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REGULAR ARTICLE

Constructivist Learning Approaches Do Not Necessarily Promote Immediate Learning Outcome or Interest in Science Learning

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Abstract This study compares direct instruction to two constructivist approaches, namely experimentation and problem-based learning, in fifth-grade science learning in Hong Kong. Constructivist instructional approaches, contrary to direct instruction, stress on students' active role in constructing knowledge in learning. Experimentation and problem-based learning are constructivist approaches commonly adopted in science classes. Research has shown that experimentation enhances cognitive and affective learning outcomes, but mixed evidence has been found in similar comparisons between problem-based learning and direct instruction. We recruited 380 fifth-grade students, each of whom participated in a single science lesson that involved one of the three distinct instructional approaches. Results showed that students in the direct instruction group outperformed both the experimentation group and the problem-based learning group in immediate learning outcome as measured by a short test, while the three groups did not differ in learning interest. Immediate learning outcome and learning interest were weakly correlated only in the problem-based learning group. Our findings may be explained by students' unaccustomedness to constructivist approaches arising from the unique cultural-educational environment in Hong Kong, where direct instruction is the norm and the curriculum prioritises memorisation and understanding of facts and concepts over discovery processes in learning. This inconsistency with the existing literature highlights the importance of considering cultural factors when evaluating the effectiveness of instructional approaches in primary school science education.

Keywords STEM education · Primary school · Constructivist learning · Problem-based learning · Cultural-educational context

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Constructivist theories of learning suggest that learning should be student-centred, allowing students to take up an active role to construct and revise knowledge, rather than sitting back and listening passively in teacher-led classroom settings as in conventional direct instruction methods (Harris & Alexander, 1998; Loyens & Gijbels, 2008). As constructivist theories emphasise the role of social interactions in learning, students usually form groups and engage in interaction (Loyens et al., 2007; Thurston, 2014). Educators of STEM subjects, especially science, have come to embrace constructivist methods (Harris & Rooks, 2010; Johnson et al., 2020; Olson & Mokhtari, 2010; Thurston, 2014). However, whether constructivist instructional methods are more effective than direct instruction, especially across various stages of education and cultural-educational contexts, is an empirical question that should be put into test. In the current study, we investigated the effectiveness of constructivist approaches, as compared with that of direct instruction, in promoting learning outcomes and learning interest in primary school science education within a cultural-educational context where direct instruction is the convention, and factual knowledge acquisition is emphasised in the curriculum.

Experimentation as Experiential Learning

As there is a huge variety of instructional methods that follow constructivist ideas, the question should be addressed by first identifying specific methods that are relevant to the subject of interest. As for science learning, experiential learning is especially relevant, as experimentation is a common way students engage in experiential learning by experiencing course-content first-hand (Johnson et al., 2020; Slavich & Zimbardo, 2012).

Science classes involving experimentation can differ in terms of the complexity of the problems to be solved. In some classes, the teacher presents questions that directly address scientific concepts and principles in a clear structure. Students are to answer the questions by conducting experiments. Classes can otherwise feature practical real-life problems that require students to figure out relevant scientific questions and design experiments themselves to tackle the larger problem. The former approach is how conventional laboratory experimentation classes are conducted, while the latter approach follows principles of problem-based learning and inquiry learning.

It has long been shown in empirical research and meta-analyses that experimentation involved in science classes enhances not only students' understanding of scientific concepts and acquisition of content knowledge, but also their attitude, interest and motivation (Hofstein, 2004; Hofstein & Lunetta, 1982; Lunetta et al., 2013; Schroeder et al., 2007), in comparison with those that adopt only direct instruction. Thus, the more interesting question lies in whether problem-based or inquiry learning, which presents ill-structured, rather than well-structured, problems with greater real-life relevance, also shows similar advantages in comparison with direct instruction (Hofstein, 2004; Hofstein & Lunetta, 1982).

Problem-Based Learning and Inquiry Learning

Problem-based learning was originally developed and implemented in medical education at university (Barrows, 1996) and has recently extended to various subjects including science in primary and secondary school settings (Hmelo-Silver, 2004; Mustafa et al., 2016; Trinter et al., 2015), while inquiry learning originates from scientific practice that emphasises posing questions and formulating empirical-based arguments (Kuhn et al., 2000). The two approaches are often found to be indistinguishable in practice and equivalent in essence (Hmelo-Silver et al., 2007). Hence, the following will address this type of learning as problem-based learning, drawing on evidence from studies investigating either approach.

It is suggested that problem-based learning is effective by enhancing students' intrinsic motivation to learn. The presentation of practical problems increases students' situational interest by highlighting a knowledge gap between what they need to know and what they already know (Rotgans & Schmidt, 2014; Schmidt, 1993). This situational interest subsequently motivates students to seek information to close the knowledge gap, which fosters students' learning. Existing studies have conducted experiments (Duran & Dökme, 2016; Prosser & Sze, 2014; Rich et al., 2005; Smits et al., 2003; Ward & Lee, 2004) and reviewed existing empirical evidence in meta-analyses (Albanese & Mitchell, 1993; Colliver, 2000; Gijbels et al., 2005; Kalaian et al., 1999; Smits et al., 2002; Walker & Leary, 2009) to investigate the effectiveness of problem-based learning in comparison with direct instruction, but results were mixed.

On one hand, some studies did demonstrate that problem-based learning promotes students' knowledge acquisition, knowledge application, problem-solving skills, and affective outcomes such as interest and motivation, supposedly because students are encouraged to acquire new knowledge and cultivate problem-solving skills by identifying and applying new knowledge to the real-life (Albanese & Mitchell, 1993; Dochy et al., 2003; Forbes et al., 2001; Rich et al., 2005; Smits et al., 2003; Walker & Leary, 2009). On the other hand, other research showed that direct instruction outcompeted constructivist instructional approaches, such as problem-based learning, with minimal guidance (Kirschner et al., 2006; Klahr & Nigam, 2004). Still other research found no differences in cognitive and affective learning outcomes between problem-based learning and direct instruction (Colliver, 2000; Smits et al., 2003).

Problem-Based Learning in Science Education

Contrary to conventional experimentation that features well-structured problems and guided instructions for students to follow, the problem-based learning approach involves presenting complex, ill-structured problems that students have to solve by setting up questions, designing experiments, and conducting them in collaborative groups. Teachers only serve as facilitators (Loyens & Gijbels, 2008; Slavich & Zimbardo, 2012). Students are allowed to have ample time for self-oriented learning, including investigating questions, setting up learning goals, gathering required information, and solving problems (Barrows, 1996; Hmelo-Silver, 2004).

In science education, prior research also presented mixed findings regarding the effectiveness of problem-based learning on students' cognitive and affective outcomes. Some studies have demonstrated the positive effects of problem-based learning on students' acquisition of content knowledge, application of knowledge, conceptual development, and science achievement in comparison with direct instruction (Akinoğlu & Tandoğan, 2007; Araz & Sungur, 2007; Karaçalli & Korur, 2014; Leuchter et al., 2014; Potvin et al., 2012; Wong & Day, 2009), whereas some have found no difference in science performance between groups taught with either approach (Chen & Chen, 2012; Drake & Long, 2009). Furthermore, despite some research showing a positive effect of problem-based learning on retention of acquired content knowledge (Karaçalli & Korur, 2014; Leuchter et al., 2014; Wong & Day, 2009), some did not (Drake & Long, 2009), and Kirschner et al. (2006) argued that problem-based learning with minimal guidance was largely ineffective.

As for affective outcomes, some studies have revealed that students in problem-based learning groups exhibited more positive attitudes towards learning science and science courses (Akinoğlu & Tandoğan, 2007; Chen & Chen, 2012) and were more likely to perceive themselves as scientists (Drake & Long, 2009). However, Karaçalli and Korur (2014) showed no difference in student's attitude towards science whether they engaged in problem-based learning or were taught with direct instruction.

Factors Modulating Effectiveness of Constructivist Approaches

As reviewed above, there is no clear evidence supporting the notion that problem-based learning is superior to direct instruction, both generally or specific to science education. However, it should also be noted that other factors, such as prior knowledge, reasoning ability and laboratory experience of students, can modulate the effectiveness of instructional methods (Han et al., 2015; Jonassen, 2011).

Another important factor to note is the form and amount of scaffolding available to students when they engage in constructivist learning. Younger students or those with limited prior knowledge may require more structured guidance to effectively engage with constructivist tasks (Lazonder & Harmsen, 2016). Researchers categorise methods with guidance into soft and hard scaffolding. The former refers to just-in-time support from teachers when the students engage in learning tasks, while the latter refers to predesigned instructional materials or artefacts such as worksheets. However, while many studies support that constructivist learning with some form of scaffolding leads to better learning outcomes than that without any guidance (Hmelo-Silver et al., 2007; Kirschner et al., 2006), Kapur (2008) showed that students who had to solve ill-structured problems without any scaffolding performed better than their counterparts who solved the same problems that were well structured as a kind of hard scaffolding in transfer tasks. The above demonstrates that scaffolding can modulate cognitive outcomes of constructivist learning in different ways. Fewer studies examined how scaffolding can influence the effect of instructional methods on students' affective outcomes, but scaffolding has been found to enhance children's interest in science (Annisa & Sutapa, 2019).

Furthermore, the effectiveness of constructivist approaches may be influenced by how accustomed students are to these approaches Loyens et al. (2009) showed that students from a lecture-based curriculum who were new to a problem-based learning approach agreed less on the suggested advantages of constructivist learning than their counterparts who had more experience with problem-based learning. However, whether accustomedness to constructivist instructional approaches is associated with actual cognitive learning outcomes remains largely unknown.

To sum up, whether problem-based learning is more effective than direct instruction can be highly context-dependent and specific to the population under investigation.

Primary Science Education in Hong Kong

The conventional instructional method adopted in science classes in Hong Kong, as in many other East Asian cultures, is teacher-centred, with direct instruction being the norm even in recent years (Fung & Liang, 2023; Kim, 2018; Lau & Lam, 2017; Liang & Fung, 2023). However, there is an ongoing movement towards incorporating more constructivist approaches into formal science lessons at school. In 2015, the Hong Kong government highlighted the importance of improving STEM education, and in 2017, introduced the concept of inquiry learning in the renewed curriculum guide (Chen et al., 2021). Nevertheless, despite providing overarching guidelines and resources to schools, the government has not altered the content of the subject curriculum, but rather, encouraged schools to form their own school-based curriculum for STEM education (Mok & Ren, 2021). Inspection of the primary school science curriculum reveals that it mainly emphasises students' remembering and understanding of factual and conceptual knowledge, rather than problem-solving skills. This is reflected by figures showing that 60.7% of the learning outcomes outlined in the 4th to 6th grade science curriculum focus on "remembering" and "understanding", rather than "applying", "analysing", "evaluating", or "creating". In addition, 64.3% of learning outcomes concentrate on factual and conceptual, rather than procedural or metacognitive knowledge (Wan & Lee, 2021). In science classes, direct instruction remains the predominant approach, as opposed to constructivist methods.

To understand the challenges of designing and implementing a constructivist STEM curriculum in local primary schools in Hong Kong from the perspective of frontline educators, we conducted a focus group interview with teachers from the participating schools prior to data collection for the current study. The interviewed teachers responded that constructivist methods had not been introduced to the school curriculum until very recently. They also expressed a need for additional support in designing relevant learning materials as well as for additional manpower support. These findings showed that the shift from predominant direct instruction methods to a more constructivist approach was new to frontline educators and consequently, both teachers and students were not accustomed to constructivist approaches in formal lessons.

Hence, the Hong Kong context is worth investigating because it represents regions where STEM education is gaining awareness and implementation, while primary school teachers and students are still less accustomed to constructivist instructional approaches, especially the problem-based approach, in comparison with the conventional direct instruction approach. In the current study, we aimed to test the effectiveness of constructivist learning within the specific cultural-educational context where such approaches are unconventional in formal classes and where there is a strong emphasis on factual knowledge acquisition in the science education curriculum.

The Current Study

The current study compared the effectiveness of problem-based learning, conventional experimentation, and direct instruction in science learning of Grade 5 students in Hong Kong. We measured immediate learning outcome in terms of grasps of factual knowledge, and learning interest, to characterise the cognitive and affective aspects of learning outcomes, respectively. We focused on testing students' acquisition of conceptual and factual knowledge because the primary school education curriculum in Hong Kong prioritises this over practical or exploration skills as outlined in the expected learning outcomes of the curriculum.

If constructivist approaches were more engaging by nature, students taught with the two constructivist approaches would show higher learning interest than students in the direct instruction group. The novelty of the two constructivist approaches might also enhance learning interest in students. Moreover, if problem-based learning is particularly engaging due to the ill-formed nature of the problems and relevance of the problems to daily life, then the problem-based learning group would exhibit higher learning interest than the experimentation group.

For immediate learning outcome, we hypothesised that students in the direct instruction group would outperform the other two groups. This was because we expected the students to be less accustomed to hands-on, discovery processes in science learning than passively remembering facts directly delivered by teachers, given the cultural-educational context in Hong Kong. However, it was also possible that students in the constructivist learning groups may outperform the direct instruction group, if low accustomedness to constructivist approaches is not a key factor that affects students' cognitive learning outcomes. We also hypothesised that the experimentation group would outperform the problem-based learning group in test performance as more hard scaffolding was available in the former than the latter. Moreover, we hypothesised a positive correlation between learning interest and immediate learning outcomes, as students who showed more interest were expected to be more motivated to learn.

We targeted Grade 5 students because it is the critical stage in which students undergo transition from middle childhood to late childhood, as well as from primary to secondary education, which requires more systematic thinking skills to cope with the increased complexity of academic work. The current research addresses a gap in understanding the effectiveness of constructivist learning in primary school science education within the traditionally teacher-centred cultural-educational context of East Asia. The unique cultural-educational context of our study also highlights the importance of considering cultural factors when making decisions on instructional methods that target specific learning outcomes.

Method

Participants

We recruited 380 5th graders (177 F) from 15 classes in four local public primary schools located in four respective lower middle-class neighbourhoods in Hong Kong. Focus group interviews revealed that the participating schools predominantly adopted the direct instruction method in science classes, corroborating recent research on the status quo of primary school science education in Hong Kong (Fung & Liang, 2023; Kim, 2018; Lau & Lam, 2017; Liang & Fung, 2023). All students were typically developing children and within the normal range of intelligence. The participants were ethnically Chinese and spoke Cantonese-Chinese, and were Chinese readers. Informed consent from parents of all participating students were obtained, and ethics approval was granted by the Human Research Ethics Committee of The Education University of Hong Kong before data collection.

Design

Five classes were randomly assigned to each of the three teaching methods. There were 122, 124, and 134 students in the direct instruction method, experimentation method, and problem-based method groups, respectively. Power analysis conducted with the Superpower package (Lakens & Caldwell, 2021) in R of version 4.1.1 (R Core Team, 2021) estimates that 120 participants are required in each group to achieve 80% power with a one-way ANCOVA with three levels and five covariates and other estimated parameters.

To characterise cognitive learning outcome, we measured immediate learning outcome indicated by students' performance on a quiz right after class; as for affective learning outcome, we measured students' interest in the science class they just had with a questionnaire. Students' general intelligence, verbal ability, and general interest in science classes were measured as control variables. We also recorded the students' performance in previous science tests in school.

Measures

All students completed the same science test right after class. There were 12 items in multiple-choice format. Seven questions were related to the target topic of sound transmission taught during the science lesson and five questions were used as control items that measured students' baseline scientific knowledge. Students also indicated their interest in the lesson they just had by completing a 9-item questionnaire on a 7-point Likert scale.

As for control variables, students' general intelligence was measured with Raven's Progressive Matrices (RPM; Raven, 1998). Students had to select the best fitted missing piece in each of 60 geometric designs from six options. Students' verbal ability was measured with a Chinese translation of the Peabody Picture Vocabulary Test (PPVT; Dunn & Dunn, 1997), a test of receptive vocabulary. An examiner read 30 words aloud, for a maximum of three times each word. Students had to select the picture that best suited each word. They also filled out a 9-item questionnaire to report their general interest in usual science lessons on a 7-point likert scale.

Procedure

Students' general intelligence and verbal ability were tested in a separate session before or after the main study took place. The main study was conducted in a usual science class in the four primary schools.

Trained research assistants from the investigation team were sent to all the classes described below, to observe and assist in the implementation of the class to ascertain strict adherence to the planned procedure. Teachers of the classes allocated to the direct instruction method provided a 40-min lecture to deliver concepts, principles, and solutions to problems about sound transmission. The students only listened passively, without engaging in any hands-on activities or filling out worksheets.

Teachers of the classes allocated to the two constructivist method groups did not give lectures on conceptual knowledge. They only taught the students to operate the provided experimental apparatus. Students in the two constructivist method groups were further divided into activity groups of four to five students, but each student had to complete their own worksheet while conducting experiments on the topic of sound transmission. The experimental set-up had been prepared by research helpers. The session took around 40 min, within which the students had to complete the experiment and the worksheet.

The worksheets for the two constructivist groups differed in content. Step-by-step instructions of an experiment that compared the sound insulation effect of four different materials with various sizes, illustrated with photos, were provided on the worksheet for the experimentation group. Students in the experimentation group had to conduct the experiment with their peers in small groups, record their measurements in a given table by conducting the experiment as instructed, rank the sound insulation properties of the materials, and fill in the missing information in sentences that concluded the major findings.

In contrast, no instructions were given on the worksheet provided for the problem-based learning group. The worksheet only presented a real-life scenario regarding sound transmission. The worksheet depicted a scenario of neighbourhood being hugely affected by transportation noise nearby, and the students were invited to help design a noise barrier to reduce the noise. The worksheet also stated that students should discuss with their groupmates how they could find out the material with the best sound insulation properties by experimenting. Space was provided on the worksheet for students to write down their experimental method and their conclusions, in an open-ended format. There were no tables, ranking questions, or fill-in-the-blank questions on the worksheet. The students were required to work out what they had to manipulate and measure within their own groups. The students then recorded their answers to the questions on the worksheet individually.

Both constructivist groups submitted the worksheet by the end of the lesson, and teachers gave no feedback on the correct answers. After the lesson, all participating students immediately took the science test that assessed their knowledge on sound transmission and baseline science knowledge irrelevant to sound transmission. They also reported their interest in the science lesson they just had, and their general interest in usual science lessons, by completing two questionnaires.

Results

Data analysis was conducted using the SPSS 28.0 statistical package. Missing data were imputed using multiple imputation with the mice package (van Buuren & Groothuis-Oudshoorn, 2011) in R (R Core Team, 2021).

Immediate Learning Outcome

Participants' answers to the 12 test questions were scored as either correct or incorrect and sum of correct items was calculated. Descriptive results are shown in Table 1. We conducted a one-way analysis of covariance (ANCOVA) (teaching approach: direct instruction, experimentation, and problem-based learning) on the sound-related test performance with gender, RPM scores, PPVT scores, and the scores from the last science test in school as covariates. The effect of teaching approach was significant, $F(2, 373) = 4.77$, $p = 0.009$, $\eta_p^2 = 0.025$ (small effect). Pairwise comparison with Bonferroni correction showed that students in the direct instruction group ($M_{\text{adjusted}} = 4.71$, $SE = 0.15$) had higher test scores than those in the problem-based learning group ($M_{\text{adjusted}} = 4.07$, $SE = 0.14$), $M_{\text{difference}} = 0.64$, 95% CI [0.13, 1.15], $p = 0.008$, Cohen's $d = 0.40$ (small effect); no significant difference was observed between the direct instruction group and the experimentation group ($M_{\text{adjusted}} = 4.25$, $SE = 0.14$), $M_{\text{difference}} = 0.46$, 95% CI [− 0.04, 0.96], $p = 0.087$, and between the experimentation group and the problem-based learning group, $M_{\text{difference}} = 0.18$, 95% CI [− 0.30, 0.66], $p > 0.90$. We replicated these ANCOVA results by additionally controlling for the test performance on the control items. We still observed a significant effect of teaching approach, $F(2, 372) = 4.31$, $p = 0.014$, $\eta_p^2 = 0.023$ (small effect). Pairwise comparison with Bonferroni correction showed that students in the direct instruction group ($M_{\text{adjusted}} = 4.69$, $SE = 0.15$) had higher test scores than those in the problem-based learning group ($M_{\text{adjusted}} = 4.13$, $SE = 0.14$), $M_{\text{difference}} = 0.56$, 95% CI [0.07, 1.06], $p = 0.021$, Cohen's $d = 0.36$ (small effect), and marginally higher scores than the experimentation group ($M_{\text{adjusted}} = 4.20$, $SE = 0.14$), $M_{\text{difference}} = 0.49$, 95% CI [0.00, 0.98], $p = 0.05$, Cohen's $d = 0.32$ (small effect); no significant difference was observed between the experimentation group and the problem-based learning group, $M_{\text{difference}} = 0.07$, 95% CI [− 0.40, 0.54], $p > 0.90$.

Learning Interest

Participants' learning interest was measured both for the specific science class targeted in our study and for their baseline learning interest in the usual science lessons at school. Descriptive results are shown in Table 1. We conducted the same ANCOVA as for test performance and did not observe a significant effect of teaching approach on learning interest for the science lesson, $F(2, 373) = 1.43$, $p = 0.24$. We also performed the ANCOVA by controlling for students' baseline learning interest together with the above four covariates, with results showing a nonsignificant effect of teaching approach, $F(2, 372) = 0.22$, $p = 0.80$.

Correlation Between Immediate Learning Outcome and Learning Interest

To test the relation between test performance and learning interest, we performed a partial correlation analysis across the three teaching approaches by controlling for gender, RPM, PPVT, and the scores from the previous science test before the study took place. We did not observe a significant correlation between immediate learning outcome and learning interest, $r(374) = 0.026$, 95% CI [− 0.08, 0.13], $p = 0.61$. We further tested the same partial correlation analysis in each teaching group. Results revealed a significant, positive correlation between test performance and learning interest in the problem-based learning group, $r(128) = 0.212$ (weak correlation), 95% CI [0.05, 0.37], $p = 0.015$. Nonsignificant correlations were observed in the direct instruction group, $r(116) = -0.028$, 95% CI [− 0.22, 0.19], $p = 0.76$, and the experimentation group, $r(118) = -0.121$, 95% CI [− 0.29, 0.05], $p = 0.19$.

Table 1 Descriptive statistics

	Direct instruction ($n = 122$)		Experimentation ($n = 124$)		Problem-based learning ($n = 134$)	
	Mean	SD	Mean	SD	Mean	SD
Scores from the previous science test	71.95	14.77	76.50	17.29	80.77	14.54
Raven's progressive matrices (RPM)	37.64	7.39	41.05	8.14	42.94	6.62
Peabody picture vocabulary test (PPVT)	23.63	3.71	23.32	4.04	24.42	2.86
Learning interest after the target science lesson	48.15	8.47	46.00	10.76	46.98	10.04
Baseline learning interest	47.38	9.48	43.16	11.93	45.43	11.58
Test performance on sound transmission	4.38	1.73	4.26	1.91	4.36	1.69
Test performance on baseline scientific knowledge	1.94	1.17	2.14	1.25	1.98	1.15

Discussion

To summarise, we found that the direct instruction group performed best in the assessment of immediate learning outcomes but all three groups did not differ in learning interest, while better test performance was associated with higher learning interest only in the problem-based learning group. The current findings partly support our hypotheses on immediate learning outcome, but do not support out hypotheses on learning interest. Our hypothesis on the association between learning interest and learning outcome is also partly supported.

Immediate Learning Outcome

As hypothesised, students in the direct instruction group outperformed the two constructivist learning groups in immediate learning outcome, after controlling for demographic variables, other cognitive abilities, and students' background knowledge of science.

Our findings contrast to previous studies that found either an advantage of using constructivist instructional approaches in science education or no significant difference between direct instruction or constructivist methods. However, studies have shown that direct instruction is favoured over problem-based learning for short-term knowledge acquisition and retention, while problem-based learning is more effective for long-term knowledge retention (Strobel & van Barneveld, 2009). Furthermore, our findings can be attributed to the unique cultural-educational context in Hong Kong, where direct instruction is the predominant method of instruction adopted in the primary school science curriculum, and memory of factual knowledge is the top priority in assessments. Despite evidence showing that constructivist approaches enhanced acquisition of content knowledge (Akinoğlu & Tandoğan, 2007; Araz & Sungur, 2007; Karaçalli & Korur, 2014; Leuchter et al., 2014; Potvin et al., 2012; Wong & Day, 2009), being unaccustomed to a new form of learning may have suppressed such benefits in our sample. Similarly, studies have found that short applications of problem-based learning were ineffective (Kazemi & Ghoraishi, 2012), and more positive effects of problem-based learning was observed when students were closer to graduation (Gijbels et al., 2005). This argument, when examined within the specific context under study, is further supported by a local case study in Hong Kong showing that an enrichment programme adopting a constructivist approach to teaching mathematics was ineffective for 4th graders new to the programme, but enhanced the academic performance of 6th graders who had taken part in the programme for a considerably longer duration (Mok & Ren, 2021). Hence, given the short-term implementation and the unconventionality of the constructivist approaches in our study, it is not too surprising that the constructivist groups performed worse in the assessment than the direct instruction group.

Apart from this, that the problem-based group performed not as well as the direct instruction group could be attributed to the former adopting a minimal guidance approach, corroborating with literature that suggest constructivist instructional approaches involving minimal guidance are not conducive to learning because of the heavy demands on working memory that interferes with knowledge accumulation in long-term memory (Kirschner et al., 2006; Klahr & Nigam, 2004; Mayer, 2004). Researchers thus suggested that tutors should provide flexible and adequate scaffolding to guide the students throughout the exploration process (Schmidt et al., 2007). However, meta-analysis results showed that despite inquiry learning with scaffolding being more effective in enhancing science achievement than that with minimal guidance, the latter still had a small advantage over teacher-led, traditional instruction (Furtak et al., 2012). Hence, it is less convincing to attribute our finding problem-based learning being less effective than direct instruction to the minimal guidance provided, in comparison with the unconventionality of the problem-based approach in the cultural context of the current study, as explained above. Moreover, we found no significant difference in immediate learning outcomes between the experimentation and problem-based learning groups, indicating that increased scaffolding, specifically hard scaffolding, does not necessarily improve learning outcomes compared to minimal guidance. This echoes with past findings that showed hard scaffolding did not enhance learning (Choo et al., 2011). Therefore, the lack of advantage of using constructivist learning approaches cannot be completely attributed to the level of guidance available. Even for the case of soft scaffolding, Chuan et al. (2011) showed the presence of a facilitator did not enhance learning outcomes in basic science knowledge than when there was no facilitator providing guidance during problem-based learning.

To conclude, the cultural-educational context in Hong Kong and the outcome variable chosen seem to be more convincing candidates of explaining our findings on immediate learning outcome.

Learning Interest

It is surprising that we did not find any difference in learning interest between the three groups, despite that the constructivist approaches were novel in formal lessons and were expected to engage students more than direct instruction would. Students in the two constructivist groups did not find the lesson more interesting than those who just sat back and listened to the teacher. Neither group dynamics, hands-on activities, nor relating the subject to daily-life problems promoted learning interest. However, this observation can be related to a study by Loyens et al. (2009), which showed that educational background and experience with constructivist learning approaches modulated students' affective learning outcomes. Loyens et al. (2009) found that students from a curriculum that mainly used direct instruction indicated lower self-perceived inability as they engaged in more constructivist learning activities over time, and the students became more convinced of the suggested advantages of constructivist learning activities as they progressed through the years. Similarly, Karaçalli and Korur (2014) also suggested that students' attitudes towards constructivist methods might not be shortly enhanced after a single session of exposure. These studies suggest that novelty does not necessarily promote learning interest. Instead, learning interest might, counterintuitively, be promoted over time as students become more accustomed to the no-longer-new learning approaches. Therefore, it is possible that our participants' limited experience with constructivist activities in science class due to the local cultural-educational context contributed to the lack of difference in learning interest between groups, and students may show more positive affective outcomes as they become more accustomed to constructivist learning activities.

Moreover, given that the interest ratings of the constructivist groups were not significantly higher than those of the direct instruction group, it is also reasonable to speculate that students in the constructivist groups were not motivated to fully engage in the activities. This lack of engagement may have prevented them from fully benefiting from the activities, which could have contributed to their relatively lower performance in immediate learning outcome. Our observation of a weak positive correlation between learning interest and immediate learning outcome in the problem-based learning group provides some support for the argument; students in the problem-based learning group tended to have better immediate learning outcome if they were more interested in the lesson, which is in line with the theory that learning is fostered by higher situational interest that motivates students to close knowledge gaps in face of problems. However, we observed no such correlation in the experimentation group, indicating that the association between interest and immediate learning outcome may depend on the specific type of constructivist instructional approach adopted. On the other hand, the possible lack of motivation in students could also suggest that constructivist approaches, despite being arguably more engaging, do not necessarily enhance students' motivation to engage with the lesson.

Enhancing Content Knowledge or Skills?

In the present study, we focused on the grasp of conceptual and factual knowledge immediate after class rather than problem-solving skills, or the development of subject-specific skills, to cater for the uniqueness of the context where our data collection set stage. We did not assess students' problem-solving or subject-specific practical skills, which have been shown to be enhanced by problem-based learning (Dochy et al., 2003; Strobel & van Barneveld, 2009; Tatar & Oktay, 2011). These findings are in line with the theory of situated learning (Brown et al., 1989), which suggests learning is context-dependent and should be situated in the context where the knowledge is intended to be applied, and an encoding/retrieval specificity effect (Barrows, 1986). Nevertheless, in the primary school curriculum in Hong Kong, these skills are of a lower priority than the acquisition of factual knowledge. As the test of content knowledge in paper-and-pencil form differs from the form of the learning process, this might explain why we did not find constructivist approaches superior to direct instruction, specifically for short-term knowledge acquisition. The incongruency in forms of learning and testing can also explain findings of problem-based learning being more effective in enhancing clinical knowledge and skills, but less effective in acquiring basic scientific knowledge than traditional learning, in medical students (Kalaian et al., 1999).

Our finding thus implies that educators should take into consideration what they want to achieve when designing the instructional method for a class. If they aim to improve students' academic performance in regular exams that focus on paper knowledge, especially in a cultural-educational context similar to Hong Kong, constructivist learning might not necessarily be an ideal alternative to direct instruction.

Implications

Our findings show that constructivist learning is not necessarily more effective than direct instruction. Educators need to take into account the aim of the lesson—to deliver factual knowledge or to hone students' practical skills—and the uniqueness of cultural-educational context of where the class takes place. Our study highlights that in places where the curriculum emphasises on memory of factual knowledge and where the students are accustomed to being a passive listener in formal lessons, direct instruction might be a better way of instruction to promote students' short-term learning of conceptual facts. If educators aim to improve academic achievements in the short term by introducing constructivist methods into science classes, it may not yield desired results if students are not sufficiently prepared for the change. Also, introducing group dynamics and making the tasks more hands-on or relevant to daily-life problems do not necessarily engage students more, and being interested in the class activities does not necessarily promote learning outcomes either. When designing lessons, educators should consider highly specific factors to make informed decisions. As the accustomedness to constructivist approaches likely plays a part in enabling students to better benefit from active learning, we recommend that educators begin introducing these approaches and incorporate more constructivist activities in class at lower grade levels. This can enable students to adapt and derive greater benefits when they progress to late primary education.

Limitations

A main limitation of the current study is the limited scope. We focused on measuring immediate learning outcomes in terms of the grasp of conceptual and factual knowledge, but there are various cognitive outcomes that constructivist learning can enhance.

Another limitation is that we did not include a delayed post-test, so we could not test knowledge retention, which had been shown to be promoted by problem-based learning in some past studies (Karaçalli & Korur, 2014; Leuchter et al., 2014; Wong & Day, 2009).

A third limitation is that we focused on the accustomedness to constructivist approaches at the school level, rather than individual students' familiarity with constructivist approaches. Some students might have participated in extracurricular activities or tutorial classes using constructivist approaches, but we did not capture individual differences in familiarity with these methods. Hence, our findings cannot explain how individual students' familiarity with constructivist approaches affects their immediate learning outcomes or learning interest. While we acknowledge that examining these individual differences could further clarify if increased familiarity boosts learning outcomes and interest, extracurricular activities are less frequent and intense, and it is not guaranteed that students take them as seriously as formal classes. Furthermore, students in the constructivist groups did not show higher learning interest than those in the direct instruction group, contrary to what would be expected if they already had some familiarity with constructivist approaches. Therefore, it is unlikely that individual differences in experience outside of school undermine the validity of the current results.

Generalisability of the current findings is another limitation, given the cultural-educational background we focused on. The participating schools were all new to adopting constructivist approaches in formal science classes, yet an increasing number of local primary schools have begun incorporating these methods into their curricula. Despite this trend, recent literature indicates that the actual implementation is still in its early stages, with schools predominantly teaching through direct instruction while experimenting with these new learning approaches (Fung & Liang, 2023; Kim, 2018; Lau & Lam, 2017; Liang & Fung, 2023). This suggests that a considerable number local schools are in a similar situation to the participating schools, differing only in the extent to which constructivist approaches have been adopted. Our findings can, thus, be a reference for schools in Asian cultures where learning of facts and concepts is emphasised and direct instruction is the norm, but might not be generalised to other dissimilar cultures or specific schools that already have a long tradition of adopting constructivist approaches in formal science education. Generalisability of our findings is restricted to the stage of primary school education as well, as secondary school education starts to emphasise more on experimentation skills and students are expected to become more accustomed to engaging in hands-on activities in formal science lessons.

Future Directions

Future studies can also consider including metacognition, exploration skills, and practical subject-related skills as potential outcome variables. A delayed post-test can also be introduced to investigate the effect on knowledge retention. Furthermore, cross-cultural research can be conducted to examine the effect of curriculum, which is a more macro factor, on the effectiveness of different instructional methods. A suggestion for such research to be conducted within the local context is to compare schools that follow different curriculums. In the present study, we recruited students from public primary schools, but international schools in the same area often prioritise exploration and self-directed learning in their curriculum. We expect future studies incorporating these factors to further illuminate the role of cultural-educational context in modulating the effectiveness of constructivist instructional approaches from multiple perspectives.

Another future research direction is to directly examine the relationship between individual students' familiarity with constructivist methods and their learning outcomes and interest, also accounting for students' experience outside of school. This could be achieved by examining how students' lengths and forms of exposure to constructivist approaches are associated with their learning outcomes and interest. This research direction could also be studied longitudinally by modelling changes in students' learning outcomes and interest in science over time, taking into account their experience with constructivist approaches both inside and outside of formal schooling.

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Declarations

Conflict of interest The authors declare that they have no conflict of interest.

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