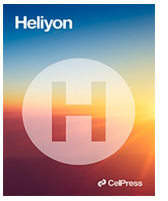
Heliyon 11 (2025) e42150

Contents lists available at ScienceDirect

Heliyon

journal homepage: www.cell.com/heliyon



Research article

An autonomy-supportive intervention program for STEM teachers to enhance engagement among students

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ARTICLE INFO

Keywords:
Autonomy-supportive teaching
Engagement
Intervention
Motivation regulation
STEM

ABSTRACT

Grounded in a self-determination theory framework, this study examined the effectiveness of an autonomy-supportive intervention offered to secondary school STEM teachers and their students in Singapore, with the focus on increasing students' perceived autonomy-supportive teaching, motivation regulations, and classroom engagement and decreasing students' tension. A total of 20 teachers from three secondary schools were randomly assigned into either an experimental (n = 10) or control (n = 10) group. Teachers in the experimental group underwent an autonomy-supportive intervention program and were encouraged to implement their new teaching style for 20 weeks. Students in both groups (Experimental = 295, Control = 251) filled in pre- and post-intervention questionnaires to assess their perceptions of autonomy support, motivation regulation, engagement, and tension. Repeated-measures multivariate analyses of variance (MANOVAs) with follow-up ANOVAs and pairwise comparisons showed that students in the experimental group, compared to students in the control group, reported longitudinal gains in perceived autonomy-supportive teaching (M = 3.58, SD = .86 to M = 3.74, SD = .83), in some motivational regulations (i.e., identified regulation, from M = 3.08, SD = .95 to M = 3.36, SD = .92), and in some types of engagement (i.e., behavioral engagement, from M = 3.58, SD = .65 to M = 3.68, SD = .66). These pilot study findings provide a good foundation to develop an effective and beneficial autonomy-supportive intervention program for STEM teachers. Limitations and future directions are discussed.

A supportive classroom environment cultivates inquisitive, enthusiastic, and highly committed students. One key factor that creates the supportive quality in a classroom is the teacher's motivating style [1]. When teachers are autonomy-supportive, students experience strong motivational satisfaction, find learning meaningful and self-relevant, and display active engagement [2,3]. To help teachers develop a more autonomy-supportive motivating style, researchers in physical education and exercise settings have developed and implemented autonomy-supportive teaching interventions (e.g., Ref. [4–6]). Outside of these settings, however, not many studies have been conducted in the traditional classroom setting, and practically no autonomy-supportive teaching intervention has been developed for teachers and students in Science, Technology, Engineering, and Mathematics (STEM) courses. The goal of the

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https://doi.org/10.1016/j.heliyon.2025.e42150
Received 22 August 2024; Received in revised form 16 January 2025; Accepted 20 January 2025
Available online 22 January 2025
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present study was to evaluate the capacity of an autonomy-supportive teaching intervention program developed specifically for teachers in STEM courses as they seek to support their students' motivation and classroom engagement.

1. Self-regulated learning, motivation, and autonomy-supportive teachers

Self-regulated learners proactively initiate thoughts (e.g., plans, goals), feelings, and behaviours in order to achieve personal goals, and they cyclically adapt these thoughts, feelings, and behaviours based on performance feedback [7,8]. With regards to motivational processes, self-regulated learners have higher intrinsic motivation, as they take pleasure and excitement in performing a learning activity and put in greater effort and persistence and are more engaged during learning [9,10].

Within the Self-determination theory (SDT; [11,12]) framework, a student's motivation can be facilitated and enriched by appreciating and supporting their psychological needs for autonomy, competence and relatedness. These three basic needs relate to feeling volition and personal ownership over one's behaviour, feeling effectiveness and mastery, and feeling accepted by and connected to close others. Satisfaction of these needs promotes intrinsic motivation and volitional internalization for performing a task or activity [13]. As learners feel a sense of personal ownership, effectance, and acceptance during their learning, they become more self-determined and self-regulated in their learning.

To nurture and involve the students' psychological needs, classroom settings should be equipped with autonomy-supportive resources. With supportive classroom conditions, students' inner psychological needs can be appreciated and supported; however, they can be also suppressed and thwarted by controlling and pressuring classroom environments [14–16]. Autonomy-supportive classroom conditions include the teacher's motivating style (i.e., autonomy-supportive), opportunities for need satisfaction (e.g., choice, optimal challenges, cooperative learning), interesting and personally meaningful learning activities, and opportunities to pursue personal interests, personal goals, and self-endorsed values [17].

One key factor influencing the supportive quality of classroom conditions is the autonomy-supportive teacher. Autonomy-supportive teachers identify and nurture students' needs, interests, and preferences and create classroom opportunities for students to fulfil their psychological needs [1,18]. Autonomy-supportive teachers allow students to act upon their personal interests and values; provide students with choice; and give meaningful rationale when choice is constrained [19]. Such teachers effectively support their students' basic psychological needs through empathically adopting the learners' internal frame of reference which allows a more student-attuned learning environment as it acts in accordance with students' interests, preferences, and goals.

2. Autonomy-supportive teaching interventions

SDT-based autonomy-supportive interventions programme (ASIP) provides training for teachers to obtain an autonomy-supportive teaching style [20]. In general, what empirical studies show is that these teacher-training programs have been successful for both teachers and students. The findings showed that autonomy-supportive teaching style increased autonomous motivation, need satisfaction, behavioural regulation, and well-being; decreased amotivation and need frustration; as well as facilitated academic performance, time management, and adaptive classroom functioning [1,4,5,20–22]. A recent study also found that combined web-based and face-to-face autonomy-supportive interventions produced the greatest effects on motivational outcomes in the physical education context [23].

In Singapore, some empirical studies on autonomy-supportive teaching have been conducted in the secondary school setting (e.g., Ref. [6,24,25]). The secondary school period is a distinctive period for adolescents. The transition to secondary school is particularly daunting because of the shift in emphasis from supportive, mastery-based environment in primary schools to a performance-based environment characterized by increased academic rigour, more complex and teacher-directed instructions, and high-stake outcomes [8,26,27]. Thus, an autonomy-supportive classroom setting is needed to appreciate, maintain, and enhance students' autonomous self-regulation and motivation in order to cope with the higher level of learning. These SDT based teacher autonomy-supportive interventions have increased students' psychological need satisfaction and lowered tension-pressure [16,21] to produce multiple beneficial academic outcomes [2]. Tension can be seen as a negative affect arising from a focus on high-stakes outcomes that could affect motivation and learning, though not many studies included tension as an ASIP outcome measure [28].

Wang and colleagues (2016) conducted a short 5-week intervention on how teachers trained in ASIP impact their students' perceived autonomy support, psychological needs, learning strategies and achievement. Their findings revealed that students taught by autonomy-supportive teachers had significant positive changes across all the above student outcomes. As shown by their increased achievements, students in the autonomy-supportive condition were more self-efficacious and autonomous in learning than those in the control condition. The interventions laid out the fundamental groundwork for the development and implementation of an extended autonomy-supportive interventions in Singapore's academic settings. Because Singaporean education has such a strong focus on the Science, Technology, Engineering, and Mathematics (STEM) curriculum [29], our plan was to offer an ASIP to STEM teachers.

Singapore's 15-year-old students achieved top scores in mathematics and science in Programme for International Student Assessment 2015 (PISA; [30]). A lot of emphasis has been placed to develop STEM capabilities among Singapore teachers and students. Programmes such as STEM Applied Learning Programmes and STEM Inc., have been introduced in schools with funding from Ministry of Education since 2014 [29]. Given the strong emphasis on STEM and expectations on high achievement standards some teachers may lack strategies for motivating students in the STEM classrooms. It is thus important to determine the effects of the ASIP training on STEM teachers.

Students' engagement is an important area of study because it functions as a behavioral pathway by which students' motivational processes contribute to their subsequent learning and development [10]. Engagement is also important because teachers rely on it as

an observable indicator of their students' underlying motivation during instruction [10]. Therefore, engagement is important both because it predicts important outcomes (e.g., learning, development) and because it communicates to the teacher students' underlying motivation during a learning experience.

Reeve et al. [10] defined engagement as a four-component construct which includes behavioural, emotional, cognitive and agentic engagement. Behavioural engagement refers to observable students' behaviour related to effort-exertion, participation, and persistence. Emotional engagement refers to students' affective responses to learning, which include positive activation such as interest, enjoyment. Cognitive engagement refers to students' level of investment in learning, such as concentration and the use of strategic learning strategies. Agentic engagement refers to students' contributing into their own learning by taking initiative and by being proactive in ways that catalyze their own learning. Importantly, previous studies have shown that the students of teachers who participate in an autonomy-supportive teaching intervention, compared to students of teachers who do not participate in the intervention, display strong post-intervention gains in their classroom engagement [4,31–34].

Equally importantly, previous studies in which teachers have been trained to be more autonomy-supportive during instruction show that students of these teachers, compared to students of teachers in a control group, develop the autonomous motivation and self-regulating learning that allows them to display such greater classroom engagement. For instance, the students of teachers who participate in an autonomy-supportive teaching intervention not only show greater engagement but also a greater capacity for autonomous self-regulated learning [6,35] as well as a lesser tendency to rely on externally-regulated learning [36]. While hopeful and instructive, most of these autonomy-supportive teaching intervention studies have been conceptualized and implemented in the physical education and sport settings. In contrast, we know of no autonomy-supportive teaching intervention that has been tailored specifically to the STEM course setting. This is a very important oversight because student success in STEM courses requires an unusual level of autonomous self-regulation and engagement [37]. To support student gains in autonomous self-regulation and engagement, we suggest that teachers of STEM courses can be taught how to be substantially more autonomy-supportive toward students.

3. Purpose of the present study

This study was a pilot study aimed to examine the effects of a 20-week autonomy teaching intervention on secondary school students taking a STEM course in Singapore. The objectives were 1) to evaluate the effectiveness of the ASIP training for STEM teachers, 2) to examine the effects of an ASIP intervention on students' perceived autonomy-support and self-regulated learning behaviour, and 3) to examine its effectiveness in improving student classroom engagement (behavioural, emotional, agentic, and cognitive) and decrease their tension. Effectiveness of the intervention was examined by making comparisons to a control group of teachers who received no training and continued with their usual preferred teaching styles. Based on the research aims, the following hypotheses were formulated for this pilot study.

H1. Teachers in the intervention group would increase their autonomy-supportive style and lower their controlling style, compared to the teachers in the control group.

H2. Students of teachers in the intervention group would report greater perceived autonomy-supportive teaching and self-regulated learning behaviour, compared to students in the control group.

H3. Students of teachers in the intervention group would report greater classroom engagement and lesser course-related tension, compared to students in the control group.

4. Method

4.1. Participants

Teacher-participants were 20 secondary one to four level math and science teachers from three different schools in Singapore. Teachers were ten females and seven males (three teachers in the control group did not indicate their gender) with an average of 10.4 years of teaching experience. Student-participants were these teachers' 546 secondary school students, including 261 males and 269 females (17 students did not report their gender). Students were in secondary one to four levels (similar to grades 7 to 10 in the US system), with 295 students in the intervention group and 251 in the control group. Each class had an average of about 35 students.

4.2. Intervention procedure

Before conducting the study, ethical approval was granted by the university's institutional review board (IRB-2021-03-033) from April 5, 2021 till August 29, 2022. Consent from parents/guardians was waived by the IRB board. A total of 20 teachers teaching Mathematics and Science were involved: 10 teachers were randomly assigned in the intervention group and 10 teachers were assigned to the control group. The teachers in the intervention group underwent three training sessions which taught them to create an autonomy-supportive learning environment. After training, teachers in the intervention group were encouraged to implement their new teaching style to their students for 20 weeks while teachers in the control group kept their own teaching style for the same period. After the study, teachers in the control group were given the opportunity to receive the same ASIP training (i.e., a waiting list control group).

Students filled in questionnaires to assess their perceptions of autonomy support, self-regulation behaviour in learning, and

engagement during pre- (one to two weeks prior to the intervention) and post-intervention (one to two weeks after the intervention). Teachers in both groups completed a questionnaire that measured their motivating styles at post-intervention (one to two weeks after intervention). Details of the training procedure are elaborated as below.

This program is adapted from the intervention design of ASIP by Cheon and his colleagues [38] in the Physical Education setting. The program has three stages. Stage 1 started with a workshop for teachers reflecting on their teaching style and how it aligns with two scenarios (autonomy-supportive and controlling), followed by a presentation on teacher motivating styles and its impact on student motivation. The participants discussed the feasibility, potential obstacles, and specific "how to" ideas related to enacting an autonomy-supportive style in the classroom. Stage 2 provided teachers with a comprehensive training package on SDT-based Six Acts of Autonomy-Supportive Behaviour [38]. Examples video clips were shown to provide teachers how they can operationalize and implement autonomy-supportive lessons in the classroom. After viewing the video clips, teachers discussed, practiced, received feedback on, refined, and personalized each recommended autonomy-supportive instructional behavior until they felt comfortable with the idea of implementing each act of autonomy-supportive teaching in their own classroom with their own students. After the teachers tried out their lessons for two weeks, they are invited to the final stage. In Stage 3, teachers discussed their approaches and shared their experiences with autonomy-supportive teaching. They were encouraged to continue to adapt their lesson plans and align their instructional goals and teaching practices with an autonomy-supportive teaching structure.

The following set of instructional behaviours on Six Acts of Autonomy-Supportive Behaviour [39] was given as a guide to teachers in the experimental group.

4.2.1. Taking students' perspective during instruction

Perspective taking is seeing and experiencing classroom events as if one were the student. It originates and emerges out of the teacher's willingness to embrace a student focus and an understanding tone. While planning their lessons, teachers are encouraged to take their students' perspective into consideration. Based on their understanding of their students and taking feedback about their preferences, teachers can adjust their instruction according to the students' needs, interests, and preferences. Two key questions to ask are: "Will my students find this lesson to be need-satisfying, curiosity-provoking, interesting, and personally important?" and "How can I make this lesson more need-satisfying, curiosity-provoking, interesting, and personally important to my students?" During and after the lesson, teachers are encouraged to conduct formative assessments to give students an opportunity to express how they feel about the lesson and what they hope to learn from it. With this student input in hand, the teacher can then offer the learning activity in a way that aligns with students' preferences.

4.2.2. Nurture inner motivational resources

Nurturing inner motivational resources refers to the teacher's instructional effort to appreciate and support students' interests, intrinsic motivation, psychological needs (autonomy, competence, relatedness), personal goals, and self-endorsed values. Teachers were encouraged to align classroom teaching activities with students' preferences, interests, sense of enjoyment, sense of challenge, competencies, and choice-making. External means such as incentives, rewards, directives, deadlines, and assignments to foster students' motivation in academic learning were discouraged while autonomy-supportive alternatives were encouraged. For instance, instead of offering the student an incentive or reward, the teacher could invite the student to pursue a personal interest or could pair the learning activity with an opportunity to pursue an optimal challenge (competence satisfaction) or pursue a prosocial goal with a classmate (relatedness satisfaction). Hence, teachers should seek ways to build instructional activities around students' inner resources, that is, activities that can satisfy the three psychological needs (competence, autonomy, and relatedness).

4.2.3. Provide explanatory rationales

A rationale is a verbal explanation as to why putting forth effort during a learning activity might be a personally useful thing to do. In a STEM course, students are often asked to engage in a difficult or an intrinsically uninteresting task without being provided the reasons for undertaking them. Autonomy-supportive teachers can improve students' self-determined motivation by providing a persuasive and satisfactory justification on the tasks which the students were asked to engage in. Providing rationales allows a process of internalization to occur [17] which helps students to personally invest volitional effort in classroom participation. Without rationales for instructed tasks, students will find it hard to be motivated to engage in an otherwise uninteresting or difficult activity.

4.2.4. Rely on invitational and informational language

Invitational language means using phrases such as "You may …" and "You might consider …" to support students' volition during behavioral initiatives. Informational language means providing students with the special insights, tips, and strategies they need to better diagnose and solve the problems they face. Teachers were encouraged to communicate with their students using informational and flexible messages instead of being controlling, demanding, and rigid. Informational messages provide students with new strategies and insights they can use to better approach learning activities, and they inform students on the progress they are making. Such language aims to motivate students to engage volitionally in classroom activities instead of pressuring and compelling their compliance with instructions. When facing problematic student behaviours such as listlessness or poor performance, autonomy-supportive teachers should treat such situations as problems to be solved rather than targets for criticism. Non-controlling and informational language should be used to help students in understanding the cause of their problems and find self-generated solutions to address them.

4.2.5. Display patience to allow time for self-paced learning

Patience is the optimistic calmness teachers show as students struggle to start, adjust, change, or improve their behavior and self-regulated learning. Controlling teachers tend to intrude into the student's workspace by demonstrating the solution and having their students replicate it, thus depriving their students the opportunity to individually learn and solve a problem. On the other hand, autonomy-supportive teachers display trust and patience and allow students to learn at their own pace. For example, teachers are encouraged to provide encouragement and understand the students' perspectives before offering useful clues for problem-solving. Since the learning process requires time, displaying patience for self-paced learning makes self-regulated learning possible.

4.2.6. Acknowledge and accept expressions of resistance and negative affect

It is common for students to occasionally have negative feelings towards classroom activities or academic learning. Controlling teachers tend to react by using pressure-inducing language to change such attitudes. In contrast, autonomy-supportive teachers acknowledge and accept such negative expressions as they understand and appreciate the perspectives of their students. Acknowledge and accept negative feelings begins with listening carefully and nondefensively to the student's complaint or upset feeling. It continues as the teacher accepts those negative feelings as a potentially valid reaction to being asked to do things that seem to the student to be uninteresting, difficult, overwhelming, unfair, anxiety-provoking, or simply not worth the effort. With the aid of other autonomy-supportive instructional behaviours mentioned above, teachers may converse and discuss with students so to dissipate those negative feelings and thus reestablish students' self-determined motivation.

These six instructional behaviours can be implemented during different periods of the lesson. When the teachers are planning and preparing for their lessons, they are encouraged to think in the perspectives of their students. If the classroom activities are potentially interesting, teachers should try their best to vitalize the students' inner motivational resources to develop the students' self-determined motivation. If the classroom activities are potentially uninteresting or particularly difficult, teachers should provide explanatory rationales which can persuade students to put in effort in the activities. During the lesson, teachers are encouraged to engage all students in the learning activities with the use of noncontrolling and informational language. In addition, teachers should display patience and provide opportunities for self-paced learning. If students show any negative responses, teachers should try to acknowledge and accept the students' perspectives which enhances communication and understanding between the students and teachers. Fig. 1 shows the intervention protocol. Due to the disruption of Covid-19 pandemic, the planned pre- and mid-semester surveys for the teachers, the in-class observations of teachers' autonomy-supportive instructional behaviors by trained raters, and mid-semester surveys for students were not able to be conducted.

4.3. Measures

The questionnaires contained all the following self-report measures. For the students' survey, a 5-point scale format, ranging from 1 (strongly disagree) to 5 (strongly agree) was used for all measures, except for engagement scale (1 = never, and 5 = always).

4.3.1. Teacher survey

Situations in School (SIS). The SIS (Aelterman et al., 2019) was used to measure the teachers' autonomy-supportive and controlling motivating styles. The SIS presents 15 daily classroom scenarios that deal with different aspects of the daily teaching situation. The SIS offer four different teaching behaviours a teacher might use to handle each teaching situation: autonomy-supportive, controlling, structure, and chaos. We only used autonomy-supportive and controlling subscales in this study, as these were the behaviours that correspond with the training provided in the ASIP. One example of autonomy-supportive style item is 'When you are thinking about classroom rules. You invite students to suggest a set of guidelines that will help them feel comfortable in class'. An example of controlling style item is 'When you are thinking about classroom rules. You post your rules. Tell your students they have to follow all the rules. Post the sanctions for disobeying the rules. Responses were captured on a 5-point Likert scale (1 = does not describe me at all

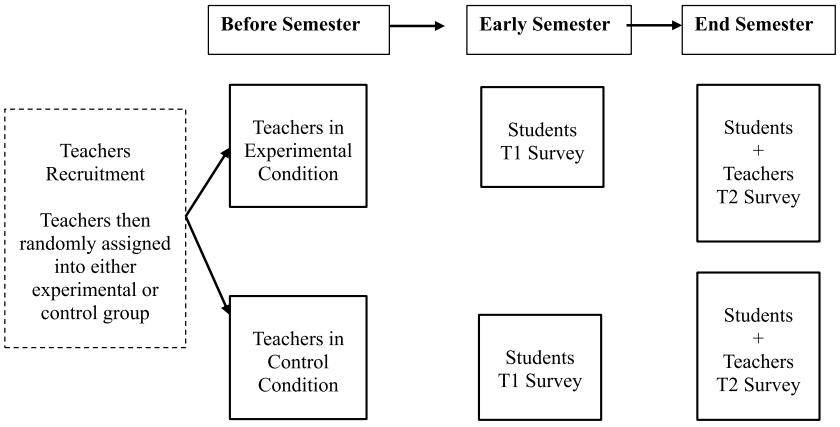

Fig. 1. Intervention protocol of the ASIP.

to 5 = does describe me extremely well). The 15 items in each subscale were averaged to obtain a score for autonomy-supportive style and controlling style. Inter-item reliabilities for the autonomy-supportive and controlling subscales were .88 and .87 respectively at post-intervention.

4.3.2. Student survey

Learning Climate Questionnaire (LCQ). We used the Learning Climate Questionnaire (LCQ) developed by Williams and Deci [40] to assess students' perceptions that their teacher engaged in autonomy-supportive teaching while delivering the lessons. This measure consisted of 6 items (e.g., 'I feel like my teacher provides me with choice and options'). Scores were calculated by averaging the individual item scores. Higher average scores indicate a higher level of perceived autonomy support from the teachers, and vice-versa. Inter-item reliability for the LCQ was $\alpha = .84$ at pre-intervention and $\alpha = .89$ at post-intervention.

Academic Self-Regulation Questionnaire (SRQ-A). We used 14 items from the Academic Self-Regulation Questionnaire (SRQ-A) developed by Ryan and Connell [41,42] to assess the behavioural regulation in learning among students. The SRQ-A asks students why they do their schoolwork and why they participate in class, and assesses the following four reasons: external regulation (four items; e.g., 'Because I will get into trouble if I don't'), introjected regulation (four items; e.g., 'Because I want the teacher to think I'm a good student'), identified regulation (three items; e.g., 'Because it is important to me'), and intrinsic motivation (three items; e.g., 'Because learning things in the classroom is fun'). Alpha coefficients were satisfactory for the pre- and post-measures (pre-external $\alpha = .82$, post-external $\alpha = .82$, pre-introjection $\alpha = .73$, post-introjection $\alpha = .79$, pre-identified $\alpha = .79$, post-identified $\alpha = .82$, pre-intrinsic $\alpha = .84$, post-intrinsic $\alpha = .85$).

Engagement-Disengagement Scale (EDS). The engagement scale of the EDS [43] was used to measure students' engagement in learning. The EDS assessed four dimensions of engagement: behavioural engagement (5 items; e.g., 'In this class, I work as hard as I can'), emotional engagement (5 items: e.g., 'When we work on something in this class, I feel interested'), agentic engagement (4 items; e.g., 'In this class, I let my teacher know what I need and want') and cognitive engagement (5 items; e.g., 'When reading for this class, I try to explain the key concepts in my own words'). Inter-item's reliability coefficients for the behavioural, emotional, agentic, and cognitive engagements were .79, .85, .82, and .79 respectively at pre-intervention and .79, .89, .89, and .86 respectively at post-intervention.

Tension. The tension-pressure subscale of the Intrinsic Motivation Inventory (IMI, [44]) was used to assess tension (4 items, e.g., 'I felt pressured while doing the activities in this class'). Cronbach's alphas were .78 for pre-intervention and .82 for post-intervention.

4.4. Data analysis

Before the study, a sample size calculator using Cohen's *d* was used to estimate the minimum sample required to test our hypotheses. To achieve a mean difference of .30 (a small to medium effect size; Cohen, 1988) with equal standard deviations, power = .80, and $\alpha = .05$, 10 teachers per group produced an effect size of $d = .38$, which suggests that our study was slightly underpowered. Mplus 8.0 [45] was used to compute the intraclass correlations (*ICC*s) of the key variables by school. The *ICC*s ranged from .001 to .025 with an average *ICC* of .023. This indicates that school membership had minimal effect on the total variance of the dependent measures. To enhance the ease of interpreting our findings, we elected to conduct a series of Multivariate Analysis of Variance (MANOVA) with follow-up ANOVAs to examine the intervention effect on all dependent measures. In these analyses, we first conducted a repeated-measures MANOVA (controlling for pre-intervention scores) to examine for post-intervention effect differences between the two groups of teachers (intervention and control) on motivating styles (autonomy-supportive and controlling). We next conducted a repeated-measures MANOVAs to examine for post-intervention group differences in students' motivational regulations as well as the four types of engagement. We then conducted a final repeated-measures MANOVA to examine for group differences in the tension score. For each MANOVA, we conducted follow-up ANOVAs and pairwise comparisons. In each analysis, the critical test was for a significant condition × time interaction effect to show that the dependent measure increased or decreased more in the intervention group than it did in the control group.

5. Results

5.1. Sensitivity analysis

A preliminary MANOVA comparing Math vs. Science teachers' pre- and post-measures motivating style scores found no significant differences. For the students taking Math vs. Science classes, their pre- and post-measures were also found to be not significantly

Table 1
Results of the repeated-measures MANOVA on teachers' pre- and post-intervention motivating styles.

	Control Group				Intervention Group			
	Pre		Post		Pre		Post	
Variables	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Autonomy-Supportive	3.59	.51	3.45	.65	3.17	.64	3.10	.60
Controlling	2.72	.69	2.30	.53	2.15	.54	1.80	.43

different, except for post-external regulation whereby the students in Science classes had higher scores compared to the students in the Math classes. We therefore combined the math and science classrooms into a single sample.

5.2. Teachers' motivating styles

The results of the repeated measures MANOVA indicated the teachers in the intervention group reported significantly lower autonomy-supportive motivating styles and lower controlling style at pre-intervention, compared to the teachers in the control group, Wilk's $\Lambda = .674$, $F\,(2, 17) = 4.11$, $p < .05$, partial $\eta^2 = .33$. In addition, there is a significant time effect in their motivating styles, Wilk's $\Lambda = .661$, $F\,(2, 17) = 4.36$, $p < .05$, partial $\eta^2 = .34$. Teachers from both groups reported lower controlling style at post-measures (see Table 1). Follow-up ANOVA found that at post intervention, teachers in the intervention group reported a significantly lower controlling style than did teachers in the control group ($F\,(2, 17) = 9.03$, $p < .01$, partial $\eta^2 = .33$).

5.3. Perceived autonomy-support and behavioural regulation

The Pearson correlation matrix for all the student-reported variables in pre- and post-intervention is shown in Table 2. The repeated measures MANOVAs were performed to investigate group differences in behavioural regulation in learning and the extent of perceived autonomy-support in the classroom environment. Five dependent variables were used: external regulation, introjected regulation, identified regulation, intrinsic motivation, and perceived autonomy-support. Table 3 presents the means and standard deviations of the five variables broken down by experimental condition.

There was no statistically significant overall condition × time interaction effect between the control and experimental groups on the five dependent variables. Significant time effects were found, Wilk's $\Lambda = .747$, $F\,(5, 409) = 27.71$, $p < .001$, partial $\eta^2 = .25$. Follow-up tests indicated a marginally significant interaction effect for identified regulation ($F\,(1, 413) = 3.67$, $p = .056$, partial $\eta^2 = .01$). The students in the intervention group increased their identified regulation over time while the students in the control group had no change in identified regulation (see Fig. 2).

5.4. Student engagement and tension

There was no statistically significant overall condition × time interaction effect between the control and experimental groups on the four engagement variables. However, there was a significant condition × time interaction effect for behavioural engagement only, $F\,(1, 406) = 3.86$, $p < .05$, partial $\eta^2 = .01$. Specifically, the students in the intervention group reported a higher post-intervention gain in their behavioural engagement than did the students in the control group. Table 4 shows the descriptive statistics for the engagement measures in the two groups.

A separate repeated MANOVA with pre- and post-tension as the dependent variable and group as independent variable revealed significant time effect, Wilk's $\Lambda = .921$, $F\,(1, 404) = 34.68$, $p < .001$, partial $\eta^2 = .08$, but no interaction effects. Students in both groups reported lower tension at post-intervention (See Table 4).

6. Discussion

The purpose of this pilot study was to examine the effects of a 20-week ASIP in terms of the teachers' motivating styles and students' perceived autonomy-supportive teaching, self-regulated learning, classroom engagement and felt tension in a STEM course in Singapore.

We tested three hypotheses. As to the first hypothesis, the findings confirmed that teachers in the intervention group reported a significantly lower controlling style, compared to the teachers in the control group. However, their autonomy-supporting style was not higher than the teachers in the control group. Two possible reasons could account for the results. Firstly, this study was conducted during the peak of the COVID-19 pandemic when the delta variant just emerged and cases in schools spread and was on the rise [46].

Table 2
Correlation matrix between key variables for pre- and post-intervention.

Variables	1	2	3	4	5	6	7	8	9	10
1.External Regulation	–	.51**	−.02	−.21**	−.13**	−.25**	−.28**	−.22**	−.21**	.34**
2. Introjected Regulation	.48**	–	.40**	.21**	.32**	.14**	.11*	.09	.13**	.20**
3. Identified Regulation	.01	.42**	–	.73**	.92**	.59**	.64**	.38**	.47**	−.22**
4. Intrinsic Regulation	−.26**	.24**	.65**	–	.94**	.65**	.80**	.53**	.47**	−.25**
5. Perc. Auto-Support	−.14**	.35**	.89**	.92**	–	.66**	.78**	.50**	.50**	−.25**
6. Behavioural Engage	−.12**	.26**	.62**	.50**	.61**	–	.78**	.64**	.59**	−.29**
7.Emotional Engage	−.23**	.18**	.61**	.77**	.76**	.60**	–	.70**	.60**	−.34**
8. Agentic Engage	−.24**	.10*	.38**	.50**	.48**	.55**	.61**	–	.54**	−.22**
9. Cognitive Engage	−.06	.22**	.47**	.41**	.48**	.57**	.49**	.44**	–	−.17**
10.Tension	.32**	.17**	−.17**	−.36**	−.30**	−.18**	−.43**	−.30**	−.18**	–

Note. *p < .05. **p < .01. Correlation listed below the diagonal is for pre-intervention and above the diagonal is for post intervention. Perc. Auto-Support = Perceived Autonomy-Support. Engage = Engagement.

Table 3
Results of the repeated-measures MANOVA for motivation regulation and perceived autonomy-support.

Variables	Control Group				Intervention Group			
	Pre		Post		Pre		Post	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
External Regulation	2.94	1.05	3.11	.94	3.04	1.02	3.20	1.01
Introjected Regulation	3.03	.84	3.28	.90	3.08	.95	3.36	.92
Identified Regulation	3.93	.64	3.94	.75	3.95	.72	4.09	.69
Intrinsic Regulation	3.45	.83	3.57	.92	3.58	.86	3.74	.83
Perceived Autonomy-Support	3.56	.71	3.80	.79	3.64	.69	3.97	.66

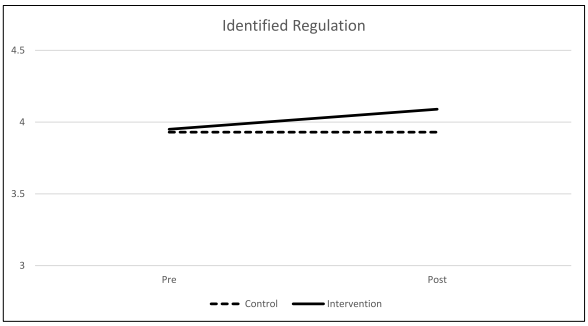

Fig. 2. Graphical presentation of the ASIP effects on students' identified regulation.

Table 4
Results of the repeated-measures MANOVA for outcome measures.

Variables	Control Group				Intervention Group			
	Pre		Post		Pre		Post	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Behavioural Engagement	3.61	.63	3.58	.72	3.58	.65	3.68	.66
Emotional Engagement	3.49	.73	3.43	.86	3.56	.72	3.62	.81
Agentic Engagement	2.90	.88	2.85	1.01	2.89	.83	2.95	.97
Cognitive Engagement	3.53	.69	3.45	.92	3.53	.75	3.49	.86
Tension	2.47	.69	2.23	.83	3.53	.78	3.49	.86

Teachers needed to check attendance, screen for close contacts, conduct online lessons or hybrid lessons during this period. It was not easy to be autonomy-supportive due to restrictions placed by the government and schools. Secondly, it is easier to learn how to be less controlling than it is to learn how to be more autonomy supportive. To be less controlling, teachers need to learn how to remove directives, commands, extrinsic sources of motivation, and a pressuring type of language from their teaching style. Teachers were able to do this. To be more autonomy supportive, teachers need to add new instructional behaviors to their teaching repertoire. Teachers in these STEM classes were less able to do this, perhaps because of the COVID crisis. H1 was only partially supported. Katz and Moè [47] recently found that during the COVID-19 lockdown in Italy, teachers' adoption of motivating styles may be influenced by their coping mechanisms such as emotion regulation and self-compassion. In their study, before the lockdown, emotional reappraisal mediated the relationship between need satisfaction and autonomy-supportive style, however, during the lockdown, emotion reappraisal was unrelated to motivating styles. On the other hand, self-compassion became a significant mediating factor during the lockdown. In addition, the relationships between emotion suppression and self-derogation with controlling style also became more pronounced. This provides evidence that the COVID-19 pandemic impacted teachers' well-being and teaching styles.

The second hypothesis tested the effects of the intervention on students' perceived autonomy-support from their teachers as well as their motivation regulations. The findings supported some success of the intervention in that students in the intervention group reported higher identified regulation while students in the control group did not change their identified regulation (see Fig. 2). Students in both groups reported higher post-intervention external, introjected, and intrinsic regulations. H2 was partially supported.

Identified regulation occurs when extrinsically motivated behaviours are performed voluntarily out of the individual's own accord, when students consider those behaviours to be useful or even essential for personal development. Individuals can relate with the importance and beneficial outcomes of self-regulating their behaviours, which may then develop as part of their own values [12]. Teachers in the intervention condition supported students' identified regulation by, for example, providing explanatory rationales. Similarly, Jang [48] found that externally given rationale delivered in an autonomy-supportive manner, improved identified

regulation and increased students' engagement and learning. Jang [48] explained that, grounded on in SDT, rationale communicated in an autonomy-supportive way facilitates engagement and learning through the revelation of an activity's value and personal benefit [8,49]. Adding personal relevance to the learning material helps students relate to and internalize the value of the task (i.e., identified regulation), and this internalization prompts voluntary participation in the learning activity.

The last hypothesis examined if the effects of teacher participation in the autonomy-supportive intervention could increase students' engagement and decrease tension. Students of teachers in the intervention condition did report higher behavioral engagement, though they did not report higher emotional, agentic and cognitive engagement. The non-significant results for emotional, agentic, and cognitive engagement could be due to the anxiety and unusually restricted online learning environment caused by the Covid-19 pandemic as mentioned above. We suspect that students of teachers in the intervention condition were able to increase their behavioural effort because of their increased identified regulation reported for H2.

Students from both groups reported lower tension at post measures. Again, the reduction in tension could be due to the pandemic as restrictions eased off toward the end of the intervention, and not the effect of ASIP. The pandemic likely created a diffusion effect within each school as teachers in the experimental group likely (and perhaps necessarily) shared some tension- and pressure-reducing instructional strategies with their colleagues in the control group [50]. Such a diffusion effect would explain the many "Time" main effects observed in the analyses. Therefore, H3 was partially supported, albeit weakly.

Although this intervention study was not designed to investigate a mediation relationship among autonomy support, identified regulation and engagement, it could be possible that identified regulation mediated the autonomy-supportive teaching effect on increased behavioral engagement via students' greater value of learning (i.e., identified regulation). Perhaps results from the study by Mouratidis et al.'s [51] could better illustrate that autonomous motivation (intrinsic motivation and identified regulation) mediate the relationship between perceived autonomy support and structure, and study effort and procrastination. Their study was a longitudinal study, where measurements to investigate teachers' role to enhance students' quality of motivation and in turn their study effort, were collected throughout the year. The authors explained that students who find schoolwork interesting (i.e., intrinsic motivation) and valuable (i.e., identified regulation) are more likely to invest more effort and procrastinate less in the long run. Despite only having a significant increase in identified regulation, the students still showed enhanced behavioural engagement.

6.1. *Autonomy-supportive teaching: STEM vs. PE*

Autonomy-supportive teaching interventions in the PE setting show that teachers have learned how to be more autonomy supportive, less controlling, and their students show post-intervention gains in their intrinsic motivation, identified regulation, and classroom engagement, broadly speaking [4,31]. In the present pilot study, we showed that an autonomy-supportive teaching intervention in the STEM setting only decreased controlling teaching and increased students' identified regulation and behavioural engagement. This means that the STEM teachers in our study were able to deliver some benefits of autonomy-supportive teaching, as they increased students' identified regulation and effort but not students' intrinsic motivation. This could be due to the different subject matters, the different classroom structures and routines, the COVID crisis, or simply because teachers need more support in their effort to provide STEM instruction is a highly autonomy-supportive way.

PE and STEM subjects are of a different status, as Singapore has always emphasised the importance of STEM education for its economic growth (Teo & Choy, 2022). In STEM classes, high-stakes examinations are common. In PE classes, however, high-stakes examinations are not involved, as PE is a non-examinable school subject. As such, STEM teachers may be less willing to adopt ASIP fully in the classroom. This is an important aspect of the STEM course to note because previous ASIP investigations in course subjects without a high-stakes focus (reviewed in Ref. [1]) generally reported robust effects across multiple dependent measures and also larger effect sizes than we observed in the current ASIP investigation in a STEM course. It is also possible that teachers in the intervention group could comprise of different profiles of teachers: some teachers may have been autonomy-supportive and less controlling in their teaching all along, some teachers may just begin to be more autonomy-supporting and less controlling, others may be focusing on being more autonomy-supportive only while some teachers may focus on being less controlling only in their teaching.

As to practical implications, we prioritize two suggestions. First, Singaporean STEM courses generally have a high performance and a high-stakes focus, compared to non-STEM courses. Thus, a future follow-up ASIP with teachers of STEM courses will need to help STEM teachers provide their performance-oriented, high-stakes instruction in an autonomy-supportive way. Such an ASIP could train teachers to asks students how they feel about high performance and high-stakes aspects of the course (i.e. perspective taking), acknowledge and accept students' negative feelings about these pressuring-inducing aspects of the course, listen to students' suggestions about how instruction might be adapted to become less pressuring and more volitional, and provide rationales to explain why high performance and high stakes might at times be a necessary part of the STEM course. Second, future studies need to measure teachers' motivating styles before the training session and compare these baseline scores with teachers' after-training and post-intervention scores. In addition, there is also a need to examine the profiles of the sub-groups of teachers according to their post-intervention changes in their motivating styles. This pilot study has provided some insights to the pursuit of the larger educational objective to help teachers deliver STEM instruction in an autonomy-supportive way.

6.2. *Limitations*

There are some limitations that should be acknowledged from this intervention. First, we were unable to collect classroom observations to assess the degree of autonomy-supportive teaching behaviours displayed by the teachers during the intervention period. The absence of classroom observations was due to the Covid-19 restrictions. Future studies need to conduct classroom observations or

conduct qualitative studies to add insights from the teachers' perspective. In addition, a recent study by Ahmadi et al. [52] on classification system of need-supportive behaviours could be used for teacher observation in future studies. Second, student measurements were only completed at 2 time points – pre- and post-intervention due to the Covid-19 restrictions. Further, students' post-intervention responses were recorded only one or two weeks after the intervention, which is important because it may take teachers more than one or two weeks to put a more autonomy-supportive teaching style into practice. Third, most teachers participated in the study voluntarily, however, some teachers may be required by their superiors to take part in the study. Teacher participation in the study was therefore decided by the heads of school rather than by the teachers themselves, which is important because this might affect teachers' willingness to work on their motivating style. Future studies need to differentiate the teachers in terms of their autonomy to participate in the study. Finally, if the intervention period were to extend to a year-long programme and measurements were made more frequently during the academic year instead of only pre- and post-intervention, it may provide a more dynamic way of understanding the results.

6.3. Conclusion and future direction

This pilot study examined the effectiveness of an autonomy-supportive teaching intervention on Singaporean teachers and students in math and science courses. Teachers in the autonomy-supportive teaching intervention did learn how to get halfway to an autonomy-supportive motivating style, as they took controlling instructional behaviours out of their teaching style and were able to support students' identified regulation and effort. To get STEM teachers all the way to a full autonomy-supportive motivating style, future research will need to restructure or reprioritize the intervention experience to help STEM teachers learn how to make learning math and science a highly intrinsically motivating, personally useful, and self-determined thing to do.

CRediT authorship contribution statement

Chee Keng John Wang: Writing – original draft. **Johnmarshall Reeve:** Writing – original draft. **Woon Chia Liu:** Writing – original draft. **Ying Hwa Kee:** Writing – review & editing. **Betsy Ng:** Investigation. **Li Lian Chua:** Project administration. **Leng Chee Kong:** Project administration.

Ethical approval

Before beginning the investigation, the Nanyang Technological University's Ethical Review Board's ethical approval was sought and approved (IRB-2021-03-033). Permission to conduct research in school was granted by the Ministry of Education, Singapore.

Availability of data and materials

Data for this paper will be archived in the NIE Digital Repository for ten years after it has been Accepted for publication. The link is https://repository.nie.edu.sg/home.

Funding

This research is funded by the Ministry of Education, Singapore Education Research Funding Programme OER 12/19 LWC Creating a Motivating School.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:LIU WOON CHIA reports financial support was provided by Government of Singapore Ministry of Education. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

[1] J. Reeve, S.H. Cheon, Autonomy-supportive teaching: its malleability, benefits, and potential to improve educational practice, Educ. Psychol. 56 (1) (2021) 54–77.
[2] S.H. Cheon, J. Reeve, M. Vansteenkiste, When teachers learn how to provide classroom structure in an autonomy-supportive way: benefits to teachers and their students, Teach. Teach. Educ. 90 (4) (2020) 103004, https://doi.org/10.1016/j.tate.2019.103004.
[3] R.M. Ryan, E.L. Deci, Intrinsic and extrinsic motivation from a self-determination theory perspective: definitions, theory, practices, and future directions, Contemp. Educ. Psychol. 61 (2020) 101860, https://doi.org/10.1016/j.cedpsych.2020.101860.
[4] S.H. Cheon, J. Reeve, A classroom-based intervention to help teachers decrease students' amotivation, Contemp. Educ. Psychol. 40 (2015) 99–111, https://doi.org/10.1016/j.cedpsych.2014.06.004.
[5] J. Edmunds, N. Ntoumanis, J.L. Duda, Testing a self-determination theory-based teaching style intervention in the exercise domain, Eur. J. Soc. Psychol. 38 (2) (2008) 375–388, https://doi.org/10.1002/ejsp.463.
[6] J.C.K. Wang, B.L.L. Ng, W.C. Liu, R.M. Ryan, Can being autonomy-supportive in teaching improve students' self-regulation and performance? in: W.C. Liu, J.C. K. Wang, R.M. Ryan (Eds.), Building Autonomous Learners: Perspectives from Research and Practice Using Self-Determination Theory Springer, New York, 2016, pp. 227–243.

[7] B.J. Zimmerman, Attaining self-regulation: a social–cognitive perspective, in: M. Boekaerts, P. Pintrich, M. Zeidner (Eds.), Handbook of Self-Regulation, Academic Press, Orlando, FL, 2000, pp. 13–39.
[8] B.J. Zimmerman, Achieving self-regulation: the trial and triumph of adolescence, in: F. Pajares, T. Urdan (Eds.), Academic Motivation of Adolescents, vol. 2, Information Age, Greenwhich, CT, 2002, pp. 1–27.
[9] C.P. Niemiec, R.M. Ryan, Autonomy, competence, and relatedness in the classroom: applying self-determination theory to educational practice, Theor. Res. Educ. 7 (2) (2009) 133–144, https://doi.org/10.1177/1477878509104318.
[10] J. Reeve, S.H. Cheon, H. Jang, How and why students make academic progress: reconceptualizing the student engagement construct to increase its explanatory power, Contemp. Educ. Psychol. 62 (2020), https://doi.org/10.1016/j.cedpsych.2020.101899. Article 101899.
[11] E.L. Deci, R.M. Ryan, Intrinsic Motivation and Self-Determination in Human Behavior, Plenum Press, New York, 1985.
[12] E.L. Deci, R.M. Ryan, The 'what' and 'why' of goal pursuits: human needs and the self-determination of behaviour, Psychol. Inq. 11 (2000) 227–268.
[13] R.M. Ryan, E.L. Deci, Self-determination Theory: Basic Psychological Needs in Motivation, Development, and Wellness, The Guilford Press, New York, 2017.
[14] N. Aelterman, M. Vansteenkiste, L. Haerens, B. Soenens, J.R.J. Fontaine, J. Reeve, Toward an integrative and fine-grained insight in motivating and demotivating teaching styles: the merits of a circumplex approach, J. Educ. Psychol. 111 (2019) 497, https://doi.org/10.1037/edu0000293.
[15] J. Reeve, Why teachers adopt a controlling motivating style toward students and how they can become more autonomy supportive, Educ. Psychol. 44 (2009) 159–175.
[16] B. Soenens, E. Sierens, M. Vansteenkiste, F. Dochy, L. Goossens, Psychologically controlling teaching: examining outcomes, antecedents, and mediators, J. Educ. Psychol. 104 (1) (2012) 108–120, https://doi.org/10.1037/a0025742.
[17] J. Reeve, H. Jang, P. Hardre, M. Omura, Providing a rationale in an autonomy-supportive way as a strategy to motivate others during an uninteresting activity, Motiv. Emot. 26 (2002) 183–207.
[18] J. Reeve, Teachers as facilitators: what autonomy-supportive teachers do and why their students benefit, Elem. Sch. J. 106 (3) (2006) 225–236, https://doi.org/10.1086/501484.
[19] B. Soenens, M. Vansteenkiste, W. Lens, K. Luyckx, L. Goossens, W. Beyers, R.M. Ryan, Conceptualizing parental autonomy support: adolescent perceptions of promotion of independence versus promotion of volitional functioning, Dev. Psychol. 43 (3) (2007) 633–646.
[20] J. Reeve, R.M. Ryan, S.H. Cheon, L. Matos, H. Kaplan, Supporting students' motivation. Strategies for Success, Routledge, Abingdon, UK, 2022, https://doi.org/10.4324/9781003091738.
[21] S.H. Cheon, J. Reeve, Y.G. Song, A teacher-focused intervention to decrease PE students' amotivation by increasing need satisfaction and decreasing need frustration, J. Sport Exerc. Psychol. 38 (2016) 217–235.
[22] J. Reeve, H. Jang, What teachers say and do to support students' autonomy during a learning activity, J. Educ. Psychol. 98 (2006) 209–218.
[23] H. Tilga, H. Kalajas-Tilga, V. Hein, A. Koka, Web-based and face-to-face autonomy-supportive intervention for physical education teachers and students' experiences, J. Sports Sci. Med. 20 (4) (2021) 672–683, https://doi.org/10.52082/jssm.2021.672.
[24] Y.M. How, J.C.K. Wang, Creating an autonomy-supportive physical education (PE) learning environment, in: W.C. Liu, J.C.K. Wang, R.M. Ryan (Eds.), Building Autonomous Learners: *Perspectives from Research and Practice Using Self-Determination Theory*, Springer, New York, 2016, pp. 207–225.
[25] B. Ng, W.C. Liu, C.K.J. Wang, A preliminary examination of teachers' and students' perspectives on autonomy-supportive instructional behaviors *Qualitative Research in Education* 4 (2) (2015) 192–221.
[26] J.S. Eccles, C. Midgley, A. Wigfield, C.M. Buchanan, D. Reuman, C. Flanagan, D. Mac Iver, Development during adolescence: the impact of stage-environment fit on young adolescents' experiences in schools and in families, Am. Psychol. 48 (2) (1993) 90–101, https://doi.org/10.1037/0003-066X.48.2.90.
[27] C. Midgley, K.C. Edelin, Middle school reform and early adolescent well-being: the good news andmthe bad, Educ. Psychol. 33 (1998) 195–206.
[28] E. Manuoğlu, E. Güngör, Predictors and mediators of pressure/tension in university students' distance learning during the Covid-19 pandemic: a self-determination theory perspective, Oxf. Rev. Educ. 50 (1) (2024) 60–77, https://doi.org/10.1080/03054985.2023.2197203.
[29] T.W. Teo, B.H. Choy, STEM education in Singapore, in: O.S. Tan, E.L. Low, E.G. Tay, Y.K. Yan (Eds.), Singapore Math and Science Education Innovation: beyond PISA, Springer, Singapore, 2021, pp. 43–59.
[30] OECD, PISA 2015 key findings for Singapore. https://www.oecd.org/countries/singapore/pisa-2015-singapore.htm, 2019. (Accessed 17 June 2019).
[31] S.H. Cheon, J. Reeve, Do the benefits from autonomy-supportive PE teacher training programs endure?: a one-year follow-up investigation, Psychol. Sport Exerc. 14 (4) (2013) 508–518, https://doi.org/10.1016/j.psychsport.2013.02.002.
[32] S.H. Cheon, J. Reeve, Y. Lee, N. Ntoumanis, N. Gillet, B.R. Kim, Y.G. Song, Expanding autonomy psychological need states from two (satisfaction, frustration) to three (dissatisfaction): a classroom-based intervention study, J. Educ. Psychol. 111 (4) (2019) 685–702, https://doi.org/10.1037/edu0000306.
[33] J. Reeve, S.H. Cheon, T.H. Yu, An autonomy-supportive intervention to develop students' resilience by boosting agentic engagement, IJBD (Int. J. Behav. Dev.) 44 (4) (2020) 325–338.
[34] S.O. Ulstad, H. Halvari, O. Sorebo, E.L. Deci, Motivational predictors of learning strategies, participation, exertion, and performance in physical education: a randomized control trial, Motiv. Emot. 42 (4) (2018) 497–512, https://doi.org/10.1007/s11031-018-9694-2.
[35] B. Flunger, A. Mayer, N. Umbach, Beneficial for some or for everyone? Exploring the effects of an autonomy-supportive intervention in the real-life classroom, J. Educ. Psychol. 111 (2) (2019) 210–234, https://doi.org/10.1037/edu0000284.
[36] E. Huescar, J.A. Moreno-Murcia, J.F. Domenech, J.L. Nunez, Effects of an autonomy-supportive physical activity program for compensatory care students during recess time, Front. Psychol. 10 (2019) 3091, https://doi.org/10.3389/fpsyg.2019.03091.
[37] J. Han, T. Kelley, J.G. Knowles, Factors influencing student stem learning: self-efficacy and outcome expectancy, 21st century skills, and career awareness, J. STEM Educ Res 4 (2021) 117–137, https://doi.org/10.1007/s41979-021-00053-3.
[38] S.H. Cheon, J. Reeve, N. Ntoumanis, A needs-supportive intervention to help PE teachers enhance students' prosocial behavior and diminish antisocial behavior, Psychol. Sport Exerc. 35 (2018) 74–88, https://doi.org/10.1016/j.psychsport.2017.11.010.
[39] J. Reeve, Autonomy-supportive teaching: what it is, how to do it, in: W.C. Liu, J.C.K. Wang, R.M. Ryan (Eds.), Building Autonomous Learners: Perspectives from Research and Practice Using Self-Determination Theory, Springer, New York, 2015, pp. 129–152.
[40] G.C. Williams, E.L. Deci, Internalization of biopsychosocial values by medical students: a test of self-determination theory, J. Pers. Soc. Psychol. 70 (1996) 767–779.
[41] R.M. Ryan, J.P. Connell, Perceived locus of causality and internalization: examining reasons for acting in two domains, J. Pers. Soc. Psychol. 57 (1989) 749–761.
[42] R.M. Ryan, E.L. Deci, An overview of self-determination theory, in: E.L. Deci, R.M. Ryan (Eds.), Handbook of Self-Determination Research, University Rochester Press, Rochester, NY, 2002, pp. 3–33.
[43] J. Reeve, How students create motivationally supportive learning environments for themselves: the concept of agentic engagement, J. Educ. Psychol. 105 (2013) 579–595.
[44] E. McAuley, T. Duncan, V.V. Tammen, Psycho- metric properties of the intrinsic motivation inventory in a competitive sport setting: a confirmatory factor analysis, Res. Q. Exerc. Sport 60 (1989) 48–58, https://doi.org/10.1080/02701367.1989.10607413.
[45] L.K. Muthén, B.O. Muthén, Mplus User's Guide, seventh ed., Muthén & Muthén, Los Angeles, CA, 2014.
[46] E. Su, Singapore reports highest single-day rise in COVID-19 cases, Reuters (2021, September). https://www.reuters.com/world/asia-pacific/singapore-reports-highest-single-day-rise-covid-19-cases-2021-09-23.
[47] I. Katz, A. Moè, Exploring teachers' psychological needs, motivating styles, emotion regulation and self-compassion: a comparative study before and during the COVID-19 lockdown, Teach. Teach. Educ. 148 (2024) 104706.
[48] H. Jang, Supporting students' motivation, engagement, and learning during an uninteresting activity, J. Educ. Psychol. 100 (4) (2008) 798–811, https://doi.org/10.1037/a0012841.
[49] R.M. Ryan, E.L. Deci, Self-determination theory and the facilitation of intrinsic motivation, social development, and well-being, Am. Psychol. 55 (1) (2000) 68–78.

[50] R.G. Craven, H.W. Marsh, R.L. Debus, U. Jayasinghe, Diffusion effects: control group contamination threats to the validity of teacher-administered interventions, J. Educ. Psychol. 93 (3) (2001) 639–645, https://doi.org/10.1037/0022-0663.93.3.639.

[51] A. Mouratidis, A. Michou, N. Aelterman, L. Haerens, M. Vansteenkiste, Begin-of-school-year perceived autonomy-support and structure as predictors of end-of-school-year study efforts and procrastination: the mediating role of autonomous and controlled motivation, Educ. Psychol. 38 (4) (2018) 435–450, https://doi.org/10.1080/01443410.2017.1402863.

[52] A. Ahmadi, M. Noetel, P. Parker, R.M. Ryan, N. Ntoumanis, J. Reeve, M. Beauchamp, T. Dicke, A. Yeung, M. Ahmadi, K. Bartholomew, T.K.F. Chiu, T. Curran, G. Erturan, B. Flunger, C. Frederick, J.M. Froiland, D. González-Cutre, L. Haerens, C. Lonsdale, A classification system for teachers' motivational behaviors recommended in self-determination theory interventions, J. Educ. Psychol. 115 (8) (2023) 1158–1176, https://doi.org/10.1037/edu0000783.