported that Autonomy-supportive teaching behavior led a more positive flow experience than Controlling teaching behavior through comparative research. In the research (Hofferber et al., 2016), Autonomy-supportive teaching behavior was expressed as the informative feedback, the stress-free volition, and the possibilities for choice, however, Controlling teaching behavior was expressed as the controlling feedback, the stressful volition, and the fixed task succession.

Research Questions

Figure 1 illustrates the overview of the research framework. Summarizing the previous literature, Autonomy-supportive teaching behavior is more beneficial to students' learning performance (Boggiano et al., 1993; Cheon et al., 2019; Grolnick & Ryan, 1987; Manninen et al., 2020; Ulstad et al., 2018). Autonomy-supportive teaching behavior and Controlling teaching behavior would foster and hinder pupil's intrinsic motivation respectively (Assor et al., 2005; Basten et al., 2014; Deci et al., 1981; Hagger et al., 2003; Hofferber et al., 2016; Ommundsen & Kvalø, 2007; Pusak et al., 2004). Further, the intrinsic motivation positively relates with flow experience (Bakker et al., 2011; Csikszentmihalyi & LeFevre, 1989; Haworth & Hill, 1992; Kowal & Fortier, 1999; Taylor et al., 2006).

However, there were few comparative research studies on the effect of two teaching behaviors on flow experience (Hofferber et al., 2016). In the research conducted by Hofferber et al. (2016), Autonomy-supportive teaching behavior and Controlling teaching behavior were expressed to be two different instructional methods, whose differences were reflected in teachers' attitude towards feedback and students' freedom to arrange the task succession. Both types of teaching behaviors involved students in the role of completing tasks themselves. The study design did not distinguish between the flow experiences of students who performed the task independently and those who only observed others completing the task, whether students conduct the task on their own may trigger different intrinsic motivations and stimulate different flow experience. From this perspective, Autonomy-supportive teaching behavior and Controlling teaching behavior were interpreted as student active discovery and teacher direct demonstration in STEM teaching and learning process organization in the present research. The aim of the research was to verify whether Autonomy-supportive teaching behavior has a more positive effect on students' flow and STEM learning performance, compared with Controlling teaching behavior.

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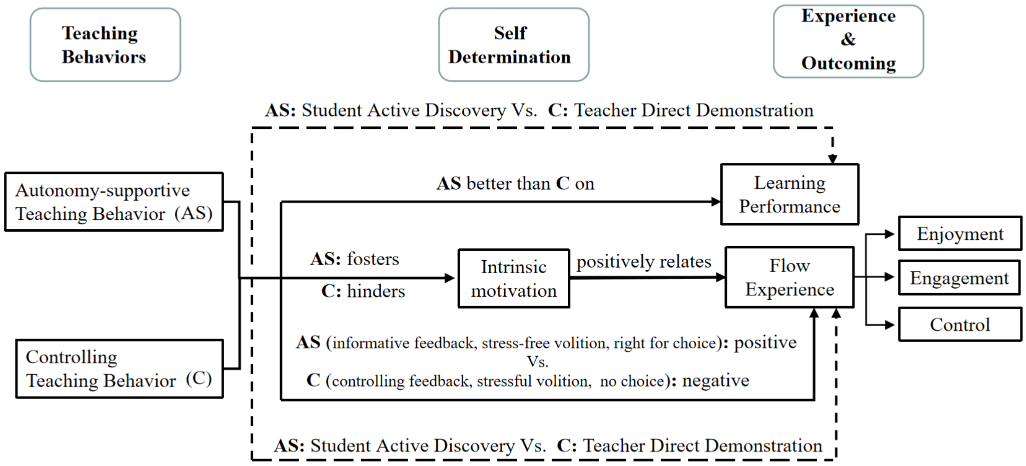
Figure1
The Research Framework from Teaching Behaviors to Learning Experience & Outcoming



Note: The solid lines reflect the correlations among two teaching behaviors, intrinsic motivation, learning performance, and flow experience in the previous studies. The dotted line represents the purpose of this research.

In the present research, a STEM project about environmental science topic with portable digital data logger technique at primary school level was conducted to explore the effect of different teaching behaviors on learning performance and flow experience, as well as its constructs. More specifically, the research questions were proposed as follows:

1. Does Autonomy-supportive teaching behavior improve primary school students' STEM learning performance better than Controlling teaching behavior?
2. Does Autonomy-supportive teaching behavior have a more positive effect than Controlling teaching behavior in promoting flow experience and its constructs, including enjoyment, engagement, and control?

Research Methodology

STEM Project Design

STEM education is considered the purposeful integration of various disciplines to solve practical problems (Breiner et al., 2012). Generally, STEM is a standards-based meta-discipline, which can be implemented through a flexible integration of subjects and comprehensive instructional methods (Merrill, 2009). In the present research, the STEM project used a realistic environmental problem, requiring students to solve by integrating various subjects' knowledge, such as physics, chemistry, geography, environment, mathematics, and data processing with portable digital data logger technique.

The theme and content of the project was taken from a primary environmental science lesson about *Water Resources and Water Pollution* under the Curriculum standards of the Ministry of Education (MoE) in People's Republic of China. The STEM project revolved around the problem about *"Is Our Water Resource Inexhaustible"*, involving the knowledge such as water source, quality detection (e.g., pH), water cycle, water pollution (e.g., water eutrophication), and protection ways.

The project was designed as three sections, including Story Introduction, Experiment and Publicity Task, and Reporting and Sharing. Story Introduction was set as the first section, in which an adventure story named Little Water Drop was regarded as the teaching background and supplementary material. Experiment and Publicity Task involved a learning task about testing the water quality parameters for different water samples with a portable digital data logger technique, and a publicity design about water resource protection based on experimental result. In this section, students needed to not only master relevant technical and mathematical thinking for the experimental

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measurement and the data processing, but also integrate their humanistic and artistic literacy into the publicity design task. In the Reporting and Sharing section, students discussed and reported the outcome of exploration, and shared their learning experience. Within three sections, the second one is the key to convey the important idea about sustainable development through the integration of science, technology, engineering, and mathematics.

Instructional Design and Procedures

To explore the differences of learning performance and flow experience with two teaching behaviors, Autonomy-supportive teaching behavior and Controlling teaching behavior were adopted in Autonomy-supportive group and Control group respectively. There were similar teaching processes in the two groups except for the second section in STEM project, where Autonomy-supportive group adopted the *Student Active Discovery* process, but Control group adopted the *Teacher Direct Demonstration* process, as shown in Table 1.

In Autonomy-supportive group, there were three steps within the Experiment and Publicity Task. Firstly, the teacher introduced the portable digital data logger technique and the purpose of the activity. Then, students were arranged into small groups to conduct the experiment of water quality measurement by themselves, as well as recorded and analyzed the experimental data. Finally, based on the data, students drew a conclusion and completed the design task about publicity of water resource protection. In Control group, the teacher firstly introduced the portable digital data logger technique and the purpose of the activity as well. Then the teacher demonstrated the experiment of water quality measurement on the platform and students observed the experimental demonstration, recorded and analyzed the experimental data. Finally, students drew a conclusion from the data and complected the design task of publicity. The difference lay in the second step of experimental implementation between two teaching behaviors. More pertinently, compared with Control group, Autonomy-supportive group was expected to incorporate greater self-determination, that is greater autonomy with stronger sense of control and higher relatedness with more peer interactions. The intention is to stimulate students much richer intrinsic motivation in Autonomy-supportive group.

Table 1
The STEM Project Procedures of Two Teaching Behaviors

Section	Teaching Behaviors	
	Autonomy-supportive	Controlling
1. Story Introduction	Taking an adventure story about Little Water Drop as the teaching background and supplementary material, shown by the Q&A activity between teacher and student.	
2. Experiment and Publicity Task	*Student Active Discovery* 1. The teacher introduced experimental instruments and the purpose of the activity. 2. Students received experimental instruments and different water samples in group of four, did the water quality parameters testing (e.g., pH, TDS), and recorded and analyzed the experimental data. 3. Students drew a conclusion from the data and completed the design task about publicity of water resources' protection.	*Teacher Direct Demonstration* 1. The teacher introduced experimental instruments and the purpose of the activity. 2. The teacher demonstrated the experiment of water quality testing on the platform. Students observed the experiment, and recorded and analyzed the experimental data (e.g., pH, TDS). 3. Students drew a conclusion from the data and completed the design task about publicity of water resources' protection.
4. Report and Sharing	Students discussed and reported the outcome of experiment and design task and shared their learning experiences.	

Participants

The STEM learning activity was conducted in two primary schools in an underdeveloped area of Guangdong Province, in People's Republic of China. Except for the regular school curriculum, almost all the students in these two schools never received extracurricular STEM education, as most of them came from the low-and-medium income families with the limited financial resources. The STEM project operated as a part of the summer camp

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and recruited students on a voluntary basis. A total of 92 students were enrolled into the summer camp and took part in the STEM learning activity, including 20 four graders and 19 five graders in school A, and 27 four graders and 26 five graders in school B. They were randomly divided into Autonomy-supportive group and Control group, regardless of grade and school, in order to exclude any systematic bias of natural class (As shown in Table 2). The age of all participants ranged from 10.5 to 12.5 with an average of 11.75.

Table 2
The Detailed Grouping of Participants

School	Grade	Group		Total
		Autonomy-supportive	Control	
A	Four	10	10	20
	Five	9	10	19
B	Four	14	13	27
	Five	13	13	26
Total		46	46	92

Assessment

For obtaining students' learning performance, a test of knowledge about water resources and water pollution was administered before and after the STEM project as a pre-test and a post-test for comparison. The knowledge test was designed as two parts, including basic knowledge and deep understanding. The basic knowledge of 5 questions, presented as multiple-choice or fill-in-the-blank questions, involves the foundational knowledge of water resources, such as "*Where do you think the rain comes from?*". The deep understanding of 2 subjective questions involves students' competence of judgment and reasoning, such as "*Do you agree with the statement that fresh water is inexhaustible? why*". An expert on the STEM education and two science teachers in primary school have been invited to review all questions of the knowledge test to ensure the validity of the measurement.

Students' flow experience was obtained immediately at the end of STEM project by a flow measurement utilized by Chang et al. (2017). The flow measurement is a 5-point Likert-type scale, which was modified based on the original one designed by Pearce et al. (2005), including three constructs: Enjoyment, Control and Engagement. Enjoyment refers to the measurement of students' enjoyment in the learning process, such as "*The learning material is interesting*". Control refers to students' autonomous control of learning tasks, such as "*I know how to operate or participate in the learning activity*". Engagement refers to the degree of students' involvement in the learning activity, such as "*I am concentrated on the learning material*". Students provided their response from 1 (extremely disagree) to 5 (extremely agree) to each item based on their own feelings.

Data Analysis

After eliminating the invalid responses (blank or all the same answers) and ensuring that both pre- and post-knowledge tests for each student were valid, a total of 82 students were included in the further data processing in the research, including 45 in Autonomy-supportive group and 37 in Control group with the valid response rates of 98% and 80% respectively. For the knowledge test, the multiple-choice or fill-in-the-blank questions were scored 0 or 1 point and the subjective questions were scored 0, 1 or 2 points according to the reasonableness of the response. The data, obtained from the measurement of learning performance and flow experience, were described as mean scores and standard deviations. The Cronbach's alpha coefficients of two groups were 0.76 (Autonomy-supportive) and 0.88 (Control), confirming the internal consistency of flow experience measurement. In addition, the *t*-test statistic, ANCOVA and MANCOVA were applied to analyze the effect of different teaching behaviors on STEM learning performance and flow experience.

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Research Results

Effect of Two Teaching Behaviors on Students' Learning Performance

To explore potential original differences between Autonomy-supportive group and Control group, the independent samples *t*-test of the pre-test scores was applied. The result showed that there was no statistically significant difference between two groups (t=.357; df=80; p=.722), which indicated that students from two groups had the similar background knowledge of concepts of environmental science.

Then, the paired *t*-test was performed to investigate the effect of two teaching behaviors on students' learning performance. According to Table 3, the mean of the post-test was higher than that of the pre-test in both groups (Pre: M_A=.50, SD_A=.23; M_C=.52, SD_C=.19; Post: M_A=.81, SD_A=.17; M_C=.79, SD_C=.22). In addition, there were significant differences between the pre-test and post-test in both Autonomy-supportive group (t=-8.360; df=44; p<.001; Cohen's d=1.533) and Control group (t=-6.368; df=36; p<.001; Cohen's d=1.314). Cohen's *d* is an indicator of difference significance. Its values of .2, .5, .8 represent a small, medium, and large effect size respectively (Cohen, 1992). The results indicated that both teaching behaviors greatly contributed to the improvement of students' learning performance.

Table 3
Descriptive Statistics of Knowledge Test and the Paired T-test Results between Two Groups

Item		Pre-test	Post-test	*t*	*df*	*p*	Cohen's d
Autonomy -supportive	MA	.50	.81	-8.360	44	.0001	1.533
	SDA	.23	.17				
Control	MC	.52	.79	-6.368	36	.0001	1.314
	SDC	.19	.22				

Notes: M_A: Mean of Autonomy-supportive group; SD_A: Standard deviation of Autonomy-supportive group; M_C: Mean of Control group; SD_C: Standard deviation of Control group;

Ultimately, as to verify whether there were different levels of improvement that two teaching behaviors led to, an ANCOVA analysis was carried out. The result of Levene's test showed that the assumption of the homogeneity of variances in the groups was satisfied (F(1,80)=2.014, p=.160). Moreover, the result of homogeneity of regression slopes (F(1,80)=0.132, p=.718) was satisfactory for the remainder test. Then, an ANCOVA analysis was performed using the pre-test as a covariate. The data (F(1,80)=.365, p>.05) in Table 4 revealed no significant difference in the post-test between two groups, which indicated that the improvement of students' learning achievements with two teaching behaviors was not significantly different.

Table 4
ANCOVA on Post-test for Two Groups

Source	*F*	Effect size
Covariate	4.578*	.055
Between-group	.365	.004

*p<.05.

Effect of Two Teaching Behaviors on Students' Flow Experience

Another aim of the research was to explore the influence of two teaching behaviors on flow experience. The results showed that the homogeneity test of variance (F(1,80)=.508, p=.478) and the homogeneity test of regression slopes (F(1,80)=1.047, p=.309) were satisfactory. Accordingly, an ANCOVA was implemented on the flow

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experience to eliminate the interference of the pre- knowledge test (as a covariate). The *F* value ($F(1,80)=4.694$, $p=.033<.05$), as shown in Table 5, revealed a significant difference in the flow experience between two groups. The eta-squared effect size reflects the strength of the correlation is small ($\eta^2<.059$), moderate($.059\leq\eta^2<.138$), or large ($.138\leq\eta^2$) (Cohen, 1988). The magnitude of effect size of the present result ($\eta^2=.054<.059$) suggested that students in Autonomy-supportive Group (Adj-M_A=4.146, Adj-SD_A=.079) got slightly significant higher flow experience than those in Control group (Adj-M_C=3.890, Adj-SD_C=.088).

Table 5
ANCOVA on Flow Experience for Two Groups

Source	*F*	Effect size
Covariate	2.640	.031
Between-group	4.694*	.054

*$p<.05$

Table 6
Adjustive Descriptive Statistics of Flow Experience for Two Groups

Autonomy-supportive Group		Control Group	
Adj-M_A	Adj-SD_A	Adj-M_C	Adj-SD_C
4.146	.079	3.890	.088

Regarding flow constructs, the MANCOVA analysis was running for the difference between two groups with the score of pre- knowledge test as a covariate, as to exclude any possible bias due to the students' initiate basic knowledge level. The results (*ps*>.05) of the homogeneity of variances and the homogeneity of regression slopes both indicated that the assumptions were satisfied for the subsequent MANCOVA. The result showed that, except engagement, there were significant differences between two groups in enjoyment ($F(1,80)=10.656$, $p=.002$, $\eta^2=.118<.138$) and control ($F(1,80)=4.642$, $p=.034$, $\eta^2=.053<.059$) with a moderate and small effect size respectively (Table 7). Combining the data in Table 8, the results implied that students in Autonomy-supportive group got the higher enjoyment and control than those in Control group, and both groups had the similar engagement.

Table 7
MANCOVA on Flow Constructs for Two Groups

Source	Constructs	*F*	Effect size
Covariate	Enjoyment	.367	.004
	Control	4.598*	.052
	Engagement	4.793*	.057
Between-group	Enjoyment	10.656**	.118
	Control	4.642*	.053
	Engagement	.199	.002

*$p<.05$, **$p<.01$.

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Table 8
Adjustive Descriptive Statistics of Flow Constructs for Two Groups

Constructs	Autonomy-supportive Group		Control Group	
	Adj-M_A	Adj-SD_A	Adj-M_C	Adj-SD_C
Enjoyment	4.538	.084	4.130	.092
Control	4.016	.089	3.730	.098
Engagement	3.884	.113	3.810	.124

Discussion

The Influence of Different Teaching Behaviors on Students' STEM Learning Performance

The results of students' STEM learning performance presented that both groups had significant differences between the pre-test and the post-test, but no significant difference was detected between Autonomy-supportive teaching behavior and Controlling teaching behavior either in pre-test or post-test. In other words, both groups with the similar knowledge level had a better performance after taking part in the STEM project. The results illustrated that Autonomy-supportive teaching behavior and Controlling teaching behavior both positively promoted students' STEM learning performance.

The improvement of students' learning performance with Autonomy-supportive teaching behavior was in line with the expectation of this research and some previous studies (Basten et al., 2014; Boggiano et al., 1993; Cheon et al., 2019; Manninen et al., 2020; Ulstad et al., 2018). To be precise, Autonomy-supportive teaching behavior facilitates the individuals' internalization, a critical element of integrated self-determination (Ryan & Deci, 2000), resulting in high-quality learning (Deci et al., 1991). Therefore, learners would benefit from an Autonomy-supportive learning environment (Basten et al., 2014). The results supported that Autonomy-supportive teaching behavior increases students' academic success (Boggiano et al., 1993; Cheon et al., 2019; Grolnick & Ryan, 1987).

According to the comparison, there was no significant difference between two groups on the post-test when controlling for the pre-test. It was revealed that the learning performance of students who received Controlling teaching behavior was not inferior to those with Autonomy-supportive teaching behavior. Compared with Autonomy-supportive teaching behavior, students needed to meet more specific requirements issued by the teacher in the process of Controlling teaching behavior. It was achievers' self-concept and self-esteem that drove them to fulfill these requirements (Mamat et al., 2007). Specifically, the fulfillment of these requirements arose from a predominant extrinsic orientation rather than intrinsic orientation. The predominant extrinsic orientation may contribute to a great learning performance (Basten et al., 2014). Hence, the performance improvement of students who received Controlling teaching behavior cannot attribute to the self-determination. As Wagner et al. (2020) suggested, no relationships were found for self-determination with achievement in Controlling teaching behavior. Furthermore, this improvement could be explained from the perspective of the innovative content. Berlyne (1951) described the novelty situation as deploying an established medium in a rather unfamiliar context. Due to the research conducted in underdeveloped areas, the participants have not been in touch with STEM activity. Participants were strongly attracted by the innovative experimental content and instruments, even under Controlling teaching behavior. Consequently, since the innovative experimental content and the predominant extrinsic orientation, students who received Controlling teaching behavior made the learning progress with no difference from those who received Autonomy-supportive teaching behavior.

The Influence of Different Teaching Behaviors in STEM Project on Students' Flow Experience

Regarding flow experience, there was a significant difference between two teaching behaviors, and students with Autonomy-supportive teaching behavior had a higher mean score. It suggested that Autonomy-supportive teaching behavior gave rise to greater flow experience in contrast to Controlling teaching behavior. This outcome was consistent with the opinions of previous studies (Bakker et al., 2011; Deci & Ryan, 2000; Hofferber et al., 2016; Kowal

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& Fortier, 1999). To some extent, it reasonably attributed to the cultivation of concentration by Autonomy-supportive teaching behavior and the interruption of flow components by Controlling teaching behavior, which were mentioned by Hofferber et al. (2016). From the perspective of self-determination, Autonomy-supportive teaching behavior led to an active intrinsic motivation (Ommundsen & Kvalø, 2007). In addition, students experiencing *Student Active Discovery* process needed to judge the experimental situation, discussed with other partners, and made operation by their own. In other words, students with Autonomy-supportive teaching behavior possessed a higher level of autonomy (Taylor et al., 2006) competence (Ommundsen & Kvalø, 2007) and relatedness (Mesurado, 2009). Through promoting the active intrinsic motivation and three basic psychological needs, students were strongly self-determined, so as to obtain greater flow experience (Kowal & Fortier, 1999). On the contrary, students' autonomy may be impeded by Controlling teaching behavior, preventing intensive participatory learning from happening (Assor et al., 2005). Therefore, Autonomy-supportive teaching behavior led to better flow experience than Controlling teaching behavior.

In the further analysis of flow constructs, there were significant differences in Enjoyment and Control between Autonomy-supportive teaching behavior and Controlling teaching behavior, whereas no significant difference was detected in Engagement. The result revealed that, compared with Controlling teaching behavior, Autonomy-supportive teaching behavior allowed students to be more enjoyable and have a higher level of control in their learning process. In respect of Enjoyment, the result supported that students who received Autonomy-supportive teaching behavior showed positive emotions. This may result from the interaction with peers, meeting the beliefs of Ryan and Connell (1989). As Jose et al. (2012) noted that once experiencing the higher levels of social connectivity, youth would subsequently report higher well-being. Regarding to Control, it is strongly related to the self-determination (Hofferber et al., 2016). Correspondingly, Autonomy-supportive teaching behavior is beneficial to intrinsic motivation (Basten et al., 2014), which gives play to a core function in self-determination (Deci & Ryan, 2000). Therefore, Autonomy-supportive teaching behavior would bring students a stronger sense of Control.

However, the result of Engagement suggested that all students actively engaged in the STEM project. Similarly, Basten et al. (2014) also found in his research that both groups of autonomy-supportive guidance and controlling guidance were equally interested in the learning activities. It was proposed that the innovative experimental content strongly attracted the students, and the predominant extrinsic orientation encouraged students to actively fulfill learning requirements (Harter, 1981). In addition, the desire for the same action with peer and the expected rewards from teachers made students have great engagement in the learning no matter what kind of teaching behavior (Harter, 1981). Therefore, it is possible to present the similar level of engagement in different instructional environment, because of the innovative experimental content, the predominant extrinsic orientation, and the motivation of conformity.

Conclusions

This research conducted a STEM project with a portable digital data logger technique, in order to explore the influence of different teaching behaviors on students' STEM learning performance and flow experience as well as flow constructs. Autonomy-supportive teaching behavior and Controlling teaching behavior were respectively adopted in two groups. The results showed that both teaching behaviors enhanced students' STEM learning performance, and no difference between two groups was detected. However, students' flow experience in Autonomy-supportive teaching behavior was greater than that in Controlling teaching behavior. Regarding to flow constructs, although similar levels of engagement were presented in both groups, Autonomy-supportive teaching behavior allowed students to be more enjoyable and have a higher level of control in their learning process, compared with Controlling teaching behavior.

In STEM education, when considering the positive effect on students' learning performance, both Autonomy-supportive teaching behavior and Controlling teaching behavior were suitably employed in STEM project. However, the great flow experience was conducive to make a good psychological bedding for the follow-up learning. Therefore, it is implied that Autonomy-supportive teaching behavior with higher autonomy and stronger relatedness for inspiring students' intrinsic motivation is more suitable to improve students' flow experience when teaching innovated contents. The effects of direct instruction and discovery learning is an enduring topic of inquiry in the field of STEM education. Previous related discussions mainly focused on students' learning performance and achievement, while the present research expanded from the perspective of flow to show that student discovery activity can also promote students' better learning flow experience. Therefore, the application of Autonomy-supportive teaching behavior should be emphasized in the further teaching process.

There are still limitations in this research. Firstly, the number of participants is low, and the response rate is not high enough. Secondly, this research was to explore the correlations among teaching behavior, flow and learning

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achievement. However, there is no direct measurement evidence to prove the correlation between intrinsic motivation and teaching behavior or flow experience. Thirdly, this is short-term research with no long-term follow-up evidence to support present results. Therefore, future work will be expanded in the following aspects: (1) What effects do different teaching behaviors have on learning performance and flow experience in a long-term and large-scale STEM project? (2) How does intrinsic motivation directly influence flow and is influenced by teaching behaviors? (3) Do different teaching behaviors have different effects on students' cognitive load? It is worthwhile to suspect whether students have the similar cognitive loads with different flow experiences. With further research on the above questions, the influence of different teaching behaviors on learning performance and flow experience can be more accurately detected.

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Declaration of Interest

Authors declare no competing interest.

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