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INTERVENTION STUDY

Effects of a Dual-Approach Instruction on Students' Science Achievement and Motivation

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Abstract
The aim of the present study was to investigate the effects of an intervention on students' achievement and motivation. The intervention was in the form of an instructional approach named Dual-Approach Instruction since it was designed to facilitate both the cognitive and non-cognitive aspects of students' learning. The intervention effects were assessed through a cluster-level assignment design, which compared the control and intervention groups' achievement and motivational outcomes. A total of seven teachers and 427 grade 7 students participated in this study. Four teachers were assigned to the intervention condition and participated in a series of workshops on Dual-Approach Instruction. These teachers then applied the intervention to two topics, Speed and Density, with 231 students. The rest of the teachers and students were in the control group. Multiple regression analyses of students' achievement and motivation pre-test and post-test scores indicated that the intervention had a significant effect on students' achievement in complex problem solving, as well as in the following six motivational attributes: self-regulation, engagement, sense of competence, task goal orientation, education aspiration, and career aspiration in science. The results suggest that Dual-Approach Instruction benefits students in terms of dual outcomes: science achievement and motivation.

Keywords Basic psychological needs · Cognitive load theory · Load reduction instruction · Motivation · Self-determination theory

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Introduction

Improving students' achievement in the field of science, technology, engineering, and mathematics (STEM) is the goal of many countries (National Research Council 2015). This is advocated because workers in the globally competitive fields of economic growth, health industries, and national security require knowledge and skills in STEM (Kearney 2016; National Science Board 2015; Organisation for Economic Cooperation and Development [OECD] 2011). Students' declining interests in science and scientific pursuits and aspirations are a serious concern to some educators (Kearney 2016). Decreasing numbers of student enrolments in university science courses lead to shortages of human resources in the field, and of science teachers in schools (Bawden 2015; O'Leary 2001). It is often argued that achievement is not the sole key driver of students' choice of pursuing science-related fields (Wang and Degol 2013). Research indicates that many students who excelled in school science do not choose to pursue science-related careers (National Science Board 2014). Critically, students' motivation in a subject domain plays an important role in students' decisions to further their education and to choose to work in professions related to the domain (Wang and Eccles 2012). Therefore, both achievement and motivation in science are necessary for students to have educational and career aspirations related to science.

The purpose of the present study was to investigate whether both achievement and motivation could be effectively promoted through an instruction designed to facilitate students' cognitive and non-cognitive processes on the basis of well-documented theories. This instruction was named Dual-Approach Instruction (DAI), after a similar intervention type implemented in the Hornery et al. (2014) study called "dual approach intervention," where cognitive and non-cognitive processes were implemented in a curriculum-level intervention. The aim of DAI was to provide students with a rich curriculum to make complex learning more manageable in a learning environment which also nurtured motivation. In this study, we focused on whether the achievement and motivation of students who experienced DAI (intervention group) would be higher than the students who did not (control group). Students in the control group were taught by their usual teachers, using their normal teaching approach, which we referred to as "regular instruction." Based on the work of Forbes et al. (2017), we hypothesized that students who learned in an environment which supported both their cognitive and affective needs (i.e., DAI) would be more likely to demonstrate a dual effect of enhanced academic achievement and positive motivational outcomes. The idea behind the design of DAI is to use instructional strategies, which break down and scaffold the complexity in learning for beginning learners and nurture student motivation by supporting their basic psychological needs. DAI used (1) cognitive load theory (CLT; Sweller et al. 2011) as the main framework to support students' cognitive processes and (2) self-determination theory (SDT; Ryan and Deci 2016, 2017) as the main framework to enhance students' motivation by supporting their basic psychological needs. According to Phan et al. (2016), instruction that facilitates both cognitive and motivational aspects of teaching and learning is the best practice for optimizing students' learning in any domain.

Challenges

Improving students' achievement and motivation in science subjects is a challenging task, especially for those in secondary or high schools. Research has shown that many students in this age group experience a decline in academic self-concept and autonomous motivation from primary to high school (Ryan and Patrick 2001). There have been many reports indicating that passive, teacher-led lessons are still the norm in classrooms all over the world (e.g., Andres et al. 2010). This traditional approach to learning has been criticized for its ineffectiveness in learning about science (Wieman 2007). We believe that an effective science teaching approach provides learning opportunities that are not only meaningful, engaging, and motivating, but also within the cognitive capabilities of the students. However, most curriculum innovations have focused on either the cognitive (e.g., conceptual development or achievement) or non-cognitive (e.g., motivation) aspects of learning and instruction. Most studies of motivation are not simultaneously considering the cognitive demands or processes entailed in a given learning activity, and many studies of cognitive processes do not focus on the motivational supports entailed in learning and persistence. Research findings indicate a strong interplay between students' achievement and motivation, including self-concept (Forbes et al. 2017; Kadir 2006, 2018; Kadir and Yeung 2016; Kadir et al. 2012, 2013; Kadir et al. 2017; Kuppan et al. 2010; Marsh and Craven 2006; Yeung et al. 2010a, b), so both cognitive and non-cognitive processes have been used in the intervention reported in this study.

Cognitive Processes

Science, particularly in the field of physics, is widely perceived to be a difficult subject in school due to the complexity of its conceptual and abstract learning tasks (Shen and Pedulla 2000). According to CLT (Sweller et al. 2011), complexity in learning occurs when learners are required to concurrently process learning elements that highly interact with one another in the working memory (WM; Leahy et al. 2015). The WM of the brain is where mental activities take place (Miller 1956). An element is "anything that needs to be or has been learned, such as a concept or a procedure" (Sweller 2010, p. 124). When a learning task requires multiple elements to be learned together, the interactions between them result in high element interactivity (Sweller 2010). Such learning tasks require a large amount of working memory resources, referred to as intrinsic cognitive load, especially for students who lack relevant prior/background knowledge (Sweller et al. 2011). Due to limitations of WM resources in terms of capacity (Miller 1956) and duration (Peterson and Peterson 1959), cognitive processing of these types of complex learning tasks easily overloads students' WM, which impedes new schema construction (Sweller et al. 2011).

A schema summarizes the common elements of related information, categorizes them, and provides a generic characterization of the knowledge acquired (Anderson et al. 1978). When information is effectively processed in the WM, schemas are constructed and then stored in the long-term memory (LTM; Carlson et al. 2003), a part of the brain, which can store an infinite amount of information (Landauer 1986). When required, stored schemas can be retrieved to interact with new information in the working memory (Valcke 2002). This process develops new science knowledge as higher-level schemas (Newell and Simon 1972), which are then retained in the LTM. Over time, as the learner gains expertise, this process becomes automated, and thus requires less WM resources, enabling the learner to process complex information without experiencing cognitive overload. Therefore, schema acquisition and automation are two of the most important processes in learning and understanding (Carlson et al. 2003) and should be the goal of all instruction. When schema construction is impeded, and learning is repeatedly hindered, students' lack of success in the learning tasks could lead to frustration and negatively affect their motivation and future learning (Kadir et al. 2015).

CLT (Sweller et al. 2011) is mainly concerned with the learning of complex cognitive tasks, where learners are often overwhelmed by numerous elements of information and their interactions, which need to be processed simultaneously before meaningful learning can begin. Instructional approaches that attain meaningful learning in complex cognitive tasks have become the focus of CLT with the goal of managing the cognitive load involved in the mental processing of instructional materials (Sweller et al. 2011; Yeung 1999). Load reduction instruction (LRI; Martin 2016) is an umbrella term referring to instructional approaches, which aim to reduce and/or manage cognitive load in order to optimize students' learning, achievement, and motivation. According to Martin (2016), a major tenet of LRI is that students are at first novices in the early stages of learning with respect to the conceptual and procedural knowledge of the curriculum domain and that instructional approaches, which reduce cognitive load, are critical for optimal learning. As students develop expertise in the domain in terms of their core skills, knowledge, fluency, and automaticity, LRI emphasizes the centrality of guided discovery-, problem-, and inquiry-based learning.

In this study, the cognitive component of the intervention was in the form of LRI. Instruction was designed to reduce element interactivity at every stage of learning and to facilitate the construction, retrieval, and automation of schemas. Newly developed schemas provided mechanisms for students to solve more complex problems in the domain (each schema encapsulates interacting elements into a single unit in the working memory) thus reducing cognitive load (Blayney et al. 2010). Past research has shown that reducing element interactivity in complex learning tasks reduces cognitive load, resulting in higher achievement (Kadir et al. 2015). Therefore, we hypothesized that students experiencing effective management of element interactivity during the learning process of two conceptually challenging science topics (Speed and Density) would more successfully solve related complex problems than those students who did not receive the intervention.

Cognitive strategy used in the intervention The isolating-elements strategy has been investigated by a number of CLT researchers and has shown to be effective in helping novices manage complex learning tasks (e.g., Ayres 2013; Kalyuga 2007; Kester et al. 2006; Pollock et al. 2002). As with LRI, this strategy works by reducing element interactivity through initially presenting learners with part-tasks (so students develop partial schemas), before progressing to whole tasks, which are then used to construct full schemas (Ayres 2013; Pollock et al. 2002). The isolating-elements strategy involves creating sub-goals by removing several interacting elements from the to-be-learned task, and then introducing them at a later stage (Kalyuga 2007). For example, if the task involves the learning of concepts and procedures, then concepts are taught before or after procedures but not both at the same time. Studies by Pollock et al. (2002) and Kester et al. (2006) confirmed the effectiveness of this approach. Another approach to isolating elements is through scaffolding simple-to-complex sequences of learning activities (van Merriënboer et al. 2003). In the present study, we used two approaches to isolating elements: science learning activities were introduced to the students in a simple-to-complex sequence, and science conceptual knowledge was introduced before procedural knowledge for physics problem solving.

In a study by Blayney et al. (2010), the isolating-elements strategy was found to benefit students with low pre-existing knowledge more than those with high pre-existing knowledge in the domain. This is likely due to students with high pre-existing knowledge possessing schemas that can be retrieved from their long-term memory to interact with new elements in their working memory, and therefore requiring less working memory resources for cognitive processing (Sweller et al. 2011). Such students will have sufficient working memory resources to process learning tasks with full element interactivity (Kalyuga 2007). In contrast, students with low pre-existing knowledge lack such schemas, so they need to use more of their working memory resources to deal with the incoming information (Blayney et al. 2010). In this study, students were considered to be novices in the topics of Speed and Density and so were unlikely to have relevant schemas to help them with the learning processes. Scaffolding of information in a sequence of learning tasks using the isolating-elements strategy was used so as not to overload students' working memory (Ayres 2013; Gerjets et al. 2006).

Non-cognitive Processes

Non-cognitive processes such as students' psychological needs and motivation are equally, if not more, important than cognitive processes for supporting student learning. Research in self-determination theory (SDT) has shown that when students' psychological needs (i.e., sense of competence, autonomy, and relatedness) are satisfied, their motivation is self-determined, and they are more likely to function optimally (Deci and Ryan 2008). Without substantial motivation, students pay less attention to the learning tasks presented to them, their working memory receives less information to process, schemas are less likely to be formed, and learning is less likely to occur (Kadir et al. 2015). Even the best cognitive strategies will fail when presented to unmotivated students. Therefore, both cognitive and non-cognitive factors of learning are necessary to help students achieve learning goals and to perform optimally (Phan et al. 2016).

Non-cognitive Strategy Used in the Intervention According to SDT, the highest quality of human motivation results when basic psychological needs for competence, autonomy, and relatedness are supported (Ryan and Deci 2017). Competence is the feeling of being capable and effective in the way one interacts with the environment (Niemiec and Ryan 2009); autonomy is the feeling of doing something out of one's own choice, such that one's action is self-determined and volitional (Deci and Ryan 1985); and relatedness is the feeling of being connected to those around you (Moller et al. 2010). These needs, when fulfilled, will produce an energetic driving force for motivated behaviors (Vansteenkiste et al. 2010). In contrast, when these needs are not fulfilled, motivation, growth, and well-being will be reduced (Deci and Ryan 2000). Numerous studies using the SDT framework have shown that the fulfillment of students' basic psychological needs for autonomy, competence, and relatedness is critical for internalization of academic motivation and positive learning outcomes (Niemiec and Ryan 2009). For example, Jang et al. (2009) found that fulfillment of students' basic psychological needs was associated with positive learning experiences and higher academic achievement. Similarly, in the study by Ng et al. (2016), students with high motivation reported high satisfaction of their basic psychological needs and also had high achievement. In the intervention, we aimed to fulfill students' basic psychological needs with the goal of enhancing student motivation in science, by designing a science learning environment with essential features that support students' sense of competence, autonomy, and relatedness. The satisfaction of these needs was measured by several learning outcomes such as achievement and motivated behaviors.

Types of Motivated Behaviors In SDT, motivated behaviors can be placed along a continuum from autonomous to controlled (Ryan and Connell 1989; Ryan and Deci 2000). The most autonomous type of motivation is intrinsic motivation and is associated with activities in which individuals personally choose to participate (in the absence of external stimuli), because they find the activities interesting and enjoyable (Ryan and Deci 2016). Extrinsic motivation is subdivided into various forms of regulation ranging from autonomous to controlled. Integrated and identified regulations are forms of extrinsic motivation considered to be autonomous because individuals identify with an activity's value and ideally will have integrated it into their sense of self, so they do the activity willingly because they see the value in doing it (Deci and Ryan 2008). Introjected and external regulations are forms of extrinsic motivation considered to be controlled (Ryan and Deci 2000). Individuals who experience introjected regulation have partially internalized their behavior but are mostly energized by factors such as approval motive, avoidance of shame, and ego involvements (Deci and Ryan 2008). Those who experience external regulation do something because of "external contingencies of reward or punishment" (Deci and Ryan 2008, p. 182).

Motivational Outcomes Measured in the Study

Research has shown that satisfying students' basic psychological needs enhanced their motivation (Deci and Ryan 2000). Since the intervention involved strategies to support students' basic psychological needs, it was hypothesized that student motivation would be positively affected. In this study, student motivation was measured via several motivational outcomes. Students' behavioral outcomes from motivation (i.e., self-regulation and engagement) and their academic self-concept (sense of competence) were measured because they are desired educational outcomes. It was hypothesized that students who were motivated to learn science would be proactive in making sure that they understand the science concepts (self-regulation) and that they would be attentive during science lessons (engagement). Similarly, those who believed that they could do well in science were hypothesized to rate themselves highly on the sense of competence scale. In addition to the behavioral outcomes, several types of motivation along the SDT motivation continuum were also measured (see Fig. 1, adapted from Gagne and Deci 2005). Measuring motivation on the SDT continuum facilitates the identification of the types of motivation most affected by the intervention. The autonomous motivational outcomes were Interest (intrinsic motivation), Task Goal Orientation (identified regulation), and Educational Aspiration (integrated regulation). Career Aspiration was labeled as being part integrated and part introjected. The controlled motivation outcome was Ego Involvement (introjected regulation). Since there were no reward-punishment features in the intervention, external regulation was not measured in this study. Amotivation was out of the scope of this study, so it was also not measured. Since motivation and academic self-concept have been shown to be domain-specific (e.g., Kadir and Yeung 2016; Yeung et al. 2010a), all motivational factors were measured only within the science domain, since the intervention was on science topics.

Design of the Dual-Approach Instruction

The aim of DAI is to provide students with a rich curriculum to make complex learning more manageable in a learning environment which nurtures motivation. DAI uses instructional strategies, which reduce cognitive load for beginning learners (e.g., LRI) and nurture student motivation by supporting their basic psychological needs (e.g., SDT). The design of the DAI in this study involved a systematic revision of two complex science units from the school curriculum (Speed and Density), in relation to the learning activities and lesson delivery, to

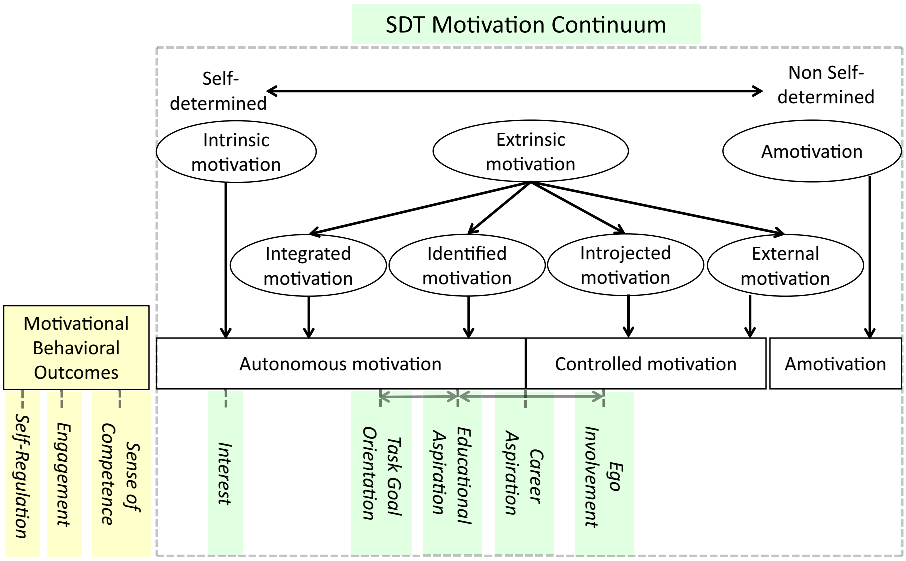

Fig. 1 Motivation variables on the self-determination theory (SDT) motivation continuum and other motivational behavioral outcomes measured in the study

make the learning processes less complex and more motivating. The design of the cognitive components was guided by the principles of cognitive load theory, which included group learning (Hardy et al. 2006; Kirschner et al. 2009) and LRI strategies such as isolating-elements (van Merriënboer et al. 2003) and guided inquiry (Riga et al. 2017). Students in the intervention group were engaged in collaboratively conducting hands-on experiments, making decisions as a team to choose the next course of action, interpreting the results with their team members, documenting the results in their own worksheet, and discussing the assumptions and results with the teacher as a class. Such activities are similar to those reported by Hardy et al. (2006), which are known to help students make sense of scientific principles. Group learning was preferred over individual learning because research in CLT has shown that students who worked on complex learning tasks in groups outperformed those who worked individually in knowledge transfer tasks (Kirschner et al. 2009). According to Kirschner et al. (2009), the high cognitive load in complex tasks would most probably overload the WM of the individual learner, but if distributed among group members, there would be sufficient WM resources to complete the task, and learning would be more effective.

Following criticisms that the inquiry-based approach to science learning is not effective for novice learners (Kirschner et al. 2006), we ensured that learners participated in a guided inquiry approach (Riga et al. 2017), which is consistent with the principles of LRI. This involved (1) reducing the difficulty of a task during initial learning, (2) providing instructional support and scaffolding through the task, (3) offering appropriate instructional feedback, (4) allowing ample structured practice, and (5) ensuring independent practice, supported autonomy, and guided discovery learning, as students developed expertise. Although numerous frameworks have recognized the roles of explicit or discovery approaches, LRI is distinct in that its emphasis is on reducing or managing the cognitive load on students as they learn through these approaches (Martin 2016). The isolated-elements strategy (e.g., Ayres 2013; Pollock et al. 2002) was used in both topics so that element interactivity was within novice students' WM capacity.

The learning sequences for each topic (Speed and Density) consisted of seven, one-hour lessons, based on the original science materials for teachers by McDermott et al. (1996) and materials developed in the PbI1@School research (Lau et al. 2011) for students. The PbI1@School research team modified the teaching materials from McDermott et al. (1996) for use in the first intake of secondary students (grade 7) in Singapore. Instructional materials for the topic of Speed were adapted from Kadir et al. (2011) and Density materials from Wong et al. (2011). At the end of the Speed unit, students were expected to be able to describe motion in terms of speed, draw a strobe diagram to represent speed, and apply the concept of speed as distance traveled per unit time to solve complex problems quantitatively. At the end of the Density unit, students were expected to be able to explain why some objects float or sink, draw diagrams to show their understanding of density as a material property, and apply the concept of density as the amount of mass in a unit of volume to solve complex problems quantitatively.

The design of the non-cognitive components of DAI was guided by the principles of SDT to support students' basic psychological needs of competence, autonomy, and relatedness through a range of strategies. Students' sense of competence was facilitated through teachers providing constructive feedback and encouragement, and activities were designed to be within students' cognitive capabilities so that they experienced successful episodes during the learning processes. Students' sense of autonomy was facilitated through meaningful and interesting hands-on activities with opportunities for students to contribute to team decisions. Teachers ensured that students worked harmoniously as a team and shared their findings with the class to develop a sense of relatedness by being a part of a learning community. The collaborative learning environment resembled that of the project work setting described in Wang et al. (2011), which included features of teacher facilitation and peer support, shown to satisfy students' basic psychological needs. In sum, the role of the teacher was to facilitate and motivate, to structure and guide activities, to ask relevant questions, and to provide support and encouragement when needed.

Please refer to the supplementary materials for more details on the learning materials and processes of the DAI. Appendix A shows a sample of eight learning activities from the topic Density. Appendix B provides details on how the activities (1) implemented the isolating-elements strategy to sequence the element interactivity and (2) fulfill students' psychological needs. Appendix C provides details on how the DAI supported students' basic psychological needs.

Design of the Science Knowledge Tests

All summative science knowledge tests for the Speed and Density topics were designed according to the stipulated school science syllabus for each topic and reviewed by both the teachers and researchers. The Prior Knowledge test was conducted before the start of each topic and the Knowledge Transfer test at the end of the last lesson of each topic. Each Prior Knowledge test was designed to assess the pre-existing knowledge of students in the topic area, so they are simple and have low element interactivity. The Knowledge Transfer test for each topic was designed to investigate students' learning transfer of each topic, specifically, their ability to apply learned concepts to solve novel (new) science problems. Therefore, the Prior Knowledge and Knowledge Transfer test questions were not identical. Each Knowledge Transfer test consisted of two sections to differentiate between students' levels of understanding of the learning materials and to uncover any intervention effects due to cognitive strategies (Leahy et al. 2015): one contained simple, low element interactivity questions (as reviewed by the teachers and researchers); the other contained more complex, high element interactivity questions.

This Study

The present study was a cluster-level assignment study (see What Works Clearinghouse 2017), which compared two groups (i.e., control and intervention) of students' achievement and motivation before and after learning four topics in their science curriculum. Past research describes the benefits of cognitive strategies, which reduce cognitive load (e.g., LRI) and non-cognitive strategies, which nurture student motivation, but these strategies were implemented independently, in separate studies. The present study adds to the research literature by implementing both types of strategies (i.e., cognitive and non-cognitive) in one curriculum-level intervention using Dual-Approach Instruction. This study reports findings of student achievement and motivational outcomes where students in an intervention group experienced a curriculum-level intervention, specifically whereby LRI strategies from CLT were combined with motivational strategies from SDT in one learning environment, during lessons of Speed and Density.

The control group experienced regular instruction for the same science topics (Speed and Density), involving lecture-style delivery of theoretical information from the teachers to their students (while students copied notes in their worksheets), and one hands-on laboratory session for each topic to affirm what students learned during the theory lessons (see Appendix D for a comparison between Dual-Approach Instruction and regular instruction and Table 1 for a comparison between the intervention and control groups).

There were several hypotheses for this study. Hypothesis 1: We would expect both groups of students to have higher achievement in simpler tasks (low element interactivity) than the complex ones (high element interactivity). Simpler tasks require less WM resources and therefore are less likely to overload students' WM during the learning process. Also, low element interactivity tasks would require simple schemas to be recalled and students would not need to deal with major interactions between elements in their WM during the tasks, risking cognitive overload. Hypothesis 2: If the intervention was effective, then we would expect no difference in the achievement between both groups of students (control vs intervention) for the topics for which there was no intervention. Hypothesis 3: We would expect a difference in the achievement between the two groups, favoring the intervention group, but only for the high element interactivity tasks as CLT strategies have been known to only benefit learning tasks of high element interactivity (Leahy et al. 2015). Hypothesis 4: If the intervention nurtured student motivation, we would expect the intervention group to have higher motivation than the control group.

Method

Participants

The data were collected from 11 grade 7 classes (i.e., first year of secondary school, commonly known as secondary one in Singapore) from a school located in the eastern part of Singapore. The school opted to have the entire cohort of grade 7 students participate in the study. Participation was voluntary and a total of 427 consenting students (232 females and 195

Table 1 Summary of comparison between the intervention and control groups for the instruction on the topics of Speed and Density

	Intervention group with Dual-Approach Instruction	Control group with regular instruction
Worksheets used to guide instruction	Load reduction instruction (LRI) was applied: simple-to-complex sequencing of information, learning tasks, and activities	Information and science word problems with high element interactivity were presented at random without a specific sequence
Hands-on activities	Students carried out a total of 6 hours of hands-on activities for both topics. Hands-on activities were in the form of guided inquiry, where students carried out many mini investigations (sub-tasks), observe patterns in the results, and came up with conclusions based on their observations. Students worked in teams of four.	Students carried out a total of 2 hours of hands-on activities for both topics. Hands-on activities were in the form of "cook-book recipe" where students followed step-by-step procedures on how to carry out a main activity to prove a theoretical concept they had learned in class during previous lessons. Students worked in pairs.
General learning processes	Teacher-student discussions of students' findings in the learning tasks at 15-minute intervals, ensuring that students have learned the simpler concepts before moving on to more complex ones. Lessons were student-centered.	Teacher delivered information and expected students to pay attention for about 40 minutes before completing transfer problems at the end of lesson. Then, teacher discussed solutions to the problems. Lessons were teacher-centered.
Basic psychological needs of students	Competence Students' sense of competence was nurtured by (1) high level of student-teacher interactions; teachers provided encouragement and constructive feedback and (2) ample opportunities at assessing student ability as they carried out many hands-on learning tasks in teams Autonomy Students took charge of their learning by actively participating in knowledge-building. The rationale for the learning tasks was explained. Students freely shared their ideas with peers and teacher. When questions were asked by teacher, ample time was given to discuss with peers before presenting the answer to minimize evaluative pressure. Relatedness Students mainly worked in teams, carried out investigations together, exchanged ideas, and contributed to knowledge-building of the lesson as a class, in a learning community. Interactions among students and teachers were apparent. Teachers ensured no student was isolated; everyone played a role.	Competence Students' sense of competence was not explicitly nurtured as there was (1) hardly any student-teacher interaction, so teachers lack opportunities to provide encouragement and feedback and (2) lack of opportunities to assess student ability—random practice questions in the worksheets they worked on individually Autonomy Students were not given the autonomy to contribute to knowledge-building. Rationale was not explained. Students were expected to be quiet and listen to the teacher deliver information. There was no sharing of ideas among students. There was evaluative pressure during lessons as individual students were selected to answer questions which could be intimidating. Relatedness Students were mainly individual learners in the classroom. They passively listened to information delivered by the teacher in front of the classroom. There was lack of learning as a community, as there was no contribution from the students. There was minimal interaction among students and with the teacher during the lecture-style lessons.

males) were involved in the study. Students were mostly from medium to high socioeconomic backgrounds and used English as the main language of communication.

All seven teachers teaching the grade 7 science classes in the school consented to participating in the study voluntarily, without receiving additional pay or incentives. The teachers were randomly assigned to either the control or intervention condition. The grade 7 classes taught by the teachers assigned to the control condition became the control group and the classes taught by the teachers assigned to the intervention condition became the intervention group. There were five classes (196 students: 118 girls and 78 boys, $M = 13.5$ years, SD = 0.3) in the control group and they experienced regular instruction in four science topics: Heat, Forces, Speed, and Density. The remaining six classes (231 students: 114 girls and 117 boys, $M = 13.4$ years, SD = 0.40) were in the intervention group and they experienced regular instruction in the science topics of Heat and Forces and Dual-Approach Instruction in the topics of Speed and Density. All lessons were conducted as part of the school science curriculum, during standard school hours. Each class size was similar, ranging from 36 to 40 students.

No teacher taught in both the control and intervention classes. All of the teachers had been full-time teachers throughout their career, were of similar age, had similar science teaching experience (i.e., at least 5 years), and had similar motivation and science teaching skills (based on teacher assessment grades acquired from the school) prior to the intervention training. To account for teacher effects (since different teachers taught the control and intervention groups), we compared all students' achievement scores on two different science topics (Heat and Forces), which were taught using traditional instruction strategies prior to the intervention. The effectiveness of the intervention was assessed in terms of student achievement and motivational outcomes. Achievement was measured by comparing students' Prior Knowledge and Knowledge Transfer test scores in four science topics: Heat, Forces, Speed, and Density. Motivation was measured using students' responses to a perception survey administered at the end of the school semester, when all teaching and testing were completed.

The study was approved by the Ministry of Education, Singapore. All ethics procedures were strictly followed, participation was voluntary, and data collected were anonymized before analysis. Teachers and students agreed to participate in the study, and to be filmed for the purpose of intervention fidelity. Parents of the student participants provided written consent for their child's participation. Teachers and students were informed that they could withdraw their participation at any time.

Procedure

The participating secondary school separates its science curriculum into physics, chemistry, and biology from grade 7 onwards. Since the school only accepts students who performed well (i.e., top 30%) in the local national examinations at the end of grade 6, students were expected to be ready to learn the separate branches of science from grade 7 onwards. At the time of the study during the first half of the year, the school was implementing the physics component of the grade 7 science curriculum, so only physics topics were used in the study. Previously, at the beginning of the year, all teachers delivered lessons on the science topics of Heat and Forces in a similar way, using the same lesson plans and materials finalized by the science department of the school. This instruction, identified as regular instruction in the study, was described by science teachers during their interviews. Characteristics described by teachers matched those in field notes taken by researchers during the regular instruction lesson observations.

Four teachers in the intervention group participated in seven 1-hour workshops on Dual-Approach Instruction, which were mostly held after school teaching hours. During the workshops, teachers were introduced to knowledge about students' cognitive processes and how to use the isolated-elements strategy to manage element interactivity at each stage of learning. They were also introduced to knowledge about self-determination theory and how to create learning climates to support students' basic psychological needs: competence, autonomy, and relatedness. Participating teachers viewed video clips of DAI featuring teachers facilitating hands-on activities, while giving positive feedback and encouraging remarks to motivate students. These clips were then analyzed and discussed. Participants received instructional materials on Speed and Density and engaged in activities where they applied their knowledge to: (1) manage element interactivity in the learning materials and instructional delivery, and (2) create learning environments to provide students with a sense of competence, autonomy, and relatedness. Researchers and teachers also role-played some DAI lesson plans on Speed and Density by taking on the roles of teachers and students. In the final workshop, student learning materials and lesson plans on Speed and Density were finalized by the researchers and teachers. Teachers then delivered lessons on Speed and Density using DAI as stipulated in the lesson plans while teachers in the control condition delivered lessons on the same topics using regular instruction. Lesson observations were conducted for both the intervention and control groups.

Both the control and intervention groups each taught their topics for seven 1-hour lessons (i.e., 3 weeks). Online questionnaires asking students to rate their motivation were completed in the computer lab in the presence of a teacher, when all four science topics had been taught. All students did the same science achievement tests in the same four science topics before the start (i.e., Prior Knowledge test) and after the completion (i.e., Knowledge Transfer test) of the lessons of each topic. To minimize missing data, teachers arranged for students who were absent to complete online surveys/tests within the next few days.

Intervention Fidelity To evaluate the extent to which the intervention was implemented as planned, we focused on five key elements of intervention fidelity: design, workshops on DAI, intervention delivery, intervention receipt, and intervention enactment (cf., Smith et al. 2007). Lesson observations in the intervention condition indicated that teachers adhered to the co-designed lesson plans, and teacher manual, and were able to administer the lessons within the stipulated timeframe. Lesson observations in the control condition indicated that the teachers were teaching in the same way as described during the interviews prior to the intervention (i.e., using the regular instruction).

The workshop series on DAI was delivered by the first author of this paper, as she had previous experience in delivering professional development programs for science teachers. All teachers in the intervention condition attended all the workshops at the same time to ensure systematic delivery across teachers, and to maximize the fidelity of intervention delivery. In addition to this, the first author was stationed in the school during the period of intervention delivery, so that teachers could readily consult about the intervention. The first author also met with the teachers in the intervention condition every week for a discussion to reflect on the intervention delivery, to ensure understanding of the intervention, and to answer any questions. To evaluate the intervention enactment, all video recordings of the lessons were viewed and checked against the lesson plans and teacher manual. No abnormalities or departure from procedures were found.

For those lessons without a researcher as observer, a 5-minute episode of each video clip was coded for student-teacher interaction and characteristics of the lesson about half-way through each lesson. Analysis of these episodes correlated with field notes taken from the lesson observations, i.e., that students in the control condition were passively listening to teacher-talk while taking notes in their worksheets, and mainly following instructions during the two laboratory sessions, and students in the intervention condition were engaged in hands-on science activities, discussing their work in teams, recording their findings in guided worksheets, with their teachers working as facilitators of learning, and providing constructive feedback and encouragement to the students. Appendix C provides details of observed teacher and student behaviors in the intervention condition, which correlate with characteristics of a learning environment where students are supported in their basic psychological needs of competence, autonomy, and relatedness.

Material

Although grade 7 students in Singapore had not yet received formal physics instruction in primary school, it was possible that some of the students had pre-existing knowledge of the topics, either from their life experiences, enrichment classes, or elements of the general science lessons they received from their previous school (i.e., primary school). To measure students' learning gains in the four science topics (Heat, Forces, Speed, and Density), Prior Knowledge tests and Knowledge Transfer tests were administered to the students before the first lesson and after the final lesson of each topic, respectively. To measure how students developed in terms of their motivation in science over time, students completed an online motivation pre-test survey at the beginning of the school year (i.e., before the start of their grade 7 science lessons) and completed the same online motivation post-test survey when all the four science topics had been taught. The duration of time between the Prior Knowledge test and Knowledge Transfer test of each science topic was about 3 weeks, and that between the pre-test and post-test of the motivation survey was 20 weeks. Appendix E provides an overview of the administration of the tests.

Measurement of Achievement Students' Prior Knowledge and Knowledge Transfer test scores were used to measure their achievement. The Prior Knowledge test for each science topic assessed students' pre-existing knowledge in the respective topics before instruction. Each Prior Knowledge test comprised five one-mark items and assessed students' understanding of basic concepts of each topic. The items were adapted from Lau et al. (2011). Each item was analyzed in terms of element interactivity by two researchers. Items were modified so that all had low element interactivity, a process that was agreed to by both the researchers and teachers to encourage student engagement in the topic. An inter-rater agreement of 96% was achieved for the coding. Scoring of the Prior Knowledge test for each of the four science topics was firstly done by the teachers, based on a common marking scheme adapted from Lau et al. (2011). The Prior Knowledge test scripts were then passed on to the researchers for scoring and an inter-rater agreement of 88% was achieved between teachers and researchers. Teachers and researchers discussed the discrepancies to arrive at the final Prior Knowledge test score for each student on each of the four topics.

The Knowledge Transfer test for each science topic was designed to assess students' understanding and ability to apply their understanding of knowledge gained during instruction to solve complex problems. Each Knowledge Transfer test totaled ten marks and comprised two sections. Section A was designed to include only low element interactivity questions and comprised five one-mark items. Section B was designed to include only high element interactivity questions and comprised structured questions totaling five marks. The items were adapted from Lau et al. (2011) and modified to meet the element interactivity requirements of each section of the Knowledge Transfer test. Each item was analyzed in terms of element interactivity and coded as “low” or “high” by two researchers. An inter-rater agreement of 82% was achieved for the coding. Discrepancies were discussed to arrive at a common conclusion. As with the Prior Knowledge test, scoring of the Knowledge Transfer test for each of the four science topics was firstly completed by teachers, based on a common marking scheme adapted from Lau et al. (2011). The Knowledge Transfer test scripts were then passed on to the researchers for scoring and an inter-rater agreement of 90% was achieved between teachers and researchers. Discrepancies were discussed to arrive at the final scores. Each student had two Knowledge Transfer test scores: one for the low element interactivity items from section A (full score = 5 marks) and another for the high element interactivity items from section B (full score = 5 marks). Examples of low element interactivity items are given in Appendix F and high element interactivity items are given in Appendix G.

Measurement of Motivation After consulting several scales, student motivational outcomes were measured using different types of motivational items ranging from autonomous to controlled regulation, as stipulated in the SDT continuum (Fig. 1). The items were given to two expert researchers in the field, who coded them according to the factors, based on the best face validity. Inter-rater codes correlated at 0.82. Confirmatory factors analyses (CFAs) further supported the contention that these items measure the respective motivational factors. The maximal reliabilities (Raykov 2004) of the eight factors at pre-test and post-test ranged from 0.80 to 0.90. These high reliabilities provided support for the motivational factors. The list of items and the maximal reliability for each motivation factor for both pre-test and post-test are given in Appendix H. Student responses to all the motivation items were given on a 6-point Likert scale ranging from 1 (disagree strongly) to 6 (agree strongly). All the items were randomized in the motivation survey form.

Self-regulation The self-regulation factor assesses students’ reported behavior when they do not understand science information. When students are motivated in science, they tend to be proactive in doing something to ensure that they understand confusing science information. Self-regulation was measured by four items (e.g., “When I’m reading my science materials and do not understand something, I stop and think it over”), adapted from the Motivated Strategies for Learning Questionnaire (MSLQ; Pintrich and Degroot 1990). In the study, this factor has maximal reliabilities of 0.86 and 0.83 for pre-test and post-test, respectively.

Engagement The engagement factor measured students’ perceptions of their attentiveness during science lessons. Engagement was measured by four items (e.g., “I am attentive to my work in SCIENCE.”), adapted from Yeung et al. (2010b) and Steinberg et al. (1992). In the study, this factor has maximal reliabilities of 0.88 and 0.90 for pre-test and post-test, respectively.

Sense of Competence The sense of competence factor measured students’ perceptions of their science ability and is a cognitive component of science self-concept. Sense of competence was measured by four items (e.g., “I am good at science”), adapted from the Academic Self-Description Questionnaire (ASDQ; Marsh, 1992) and Kadir et al. (2013). In the study, this factor had maximal reliabilities of 0.90 and 0.86 for pre-test and post-test, respectively.

Interest The interest factor measured the extent of students' enjoyment and interest in science. This is an affective component of science self-concept and is also a form of intrinsic motivation and links to self-determined regulation identified by SDT. Interest was measured by four items (e.g., "I find science interesting"), taken directly from Kadir et al. (2013) who adapted the scale from the study by Marsh et al. (1999), Elliot and Church's (1997) measure of personal interest and enjoyment and the Yeung et al. (2004) measure of students' affect in other curriculum areas. In the study, this factor had maximal reliabilities of 0.90 and 0.88 for pre-test and post-test, respectively.

Task Goal Orientation The task goal orientation factor measured the degree of students' autonomous motivation in science (i.e., identified regulation) by asking students to rate the reasons that they do their work based on their goals, values, and regulations in science. The four items that measured task goal (e.g., "An important reason I do my work in science is that I like to learn new things") were adapted from the Academic Self-Regulation Questionnaire (SRQ-A; Ryan and Connell 1989) and the School Motivation Questionnaire (SMQ; Marsh et al. 2003). In the study, this factor had maximal reliabilities of 0.90 and 0.80 for pre-test and post-test, respectively.

Education Aspiration The education aspiration factor asked students about their aspiration to pursue science courses at advanced levels in future. This factor measured the degree of students' autonomous motivation (i.e., integrated regulation). Education aspiration was measured by four items (e.g., "I would like to study SCIENCE in college/ university"), adapted from Yeung and McInerney (2005) and Kadir et al. (2012). In the study, this factor had maximal reliabilities of 0.83 and 0.84 for pre-test and post-test, respectively.

Career Aspiration The career aspiration factor asked students about their aspiration to have a science-related career in the future. This factor also measured the degree of students' autonomous motivation (i.e., integrated regulation). Career aspiration was measured by four items (e.g., "I want to have a job that has to do with science"), adapted from Yeung and McInerney (2005) and Yeung et al. (2010b). In the study, this factor had maximal reliabilities of 0.89 and 0.88 for pre-test and post-test, respectively.

Ego Involvement The ego involvement factor measured the degree of students' controlled motivation (i.e., introjected regulation) to show others that they are good in science. Ego Involvement was measured by four items (e.g., "I want to show others that I am smart in science"). The items were largely adapted from the introjected items of the Academic Self-Regulation Questionnaire (SRQ-A; Ryan and Connell 1989). In the study, this factor had maximal reliabilities of 0.82 and 0.86 for pre-test and post-test, respectively.

Statistical Analysis

We first tested the validity of the survey instrument using CFAs (please see Appendices I, J, and K for details). The data had a hierarchical structure because students in the study were nested in classes. Therefore, multiple regression analysis with adjusted standard errors was conducted. We estimated two regression models for each of the eight achievement variables and eight motivational factors. All variables were standardized before running the analyses. In model 1, we predicted students' achievement and motivation at post-test with the groups only. In model 2, we added students' Prior Knowledge/pre-test scores and gender as predictors to control for pre-existing differences and for the uneven distribution of boys and girls between the groups. We calculated R^2 as a measure of explained variance. Finally, we accounted for the non-independence of the observations by adjusting the standard errors using the sandwich estimator implemented in Mplus V7 (Muthén and Muthén, 1998–2015). According to Hedges (2007), standardized mean differences (i.e., the means of two comparison groups divided by the standard deviation) represent effect sizes. As the standardizations of all continuous variables were computed before running the analyses, the regression coefficients β of the dummy variables (i.e., groups and gender) represented the standardized mean differences. Therefore, the effects of the intervention condition compared to the control group could be interpreted as effect sizes (Hedges 2007). For ease of readability, we also conducted descriptive analysis and bivariate correlation analysis of all variables in the study.

Results

Descriptive Statistics for the Item Variables

Table 2 provides an overview of the descriptive statistics and bivariate correlations of all 33 item variables in the motivation survey at pre-test, for all participants. The mean of the variables ranged from 3.43 to 5.25. The correlations between motivational variables within the same factors were all positive and statistically significant ($p < 0.001$). For example, correlations between the variables in the Self-regulation factor (Sre1–4) ranged from 0.51 to 0.67 and that for the Engagement factor (Eng1–5) ranged from 0.47 to 0.67. Similar numbers were observed for Sense of Competence (Com1–4: 0.60 to 0.71), Interest (Int1–4: 0.56 to 0.75), Task Goal Orientation (Tgo1–4: 0.62 to 0.75), Educational Aspiration (Eda1–4: 0.45 to 0.70), Career Aspiration (Caa1–4: 0.55 to 0.77), and Ego Involvement (Ego1–4: 0.45 to 0.62). Positive and statistically significant correlations were also observed across the motivational behavioral outcome variables (i.e., Self-Regulation, Engagement, and Sense of Competence) and the motivational factors on the autonomous motivation spectrum on the SDT continuum. Variables from Ego Involvement, the only controlled motivation factor, were not statistically correlated with most of the variables from other motivational factors. Overall, the correlations ranged from −0.02 (statistically non-significant correlation between Int1: Interest variable 1 and ego 4: Ego Involvement variable 4) and 0.77 (statistically significant correlation between Caa2 and Caa3: Career Aspirations variables 2 and 3).

Validity of Motivation Survey Instrument

All CFA models converged without problems during the estimation. The model, which tested the ability of 33 motivational variables to form eight distinct motivational factors, resulted in an adequate fit at both pre- and post-tests. The goodness-of-fit indices for the model are χ^2 (467) = 934.78, $p < 0.001$, CFI = 0.94, TLI = 0.93, RMSEA = 0.05, 90% CI = [0.04, 0.05] at pre-test and χ^2 (467) = 812.16, $p < 0.001$, CFI = 0.95, TLI = 0.94, RMSEA = 0.04, 90% CI = [0.04, 0.05] at post-test.

Table 2 Descriptive statistics and bivariate correlations for the measured motivational variables of the study at pre-test

Variable	1	2	3	4	5	6	7	8	9	13	14	15	16	17
1 Sre1	–													
2 Sre2	0.58***	–												
3 Sre3	0.51***	0.67***	–											
4 Sre4	0.62***	0.70***	0.62***	–										
5 Eng1	0.40***	0.47***	0.41***	0.46***	–									
6 Eng2	0.42***	0.49***	0.38***	0.51***	0.59***	–								
7 Eng3	0.37***	0.46***	0.39***	0.42***	0.67***	0.58***	–							
8 Eng4	0.38***	0.52***	0.37***	0.44***	0.47***	0.59***	0.47***	–						
9 Eng5	0.44***	0.55***	0.43***	0.54***	0.54***	0.61***	0.47***	0.63***	–					
10 Com1	0.22***	0.31***	0.21***	0.36***	0.22***	0.29***	0.22***	0.24***	0.33***					
11 Com2	0.16***	0.26***	0.21***	0.34***	0.23***	0.23***	0.23***	0.18***	0.34***					
12 Com3	0.17***	0.25***	0.18***	0.33***	0.26***	0.23***	0.24***	0.18***	0.31***					
13 Com4	0.28***	0.35***	0.25***	0.40***	0.28***	0.34***	0.33***	0.24***	0.36***	–				
14 Int1	0.33***	0.44***	0.31***	0.46***	0.33***	0.39***	0.31***	0.39***	0.46***	0.53***	–			
15 Int2	0.34***	0.49***	0.35***	0.49***	0.40***	0.45***	0.37***	0.42***	0.51***	0.55***	0.75***	–		
16 Int3	0.47***	0.53***	0.47***	0.52***	0.41***	0.45***	0.37***	0.50***	0.52***	0.52***	0.65***	0.67***	–	
17 Int4	0.34***	0.43***	0.38***	0.45***	0.36***	0.32***	0.38***	0.28***	0.36***	0.52***	0.66***	0.66***	0.56***	–
18 Tgo1	0.50***	0.63***	0.50***	0.61***	0.42***	0.47***	0.38***	0.47***	0.55***	0.52***	0.66***	0.71***	0.63***	0.58***
19 Tgo2	0.51***	0.57***	0.46***	0.57***	0.38***	0.42***	0.37***	0.44***	0.43***	0.41***	0.58***	0.56***	0.57***	0.53***
20 Tgo3	0.51***	0.61***	0.48***	0.63***	0.41***	0.47***	0.40***	0.44***	0.53***	0.59***	0.69***	0.70***	0.64***	0.65***
21 Tgo4	0.48***	0.65***	0.55***	0.64***	0.39***	0.49***	0.42***	0.47***	0.58***	0.52***	0.62***	0.64***	0.64***	0.55***
22 Eda1	0.30***	0.42***	0.34***	0.52***	0.31***	0.38***	0.30***	0.29***	0.43***	0.50***	0.63***	0.65***	0.55***	0.51***
23 Eda2	0.25***	0.35***	0.22***	0.34***	0.25***	0.28***	0.30***	0.24***	0.32***	0.41***	0.52***	0.58***	0.43***	0.44***
24 Eda3	0.30***	0.29***	0.24***	0.31***	0.24***	0.23***	0.24***	0.19***	0.27***	0.35***	0.40***	0.41***	0.33***	0.40***
25 Eda4	0.21***	0.35***	0.21***	0.37***	0.29***	0.33***	0.29***	0.28***	0.42***	0.48***	0.64***	0.62***	0.45***	0.48***
26 Caa1	0.32***	0.42***	0.35***	0.43***	0.32***	0.31***	0.33***	0.26***	0.34***	0.40***	0.52***	0.59***	0.47***	0.55***
27 Caa2	0.27***	0.39***	0.26***	0.38***	0.27***	0.34***	0.28***	0.30***	0.39***	0.44***	0.57***	0.66***	0.49***	0.46***
28 Caa3	0.25***	0.37***	0.26***	0.34***	0.26***	0.31***	0.30***	0.26***	0.37***	0.45***	0.53***	0.61***	0.47***	0.41***
29 Caa4	0.17***	0.27***	0.13**	0.22***	0.10*	0.19***	0.16***	0.12*	0.17***	0.31***	0.44***	0.48***	0.33***	0.32***
30 Ego1	0.15**	0.17***	0.18***	0.18***	0.22***	0.22***	0.24***	0.22***	0.24***	0.31***	0.17***	0.19***	0.26***	0.13**
31 Ego2	0.08	0.14**	0.19***	0.20***	0.15**	0.15**	0.20***	0.07	0.14**	0.27***	0.15**	0.16**	0.16**	0.13**
32 Ego3	0.12*	0.13**	0.14**	0.13**	0.19***	0.14**	0.18***	0.11*	0.17***	0.22***	0.14**	0.23***	0.19***	0.17***

Table 2 (continued)

Variable	1	2	3	4	5	6	7	8	9	13	14	15	16	17
33 Ego4	0.05	0.07	0.13**	0.11*	0.08	0.02	0.12*	0.04	0.08	0.21***	− 0.02	0.07	0.13**	0.04
Mean	4.60	4.83	4.82	4.68	4.96	4.83	5.06	5.25	5.06	4.25	4.49	4.58	4.82	4.93
SD	1.03	0.95	0.98	0.97	0.86	0.86	0.75	0.84	0.87	1.11	1.16	1.14	1.02	1.05

Variable	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33
1 Sre1																
2 Sre2																
3 Sre3																
4 Sre4																
5 Eng1																
6 Eng2																
7 Eng3																
8 Eng4																
9 Eng5																
10 Com1																
11 Com2																
12 Com3																
13 Com4																
14 Int1																
15 Int2																
16 Int3																
17 Int4																
18 Tgo1	–															
19 Tgo2	0.66***	–														
20 Tgo3	0.73***	0.66***	–													
21 Tgo4	0.75***	0.62***	0.73***	–												
22 Eda1	0.62***	0.51***	0.61***	0.63***	–											
23 Eda2	0.50***	0.36***	0.54***	0.49***	0.55***	–										
24 Eda3	0.38***	0.32***	0.43***	0.44***	0.46***	0.49***	–									
25 Eda4	0.54***	0.44***	0.57***	0.52***	0.70***	0.58***	0.45***	–								
26 Caa1	0.51***	0.44***	0.55***	0.50***	0.51***	0.53***	0.36***	0.50***	–							

Table 2 (continued)

Variable	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33
27 Caa2	0.51***	0.38***	0.56***	0.53***	0.57***	0.68***	0.44***	0.58***	0.67***	–						
28 Caa3	0.48***	0.38***	0.52***	0.51***	0.55***	0.72***	0.47***	0.60***	0.60***	0.77***	–					
29 Caa4	0.37***	0.25***	0.43***	0.36***	0.42***	0.65***	0.43***	0.54***	0.55***	0.66***	0.69***	–				
30 Ego1	0.19***	0.17***	0.18***	0.21***	0.21***	0.11*	0.09	0.14**	0.09	0.11*	0.16***	0.08	–			
31 Ego2	0.13**	0.13**	0.15**	0.18***	0.22***	0.11*	0.12*	0.19***	0.11*	0.13**	0.20***	0.07	0.62***	–		
32 Ego3	0.15**	0.16**	0.10*	0.17***	0.16***	0.14**	0.16**	0.16***	0.16**	0.19***	0.19***	0.15**	0.45***	0.47***	–	
33 Ego4	0.01	0.05	0.03	0.06	0.04	0.08	− 0.00	0.05	0.06	0.08	0.14**	0.07	0.58***	0.59***	0.51***	–
Mean	4.74	4.80	4.58	4.62	4.25	3.82	4.01	4.15	4.54	4.26	3.92	3.70	3.90	3.43	4.03	3.82
SD	1.01	1.00	1.00	1.04	1.20	1.30	1.14	1.29	1.21	1.26	1.29	1.35	1.20	1.28	1.24	1.29

$N = 427$; All variables were measured on a 1–6 Likert scale; *Sre1–4*, Self-Regulation variables 1 to 4; *Eng1–4*, Engagement variables 1 to 4; *Com1–4*, Sense of Competence variables 1 to 4; *Int1–4*, Interest variables 1 to 4; *Tgo1–4*, Task Goal Orientation variables 1 to 4; *Eda1–4*, Educational Aspiration variables 1 to 4; *Caa1–4*, Career Aspiration variables 1 to 4; *Ego1–4*, Ego Aspiration variables 1 to 4; *SD*, standard deviation; $^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$

Descriptive Statistics for the Motivational Factors and Achievement Variables

Table 3 shows the descriptive statistics of the eight motivational factors and eight achievement variables at pre-test and post-test for the control group and the intervention group. The low intraclass correlations (ICCs) indicated only small differences between classrooms in the mean levels of the variables. The ICCs indicated that less than 10% of the variance in all of the motivational variables (ranging from 0.02 to 0.08) and most of the achievement variables were attributable to the classroom level, with the exception of six variables (i.e., Prior Knowledge tests of Heat, Forces, and Speed, Low element interactivity (EI) Knowledge Transfer test of Heat and high EI Knowledge Transfer tests of Speed and Density). For these six variables, between 11 and 19% of the variance could be attributed to variability on the classroom level. Table 3 showed that the control group had Prior Knowledge test mean scores ranging from 1.99 to 2.08 and the intervention group had Prior Knowledge mean scores ranging from 1.97 to 2.02 out of the full marks of 5. The low scores showed that both groups did not have high pre-existing knowledge in any of the four science topics, prior to instruction.

Multiple Regression Models

Results from the two multiple regression models (i.e., model 1 and model 2) for each of the 16 outcome variables are presented in Table 4. The results showed intervention effects on student achievement in Speed and Density high element interactivity tests, as well as student motivation in six factors.

Intervention effects on student achievement As expected, for the topics Heat and Forces in which there was no intervention, no significant difference in student achievement was found between the two groups of students, in both models 1 and 2, for both the low and high element interactivity Knowledge Transfer tests (see Table 4). In contrast, the results showed statistically significant positive effects of DAI on students' post-test achievement in high element interactivity for Speed ($\beta = 0.85$, $p < 0.001$) and Density ($\beta = 0.76$, $p < 0.001$) in model 1. The statistically significant positive effects remain strong in model 2 for both the intervention topics Speed ($\beta = 0.81$, $p < 0.001$) and Density ($\beta = 0.72$, $p < 0.001$) in the high element interactivity Knowledge Transfer tests. The effect sizes were large for both. There were no intervention effects in either model for the low element interactivity Knowledge Transfer tests. The results indicated that students in the intervention group had higher achievement in Speed and Density than those in the control group, but only for the high element interactivity Knowledge Transfer tests of those topics.

As shown in model 1, a comparably high amount of variance was explained by Speed and Density in high element interactivity Knowledge Transfer tests ($R^2 = 0.18$ and $R^2 = 0.14$, respectively). The results were similar for model 2: the largest amounts of variance in the achievement variables were also explained by high element interactivity Knowledge Transfer tests of Speed and Density ($R^2 = 0.20$ and $R^2 = 0.17$, respectively).

As seen from model 2 in Table 4, gender was a significant predictor of achievement in five variables, including three from the intervention topics: high element interactivity Knowledge Transfer tests of Speed and Density ($\beta = 0.29$ and $\beta = 0.35$, respectively, $p < 0.001$), low element interactivity Knowledge Transfer test of Density ($\beta = 0.21$, $p = 0.015$), and both low and high element interactivity Knowledge Transfer tests of Forces ($\beta = 0.51$, $p < .001$ and $\beta = 0.21$, $p = 0.006$). This indicates that boys had significantly higher achievement than girls in these five variables. The results also showed that Prior Knowledge test results were positively

Table 3 Descriptive statistics for achievement and motivation measures at pre- and post-test for control and intervention groups

Cognitive & motivation measures			Control group $n = 196$ Mean (SD)	Intervention group $n = 231$ Mean (SD)	ICC
Pre-test/Prior Knowledge test	Achievement				
		Heat	2.04 (0.66)	2.02 (0.56)	0.11
		Forces	1.99 (0.71)	1.98 (0.69)	0.13
		Speed	2.08 (0.78)	1.97 (0.63)	0.12
		Density	1.99 (1.12)	1.87 (1.00)	0.04
	Motivation	Self-regulation	4.83 (0.76)	4.65 (0.86)	0.05
		Engagement	5.01 (0.63)	5.05 (0.71)	0.04
		Sense of Competence	4.03 (1.00)	4.13 (1.04)	0.04
		Interest	4.66 (0.94)	4.74 (0.94)	0.03
		Task Goal Orientation	4.67 (0.88)	4.71 (0.89)	0.03
		Education Aspiration	4.01 (0.98)	4.10 (1.02)	0.03
		Career Aspiration	4.12 (1.03)	4.09 (1.16)	0.03
		Ego Involvement	3.72 (1.04)	3.85 (0.98)	0.03
Post-test/Knowledge Transfer test	Achievement	Low element interactivity problems Knowledge Transfer Test			
		Heat	4.21 (0.77)	4.04 (0.99)	0.12
		Forces	4.18 (0.82)	4.10 (0.83)	0.02
		#Speed	3.92 (0.77)	4.10 (0.74)	0.04
		#Density	3.91 (1.10)	4.06 (1.00)	0.04
		High element interactivity problems Knowledge Transfer Test			
		Heat	2.23 (1.29)	2.22 (1.35)	0.05
		Forces	2.26 (1.57)	2.19 (1.48)	0.06
		#Speed	2.22 (1.41)	3.50 (1.34)	0.19
		#Density	2.27 (1.40)	3.38 (1.31)	0.16
	Motivation	$n = 196$		$n = 230$	
		Self-regulation	4.21 (0.80)	4.63 (0.70)	0.03
		Engagement	4.57 (0.84)	4.83 (0.72)	0.05
		Sense of Competence	3.62 (0.93)	3.95 (0.93)	0.02
		Interest	4.13 (0.98)	4.40 (0.88)	0.09
		Task Goal Orientation	4.20 (0.89)	4.61 (0.74)	0.08
		Education Aspiration	3.56 (0.93)	3.94 (0.97)	0.05
		Career Aspiration	3.46 (0.97)	3.83 (1.05)	0.05
		Ego Involvement	3.53 (1.03)	3.65 (1.05)	0.02

ICC, intraclass correlation coefficient; # denotes intervention topics

significant predictors of achievement in low element interactivity Knowledge Transfer tests of Heat ($\beta = 0.12$, $p = 0.031$) and Density ($\beta = 0.23$, $p < 0.001$). This shows that students who did better in the low element interactivity Prior Knowledge tests also had higher achievement in the low element interactivity Knowledge Transfer tests of Density and Heat.

Intervention effects on student motivation The results indicated that students in the intervention group had higher science motivation than those in the control group on most of the motivational variables. As displayed in Table 4 in model 2, statistically significant positive effects of DAI were found in students' motivation behavioral outcomes in terms of their Self-regulation ($\beta = 0.31$, $p < 0.001$), Engagement ($\beta = 0.16$, $p < 0.05$), Sense of Competence ($\beta = 0.14$, $p < 0.01$), as well as motivation on the SDT continuum: Task Goal Orientation ($\beta = 0.21$, $p < 0.001$), Education Aspiration ($\beta = 0.17$, $p < 0.001$), and Career Aspiration ($\beta = 0.17$, $p < 0.001$). Model 1 had similar results with slightly different magnitudes of β. Small effect sizes

Table 4 Results from multiple regression analyses

	Heat: low EI				Heat: high EI				Forces: low EI				Forces: high EI			
	1		2		1		2		1		2		1		2	
	β	SE	β	SE	β	SE	β	SE	β	SE	β	SE	β	SE	β	SE
Groups	−0.19	0.19	−0.20	0.19	−0.02	0.17	−0.02	0.17	−0.10	0.09	−0.16	0.08	−0.05	0.18	−0.07	0.18
Gender			0.08	0.12			0.06	0.11			0.51***	0.11			0.21**	0.08
Pre-test			0.12*	0.05							0.08	0.08				
R^2	0.01		0.02		0.00		0.00		0.00		0.07		0.00		0.01	
Model	#Speed: low EI				#Speed: high EI				#Density: low EI				#Density: high EI			
	1		2		1		2		1		2		1		2	
	β	SE	β	SE	β	SE	β	SE	β	SE	β	SE	β	SE	β	SE
Groups	0.23*	0.12	0.22	0.12	0.85***	0.10	0.81***	0.10	0.15	0.13	0.15	0.10	0.76***	0.12	0.72***	0.11
Gender			0.06	0.09			0.29***	0.07			0.21*	0.09			0.35***	0.08
Pre-test			−0.01	0.05							0.23***	0.06				
R^2	0.01		0.02		0.18		0.20		0.01		0.08		0.14		0.17	
	Self-regulation				Engagement				Sense of Competence				Interest			
	1		2		1		2		1		2		1		2	
	β	SE	β	SE	β	SE	β	SE	β	SE	β	SE	β	SE	β	SE
Groups	0.26***	0.08	0.31***	0.04	0.16	0.11	0.16*	0.08	0.17***	0.04	0.14**	0.04	0.14	0.09	0.11	0.08
Gender			0.05	0.04			0.03	0.05			0.18**	0.06			0.17***	0.05
Pre-test			0.48***	0.04			0.47***	0.05			0.34**	0.09			0.34***	0.07
R^2	0.07		0.30		0.03		0.25		0.03		0.21		0.02		0.18	
	Task Goal Orientation				Educational Aspiration				Career Aspiration				Ego Involvement			
	1		2		1		2		1		2		1		2	
	β	SE	β	SE	β	SE	β	SE	β	SE	β	SE	β	SE	β	SE
Groups	0.23**	0.08	0.21***	0.07	0.20***	0.06	0.17***	0.05	0.18***	0.05	0.17***	0.04	0.07	0.06	0.03	0.06
Gender			0.14**	0.05			0.18**	0.06			0.18**	0.06			0.08	0.05
Pre-test			0.47***	0.07			0.31***	0.07			0.24***	0.06			0.52***	0.04
R^2	0.05		0.30		0.04		0.19		0.03		0.14		0.01		0.29	

EI, element interactivity; # denotes intervention topics; groups were coded as follows: 1, students who experienced intervention for topics Speed and Density; 0, students in the control group who did not experience any intervention; gender was coded as follows: 1, male; 0, female; pre-test for Heat, Forces, Speed, and Density refers to the Prior Knowledge test. High EI variables for Heat, Forces, Speed, and Density were not measured prior to the intervention (i.e., no Prior Knowledge test). *$p < 0.05$. **$p < 0.01$. ***$p < 0.001$

were observed in all of the motivational variables. No significant differences were found between the groups in Interest and Ego Involvement.

As shown in model 1, the highest amount of variance was explained by Self-regulation ($R^2 = 0.07$) and the smallest amount of explained variance occurred in Ego Involvement ($R^2 = 0.01$). In model 2, the largest amounts of variance were explained by Self-regulation and Task Goal Orientation ($R^2 = 0.30$); the smallest ($R^2 = 0.14$) was observed in Career Aspiration.

As seen in model 2, gender was a significant predictor of motivation in five variables: Sense of Competence ($\beta = 0.18$, $p < 0.01$), Interest ($\beta = 0.17$, $p < 0.001$), Task Goal Orientation, ($\beta = 0.14$, $p < 0.01$), Education Aspiration ($\beta = 0.18$, $p < 0.01$), and Career Aspiration ($\beta = 0.18$, $p < 0.01$). The results indicated that boys had significantly higher motivation in science than girls in these variables. Pre-test results were a positively significant predictor of motivation in all motivational variables.

Discussion

This study is the first to design a DAI intervention that incorporates both the cognitive and non-cognitive aspects of learning in a science learning environment and examines its effectiveness on students' achievement and motivation. Given that much research has shown the importance of both the cognitive and non-cognitive aspects of learning (e.g., Forbes et al. 2017; Kadir 2006, 2018; Kadir et al. 2012, 2013, 2017; Phan et al. 2016), it is surprising that intervention studies incorporating both aspects of learning in the one learning environment to study the effects on student learning and motivation are scarce. In this study, the cognitive aspect of learning was incorporated using cognitive load theory as a theoretical framework, where element interactivity was managed at every stage of learning to ensure that students would not experience cognitive overload. This study adds to the literature in that the isolating-elements strategy from CLT is applicable to and can be implemented in learning tasks such as hands-on science activities, to ensure that learning is within students' cognitive capacities. The non-cognitive aspect of learning was incorporated using self-determination theory as a theoretical framework, where students' basic psychological needs were supported in the same learning environment with the hope of nurturing student motivation. Past studies have investigated the cognitive and the non-cognitive aspects of science learning in separate studies, manipulating one variable at a time, as it is the methodological requirement of randomized controlled trials. However, this is not feasible for a curriculum-level intervention investigating the best practices of cognitive and psychological aspects of learning implemented in a curriculum design. Incorporating multiple strategies (based on best practices) in the curriculum could maximize the benefits to students (Hornery et al. 2014; Phan et al. 2016; Slavin et al. 1996). The implementation of several strategies in one study is not foreign to educational research. For example, "Success for All" reading programs (Slavin et al. 1996) have multiple components to each program, combining effective practices in beginning reading and cooperative learning. In addition, the "dual approach intervention" by Hornery et al. (2014) combined reading skills and self-concept enhancement strategies in one intervention. In this study, we used strategies that have shown to be effective for learning in different studies and incorporated them in one instruction (i.e., DAI) to measure its effectiveness on student learning and motivation. It follows a cluster-level assignment design and meets the group design standards and requirements of What Works Clearinghouse (WWC, 2017). WWC reviews and describes the standards and requirements of research studies and our study meets its requirements because our research instruments (a) demonstrate face validity, (b) demonstrate reliability, (c) are not over-aligned with the intervention, and (d) are collected in the same manner for both intervention and control groups (What Works Clearinghouse 2017). The results in the study showed that incorporating both aspects of learning in a learning environment benefited the students both in terms of their achievement and motivation in a range of factors. Although we cannot definitely rule out the possibility that gender differences or pre-existing differences within some factors potentially account for the results, this possibility is reduced by the analysis, which controlled for gender and students' pre-test scores on each outcome measure. The analysis increases the internal validity of the intervention effects detected in this study. Thus, the results provide strong support for the conclusion that experiencing the DAI had a positive impact on students' achievement and motivation.

Achievement

All hypotheses were supported. The students in both groups had higher mean scores in the low element interactivity than the high element interactivity Knowledge Transfer tests, as hypothesized (i.e., Hypothesis 1). This was probably because low element interactivity tasks were less likely to overload the working memory than high element interactivity tasks. There was no significant difference between the control and intervention groups in their achievement in the science topics (i.e., Heat and Forces) taught using regular instruction practices. The results supported Hypothesis 2 and showed that when the intervention was not present, the two groups were similar in their science achievement. This finding provided evidence as to the effectiveness of the intervention. The effectiveness of the intervention was further supported by the results which showed that the students in the intervention group had significantly higher achievement than those in the control condition, in solving complex (i.e., high element interactivity) problems in the topics of Speed and Density: the topics in which they experienced the intervention. The results supported Hypothesis 3. The finding that students performed better when element interactivity of complex tasks was broken down into successive modules of simpler, lower element interactivity learning tasks is consistent with prior research (e.g., Gerjets et al. 2006; Ngu et al. 2014). It is also consistent with the proposition that when learning tasks are sequenced in gradual increments of element interactivity for students lacking in pre-existing knowledge, learning will be more effectively facilitated, resulting in higher achievement compared to learning in environments where element interactivity is not effectively managed (i.e., Blayney et al. 2010), such as in the control group. In this study, students in the control group experienced several factors, which would likely overload their WM leading to ineffective learning as follows:

(1) students had to process complex information and solve problems with high element interactivity;
(2) teachers delivered information continuously for 40 minutes without a break;
(3) students worked individually (on their own).

In contrast, students in the intervention group experienced WM support through the following activities, which may have contributed to their higher achievement scores in the high element interactivity Knowledge Transfer tests:

(1) teachers and researchers designed all information and questions to have low element interactivity;
(2) students had a break every 15 minutes;

(3) students were engaged with their colleagues in group learning which acted as an information processing system.

As students came together to discuss their conceptual ideas, higher-level schemas were generated (Kirschner et al. 2009), which enabled solutions for more complex problems. Students in the control group had to manage learning complexity on their own and ran a higher risk of overloading their WM compared to those in the intervention group, thereby constraining them from solving complex problems effectively.

As hypothesized, there was no difference between the control and intervention groups in their achievement in low element interactivity Knowledge Transfer tests in the topics of Speed and Density (i.e., Hypothesis 3). This was probably because the low element interactivity problems were simple enough for the students in the control group to solve using the knowledge and skills gained from their regular instruction experiences. This finding correlates with the finding from past research studies showing that CLT strategies (incorporated in the intervention) were most effective with high element interactivity learning tasks (e.g., Leahy et al. 2015), not simple tasks, which do not overload the working memory (Sweller et al. 2011).

Motivation

As well as higher achievement scores, students in the intervention group also had higher motivation in science, in terms of behavioral outcomes such as self-regulating their learning (i.e., Self-regulation), beliefs that they can do well in science (Sense of Competence), and motivational outcomes such as autonomous motivation (i.e., Task Goal Orientation and Aspirations in pursuing science-related education and career paths). These findings support Hypothesis 4. Intervention students' higher motivation could be attributed to the specific design of their learning environment, which supported students' sense of competence, autonomy, and relatedness. This finding is consistent with prior research, which showed that students have higher motivation when their basic psychological needs are supported (e.g., Jang et al. 2009). In contrast, students' basic psychological needs were not supported in the control group. For example, students in the control group learned passively—they mostly experienced one-way information transmission from teacher to student. This pedagogical approach limited positive interactions with teachers and peers and there were fewer opportunities to be involved in learning activities that promoted students' sense of competence. Intervention group learners, on the other hand, experienced high levels of positive student-teacher and peer interactions with ample opportunities for students to explore their strengths and abilities, all of which develop student competence.

Student autonomy in the control group was not supported because teachers delivered information without explaining the rationale behind the learning and there was no class discussion among peers. In contrast, the autonomy of students in the intervention group was supported because the rationale behind each learning activity was explained, they were able to make choices in their learning, and there were opportunities for class discussion.

Similarly, students' need for relatedness was not supported in the control group because they were mostly passive. They passively listened to the information delivered by the teacher, thus lacked opportunities to contribute or interact with the teachers and peers in the class. Students in the intervention group, however, had their need for relatedness supported through working in teams towards common goals.

There was no significant difference in students' Ego Involvement between the control and intervention groups, which implies that students in both groups did not differ in terms of extrinsic motivation such as peer pressure. This finding is consistent with the study design since Ego Involvement was not a focus for the intervention. There were no significant differences between the two groups in terms of their attentiveness during science lessons (Engagement) or their intrinsic motivation in learning science (Interest), which could be explained as follows. Even though prior research has shown positive associations between the fulfillment of basic psychological needs with student engagement and intrinsic motivation (Niemiec and Ryan 2009), the high values reflected in the descriptive statistics in this study indicated a ceiling effect (Vogt 2005), that is, students in both groups reported such high engagement and interest in science that no significant difference could be observed in the post-tests between groups. On the other hand, even though the descriptive statistics showed high motivational values for most factors, a decreasing trend in motivation from pre- to post-test for both groups was observed. This observation was supported by past research, which identified students' motivation declining in secondary school (Ryan and Patrick 2001). Of interest, however, in this study, was the observation that the intervention group had significantly higher motivation for most motivational factors at post-test (after controlling for pre-test and gender differences). This implied that DAI reduced students' motivational decline, so if implemented across the curriculum, it could have a significant impact.

Implications for Policy and Practice

The presented findings provide clear evidence that DAI resulted in superior learning outcomes in terms of achievement and motivation. The features of DAI could easily be implemented in all curriculum domains—not just science. In this study, teachers participated in workshops run by researchers, which could be replaced or augmented by online professional development courses. Video reenactments of student involvement in learning tasks and student-teacher interactions during the lessons could be developed to demonstrate DAI implementation. An online manual could be developed detailing DAI tenets, with guidelines and tips for preparing materials and implementation strategies. These online resources could be distributed to schools as part of a teacher professional development course to introduce teachers to the instruction techniques leading to classroom implementation designed to benefit students' achievement and motivation.

To maximize student achievement and motivation, teachers should design science lessons that are authentic, meaningful, and enjoyable to nurture intrinsic motivation (Ng et al. 2016) and 'sequence lessons' so that element interactivity (i.e., cognitive load) at every stage of learning is more manageable for students and based on their pre-existing knowledge (Kalyuga 2007). Schemas formed when students successfully achieve learning sub-goals of simpler tasks help them to achieve (and experience) success prior to the main goal of tackling complex tasks without overloading their working memory (Kalyuga 2007; Sweller et al. 2011). Experiencing success increases students' sense of competence, which is crucial for their continued motivation and success (Kadir 2018; Kadir et al. 2013, 2017; Marsh and Craven 2006). Therefore, when teachers design instructional materials that are within students' cognitive capacities, students are more likely to be motivated to maintain their focus and attention on learning tasks, resulting in positive learning outcomes (Paas et al. 2005). In addition to managing students' cognitive load, this study affirms the importance of teachers creating a learning environment that also supports students' basic psychological needs (Niemiec and Ryan 2009; Wang et al. 2011). Rather than passively transmitting knowledge, teachers should present students with learning tasks that challenge them, allow them to excel, and provide constructive feedback and encouragement (fulfilling a sense of competence). Teachers should also explain rationales for learning tasks, provide ample opportunities for students to share their ideas and make decisions, ask students questions, listen attentively, avoid coercion, and minimize evaluative pressure (fulfilling a sense of autonomy). Last but not least, teachers should maximize friendly interactions with each student, ensuring that no student is isolated, treat all students with respect and kindness, and show them that their contribution to the learning community is valued (fulfilling a sense of relatedness). In the regular instruction group, which was dominated by one-way transfer of knowledge from teacher to student, such interactions were almost impossible. Although the teachers were not being disrespectful or unkind, students may not feel motivated if there are no opportunities for them to interact with the teachers or peers or contribute to knowledge-building during the lesson.

Limitations and Future Research

As with most research, this study has its share of limitations. First, we did not have subjective measures of cognitive load and students' perceptions of their competence, autonomy, and relatedness at regular intervals during their science intervention. Instead, we only had objective measures. Future research could obtain subjective measures from students about various aspects of the intervention in order to be able to measure the interaction effects of the CLT and SDT interventions and to determine any causal effects of students' achievement and motivation.

Second, the study had methodological shortcomings. We did not have a 2×2 experimental design which would separate the students into four groups: (1) no intervention, (2) motivation intervention only, (3) cognitive load intervention only, and (4) both cognitive load and motivation intervention (DAI). With such a design, we could have delineated more clearly which intervention was the most effective. However, the research literature includes many experiments demonstrating the cognitive load effects of LRI and, independently, many separate experiments demonstrating the motivation effects in SDT. Since experiments which vary both factors independently have been conducted on several occasions, we argue that additional replications are not as important as conducting an experiment in which both factors are varied simultaneously, even though the requirements of a controlled trial have not been strictly adhered to. With a larger sample size, future research could administer such a design.

Third, the short intervention period of 10 weeks meant that students were aware that classes would revert to their regular science lessons and this may have affected their motivation. Past educational research indicates that student motivation decreases in adolescents (from about grade 5 onwards) so reversing this downward trend would take time. Future research could look into extending the intervention period with more science topics to yield greater positive effects.

Fourth, the study involved students with high academic ability in a school with generally high socioeconomic status. The results may not be generalized to students of low ability or even those of average ability. Future research could involve student participants of lower academic ability to investigate the intervention effects in such a population.

Fifth, students were given one week notice of the Knowledge Transfer Test—which topic and knowledge was to be assessed. During this timeframe, students could have acquired external help from other sources (e.g., tutors, family) to revise and prepare for the tests. Future studies could look into having "surprise pop quizzes" at different intervals through the intervention to assess their knowledge transfer, which could be a better measure of the intervention effects.

Conclusion

The benefits of Dual-Approach Instruction are clear in the study: students who experienced instruction where their cognitive and affective needs were met had higher achievement and motivation than those who did not. While several studies have shown that the fulfillment of these basic psychological needs led to positive learning outcomes and motivation, this study supplements the literature by demonstrating that when these needs were met and combined with tailored instruction aligned with students' cognitive capacities, it led to superior learning outcomes in two areas: achievement and motivation. It is recommended that science lessons should incorporate both cognitive and motivational aspects of learning to optimize student learning and to nurture positive attitudes towards science, including aspirations to pursue science-related studies and careers in the future.

Compliance with Ethical Standards The study was approved by the Ministry of Education, Singapore. All ethics procedures were strictly followed, participation was voluntary, and data collected were anonymized before analysis. Teachers and students agreed to participate in the study, and to be filmed for the purpose of intervention fidelity. Parents of the student participants provided written consent for their child's participation.

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