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Students' science achievement in cognitive domains: effects of practical work and clarity of instruction

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ABSTRACT

Background: Different instructional factors are related to students' achievement in different cognitive domains. Most research studies on large-scale assessment focus on science achievement as an entire variable, without considering science achievement in different cognitive domains.

Purpose: This study investigates the predictive effects of the frequency of teachers' using practical work and clarity of instruction on students' achievement in different cognitive domains.

Sample: A regional representative sample of 3265 Hong Kong students who took part in Trends in International Mathematics and Science Study (TIMSS) 2019 was used in this study.

Design and Method: In order to disentangle the interrelationships between science instructional factors, attitudes toward science and students' achievement in different cognitive domains, we carried out structural equation modelling to explore the responses by 3265 Hong Kong students to TIMSS 2019 surveys.

Results: Frequency of teachers' use of practical work had a significant positive impact on students' achievement in the domains of knowing, applying, and reasoning, while clarity of instruction had a significantly negative impact on students' achievement in the domains of knowing and applying. Enjoyment of science mediates the relationship between the relationships between frequency of practical work and achievement in three cognitive domains.

Conclusion: This informs how teachers use practical work to enhance students' enjoyment of science, intrinsic motivation and self-concept, in order to improve their achievement in knowing, applying and reasoning science. Implications contribute to future research on how best to improve students' achievement in all three cognitive domains are discussed.

KEYWORDS
Practical work; TIMSS data; attitudes toward science; science achievement; clarity of instruction

1. Introduction

In science education research, there is a mix of findings on whether practical work promotes students' science achievement in different cognitive domains. On one side, practical work in school science has been argued to be ineffective because it could not

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cultivate students' reasoning scientific knowledge (Millar 2010) and motivate students to study science in post-compulsory education (Abrahams 2009). On the other side, a more frequent use of practical work was associated with more positive task values and self-regulation attitudes (Rogers and Fraser 2023). Although the aim of practical work is to promote both cognitive and affective domains, much of the previous research studies focused on small-scale empirical studies (e.g.Toplis 2012). To unfold the complex relationships between different instructional factors such as practical work and clarity of instruction, an analysis of international database of students' scientific achievement is needed.

Using TIMSS 2019 data, this study explores the relationships among instructional factors, namely frequency of teacher's use of practical work and clarity of instruction, and students' science achievement in different cognitive domains in Hong Kong. According to Yung, Zhu, Wong, Cheng, and Lo (2013), these instructional factors can reflect the system of 'vernacular Confucianism' which states that teachers and students are constantly under the pressure of norm-referenced summative assessment (Watkins and Biggs 2001). Though teachers are less oriented to inquiry-based instruction in Asian regions such as Hong Kong, students in these regions are usually the top performers in international assessments (Chang 2014; Lau 2014). Some studies have shown that attitudes toward science can be a factor contributing to students' science achievement in Asian regions (Chang 2014; Lay, Ng, and Chong 2013). Moreover, other studies have also demonstrated that instructional factors were significantly related to students' achievement (Hayes and Trexler 2016; Kang 2020), and attitudes toward science mediate these the interrelationships between students' achievement and instructional factors (Liou 2020). To disentangle the interrelationships between different instructional factors under the influences of Confucianism culture, attitudes toward science and students' achievement in different cognitive domains, we carried out structural equation modelling to explore the responses by 3265 Hong Kong students to TIMSS 2019 surveys.

2. Literature review

2.1 Conceptualization of cognitive domains and their relations with instructional practice and practical work

Science achievement can be conceptualised as having different cognitive skills, instead of being viewed as a single variable, as various cognitive skills influence students' learning in different ways. According to International Association for the Evaluation of Educational Achievement TIMSS 2019 study, cognitive skills are classified into three domains: (a) *knowing* refers to students' skills of recalling, describing, recognising and providing example related to basic scientific knowledge; (b) *applying* refers to students' skills of comparing, contrasting and classifying materials or groups, as well as drawing connections of scientific knowledge to the contexts; and (c) *reasoning* refers to the skills of analysing, generalising and synthesising evidence in unfamiliar and complex situations (Mullis and Martin 2017). Students in a majority of countries have demonstrated their strengths in knowing and applying, but also showed their weaknesses in reasoning scientific knowledge (Mullis et al. 2020). Students' skills of knowing and applying are not related to their understanding of scientific concepts, but students' reasoning skill is correlated to their conceptual knowledge (Stender, Schwichow, Zimmerman, and Härtig, 2018).

Owing to the importance of cognitive skills in learning science, scholarship in the field of education has moved its focus from studying factors influencing students' scientific knowledge to factors influencing developing students' cognitive skills. Instructional factors are significant predictors of students' achievement in different cognitive skills (Crowe, Dirks and Wenderoth, 2008). Students' active involvement in the learning process (i.e. practical work) and teacher's pedagogies (i.e. clarity of instruction) were two main factors contributing to students' development of cognitive skills (Zoller, 1999). However, the ways of how these main factors influence three cognitive skills, knowing, applying, and reasoning, were not addressed in previous studies.

Practical work and its impact in aiding students' acquisition of scientific knowledge remains contentious (see Abrahams 2009; Childs and Baird 2020; Osborne 2015; Wellington 1998; Wilson, Wade, and Evans 2016). Practical work is thought to be 'any science teaching and learning activity in which the students, working individually or in small groups, observe and/or manipulate the objects or materials they are studying' (Millar 2010, 109). The relationship between practical work and cognitive development has been a subject of scrutiny. For instance, Abrahams and Millar (2008) note that although practical work is useful in getting students to engage with physical objects; there seems to be little evidence which suggests that students are able to draw inferences between the activities at hand and bigger scientific ideas. Of this was in the context of instructional loopholes (i.e. not setting up tasks that make it possible for students to make such deductions). Cairns (2019) argues that despite the view that practical work is poorly understood, there are three recurring themes of it; the first one is inquiry-based instruction which is thought to be inclusive of 'activities that teach science investigation skills that are required pre-requisites for handling scientific equipment, generating and manipulating data and making inferences' (p. 2114). The second one is that students get to understand what scientific knowledge is and how it is constructed. The last one is that 'there is a simulation of the scientific inquiry process in the classroom, whereby students develop conceptual understanding through investigating phenomena using methods similar to a practicing scientist' (p. 2114).

The question of whether doing more practical work predicts science achievements is well enunciated by Lau and Lam (2017) in their PISA study which looked at 10 highly performing regions in terms of teaching practices and science performance. They note that Hong Kong, Canada, Singapore, and Macao engage in more experiments when compared to the OECD average. However, their findings revealed that teacher-centred teaching was positively aligned with science achievement across the regions. Moreover, in Finland, this teaching approach was more beneficial than other countries in the study. For instance, they observed that in Finland 'an increase of one unit of this teaching practice is associated with an increase of 11.13 points in the total score. The said findings contradicted the widely accepted view which suggests that Western students are less exposed to direct teaching' (Lau and Lam 2017, 2141).

Using the TIMMS 2011 dataset to assess the impact of teaching practices in the US as well as into contexts that are similar to Hong Kong (i.e. Singapore and Chinese Taipei), Gao (2014) found that low performing students responded differently not only between the US and Asian countries but also within Asia. In Singapore inquiry-based teaching practice (i.e. designing experiments or investigation) was found to be positively correlated with science achievement but negatively correlated with the teaching practice which required students to 'observe natural phenomena and describe what they see' (Gao 2014, 537). According to Gao (2014), "in Chinese Taipei, two different inquiry-based teaching practices, 'give explanations about something they are studying' and 'relate what they are learning in science to their daily lives', were found to be positively associated to low-achieving students' science learning" (p. 541). Moreover, for medium and high performing students, there was no correlation between science achievement and any of the inquiry-based and traditional didactic science teaching practices (Gao 2014). In effect, the findings challenged the dominant assumption which suggests that inquiry-based is effective for students across different contexts (see, Gao 2014). This means that pedagogical practices are mostly context bound.

As stated previously, attitudes toward science mediate the interrelationships between students' achievement and instructional factors (Liou 2020). However, it is unknown if the attitudes toward science mediate the relationships between frequency of practical work and science achievement in various cognitive domains. In the US, Long *et al* (2022) showed that teacher-directed and inquiry based teaching practices are significant predictors of enjoyment of science. Consequently, teacher-directed, inquiry-based and enjoyment of science were the three variables which significantly predicted science achievement. Although the other two variables (i.e. teacher-directed & enjoyment of science) were positive predictors of science achievement, inquiry-based teaching practices were a negative predictor of science achievement (Long et al. 2022). Areepattamannil, Cairns, and Dickson (2020), demonstrated that teacher-directed science instruction was positively associated with a number of variables which include, amongst others, instrumental motivation to acquire or learn science as well as enjoyment of science. They also revealed that inquiry based science instruction were also positively correlated with, amongst other variables, instrumental motivation to learn science as well as enjoyment of science. Hence, the present will focus on more than one attitude towards science.

2.2 Attitudes toward science: predictors of academic achievement

Previous research studies consider attitudes towards science as a multidimensional construct when they examine their predicting effects on academic performance. Attitudes towards science encompass a number of dimensions which include enjoyment of science, self-concept and instrumental motivation (Osborne and Collins 2000; Simon 2000). Enjoyment of science as a construct is often subsumed to refer to a feeling of excitement when one is involved in activities that are rooted in principles of science (Shumow, Schmidt and Zaleski 2013); self-concept refers to how a person perceives themselves in a discipline or way of doing things (Shavelson, Hubner and Stanton 1976); instrumental motivation arises from the desire to learn science as a way to attain practical goals, for example, obtaining social status or getting an ideal employment (Yu 2012). According to Long, Gao, Yang and Chen (2022), when examining factors contributing to science achievement, enjoyment has been taken to be in line or a part of other variables such as motivation and self-concept.

Different dimensions of attitude towards science are often measured by questionnaires or instruments that target various aspects of science-related attitudes (Potvin and Hasni 2014). In a secondary data analysis of PISA results from four countries, Lau and Ho (2020) reported that enjoyment of science learning, science self-concept, science activities significantly predict academic outcomes. However, instrumental motivation did not predict science academic performance (Lau and Ho 2020). It showed that one dimension of attitudes toward science can predict academic outcome, instead of another.

2.3 Attitudes towards science as a mediator between instructional factors and cognitive domains

A majority of previous research studies looked at the mediating role of attitudes toward science on the relationships between instructional factors and students' overall science achievement. However, the role of attitudes toward science on the relationship between achievement in various cognitive domains and instructional factors is scarce in the literature. Areepattamannil, Cairns, and Dickson (2020) demonstrated that teacher-directed science instruction was positively associated with several variables which include, amongst others, instrumental motivation to acquire or learn science as well as enjoyment of science. In other studies, students who received inquiry-based instruction had a positive attitude towards science but did not have a notable improvement on scientific achievement (Aditomo and Klieme 2020; Salchegger, Wallner-Paschon, and Bertsch 2021). In contrast, engaging students in inquiry-based scientific practices yielded positive impacts on both their attitudes toward science and science achievements (Gibson and Chase 2002; Koksal and Berberoglu 2012).

3. The present study

In the present study, we aim to investigate the interrelationships between students' perceived instructional factors, attitudes toward science and achievement in different cognitive domains in Hong Kong using TIMSS 2019 data. Two instructional factors, frequency of teachers' use of practical work and clarity of instruction were included. The mediating variables of three types of attitudes toward science, enjoyment of science, instrumental motivation and self-concept were included. Moreover, three cognitive domains of science, knowing, applying and reasoning were included as dependent variables of this investigation. Two enquiries were conducted in this study. The first enquiry is to examine the differential effects of the two instructional factors on students' achievement in different cognitive domains. The second enquiry is to investigate whether different types of attitudes toward science mediate the interrelationships between achievement in the three cognitive domains and instructional factors. The research questions below guide the present study:

(a) Do different instructional factors, namely frequency of practical work and clarity of instruction, predict students' science achievement in three cognitive domains (knowing, reasoning and applying)?
(b) Do different types of attitudes of science (enjoyment of science, instrumental motivation and self-concept) mediate the relationship between instructional

factors (frequency of practical work and clarity of instruction) and students' science achievement in three cognitive domains (knowing, reasoning and applying)?

4. Methods

4.1 Data sources and sample

The quantitative data was retrieved from the International Association for Evaluation and Educational Achievement (IEA) TIMSS 2019. TIMSS is a large-scale assessment which measures grade 4 and grade 8 students' science and mathematics achievements in every four years. In 2019, 39 countries participated in the survey for grade 8 study (Mullis et al. 2020). The assessment employs a two-staged random sampling, starting from drawing a sample of schools at the first phase and then drawing intact classes of students from the schools at the second phase (LaRoche, Joncas, and Foy 2015). They uploaded responses from students, teachers and schools to a website which can be freely downloaded by the public (Fishbein, Foy, and Yin 2021). In Hong Kong, e-survey was administered to students, teachers and schools. 3,265 Grade 8 students from 136 schools (male: 1491; female: 1774) participated in this study. Variables on students' attitudes toward sciences, students' perception on teachers' clarity of instruction and frequency of using practical work, as well as students' cognitive learning outcomes, were generated and merged using IEA IDB analyser. The curriculum in Hong Kong frames practical work as a kind of scientific processing skills (CDC 2017). It also emphasizes on the use of practical work activities for teaching and learning of science (CDC 2017).

4.2 Variables

Three outcome variables (three cognitive domains, knowing, applying and reasoning), three mediating variables (enjoyment of science, instrumental motivation, self-concept), two independent variables (clarity of instruction and frequency of teachers using practical work), total student weight and school ID were retrieved from the international TIMSS database (Table 1). The detailed descriptions of the variables are explained below:

Cognitive Domain (dependent variables) In the TIMSS 2019 science assessment, there were five imputation values for each of the three cognitive domains, knowing, applying and reasoning. These domains were the thinking processes which students needed to engage in when they answer the TIMSS items. In 2019 TIMSS, 35% of items are in the domain of knowing; 35% of items are in the domain of applying; 30% of items are in the domain of reasoning.

Attitudes towards science (moderating variables) The attitudes toward science items comprise three dimensions: enjoyment of science, instrumental motivation, and self-concept. In the TIMSS survey, students were asked to select 'agree a lot', 'agree a little', 'disagree a little' and 'disagree a lot' (Mullis and Martin 2017). For enjoyment of science, items were recoded such that a higher value denotes a higher level of interest. Examples of these items are 'I enjoy learning science', 'I wish I did not have to study science'. Composite reliability for enjoyment of science is .913 for 9 items. Items in instrumental motivation were recoded such that a higher value denotes

Table 1. Mean (M) and standard deviation (SD) values for independent variables, dependent variables and mediating variables.

Variables	*Items in TIMSS 2019*	Comments	M	SD
Dependent variables				
Knowing	Overall learner science knowing performance	Estimated from the five multiple imputation values	501.80	102.02
Applying	Overall learner science applying performance		502.24	101.59
Reasoning	Overall learner science reasoning performance		504.49	96.64
Independent variable				
Frequency of teachers using practical work	BSBS21- In science lessons, how often does your teacher ask you to conduct science experiments?	Reverse coding= 4= at least once a week 3= once or twice a month 2= a few times a year 1= never	3.51	.651
Clarity of instruction	BSBS23B- My teacher is easy to understand	Reverse coding= 4= Agree a lot; 3= Agree a little; 2= Disagree a little; 1= disagree a lot	3.03	.851
	BSBS23C- My teacher has clear answers to my questions		3.07	.830
Mediating Variables				
Enjoyment of science	BSBS22A- I enjoy learning science	Reverse coding= 4= Agree a lot; 3= Agree a little; 2= Disagree a little; 1= disagree a lot	3.03	.845
	BSBS22B- I wish I did not have to study science*		2.77	.951
	BSBS22C – Science is boring*		2.79	.912
	BSBS22D – I learn many interesting things in science		3.12	.787
	BSBS22E – I I like science		2.96	.864
	BSBS22F – I look forward to learning science in school		2.86	.887
	BSBS22G – Science teaches me how things in the world work		3.18	.772
	BSBS22H -I like to do science experiments		3.18	.820
	BSBS22I -Science is one of my favorite subjects		2.80	.941
Instrumental motivation	BSBS25A- I think learning science will help me in my daily life	Reverse coding= 4= Agree a lot; 3= Agree a little; 2= Disagree a little; 1= disagree a lot	3.18	.774
	BSBS25B- I need science to learn other school subjects		2.84	.876
	BSBS25C- I need to do well in science to get into the university of my choice		2.92	.890
	BSBS25D- I need to do well in science to get the job I want		2.81	.912
	BSBS25E- I would like a job that involves using science		2.66	.954
	BSBS25F- It is important to learn about science to get ahead in the world		2.88	.891
	BSBS25G- Learning science will give me more job opportunities when I am an adult		2.87	.895
	BSBS25H- My parents think that it is important that I do well in science		2.78	.896
	BSBS25I- It is important to do well in science		2.98	.846
Self-confidence	BSBS24A- I usually do well in science	Reverse coding= 4= Agree a lot; 3= Agree a little; 2= Disagree a little; 1= disagree a lot	2.83	.841
	BSBS24B- Science is more difficult for me than for many of my classmates*		2.61	.906
	BSBS24C- Science is not one of my strength*		2.59	.915
	BSBS24D- I learn things quickly in science		2.71	.836
	BSBS24E- I am good at working out difficult science problems		2.56	.861
	BSBS24F- My teacher tells me I am good at science		2.29	.888
	BSBS24G- Science is harder for me than any other subject*		2.65	.920
	BSBS24H- Science makes me confused*		2.72	.937

a higher level of motivation. Examples of these items are 'I think learning science will help me in my daily life' and 'I would like a job that involves using science'. Cronbach's alpha for students valuing science is .944 for 9 items. Items for students' self-concept in science were recoded such that a higher value denotes a higher level of students' self-concept. Examples of these items are 'I usually do well in science' and 'Science is more difficult for me than for many of my classmates'. Cronbach's alpha for students' self-concept is .854 for 8 items.

Instructional factors (independent variables) Clarity of instruction and frequency of teachers' use of practical work served as exogenous variables in the hypothesized model (Figure 1). For frequency of teachers' use of practical work, students responded to the item 'In science lessons, how often does your teacher ask you to conduct science experiments?'. The instructional factor, clarity of instruction, included two items on students' perception of the extent of easy understanding of science instruction. Examples of these items are 'My teacher is easy to understand'. Cronbach's alpha for students' perceived clarity of instruction is .913 for 2 items.

4.3 Procedures and data analysis

Structural equation modelling was used because it is a powerful statistical modelling technique which combines measurement model and structural model into a single model (Hoe 2008; Maricuțoiu and Sulea 2019). In our analysis, Mplus 8.3 (Muthén & Muthén, 2019) was used. Descriptive statistics and correlation among students' latent variables were calculated

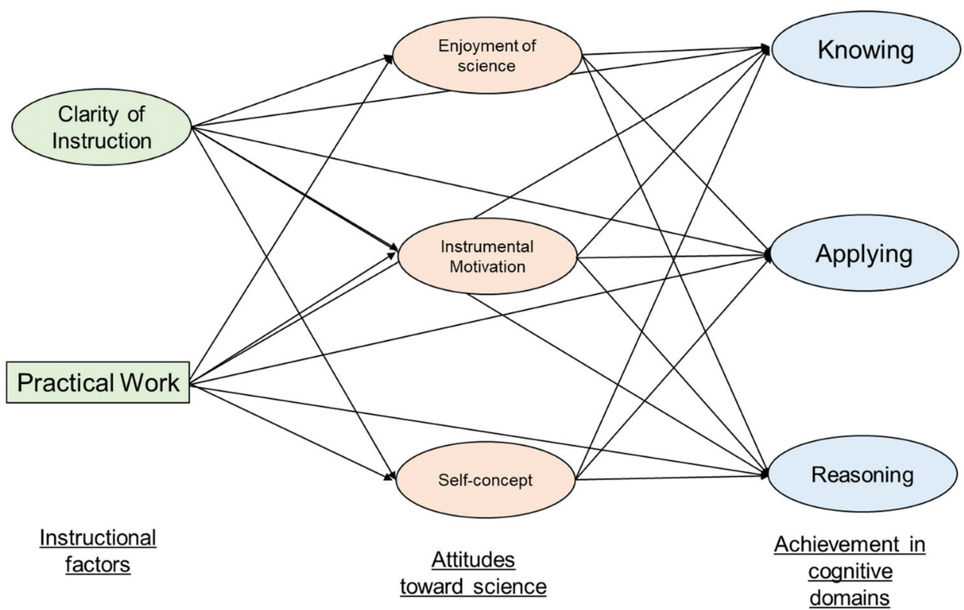

Figure 1. Structural equation models specifying the relationships among instructional factors (clarity of instruction and frequency of practical work, attitudes toward science and cognitive domains.

(Table 2). Regarding the instructional factors, the frequency of practical work ($M = 3.51$, $SD = .651$) has a higher mean score than clarity of instruction ($M = 3.05$, $SD = .810$). It was found that students' self-concept (SC) ($M = 2.60$, $SD = .741$) has the lowest mean score compared to other two dimensions of attitude toward science, enjoyment of science (ES) ($M = 2.96$, $SD = .768$) and instrumental motivation (IM) ($M = 2.85$, $SD = .775$).

The first step was to specify measurement model and to test the validity of latent constructs. Confirmatory factor analysis (CFA) was carried out on three types of attitudes toward science and clarity of instruction, as these latent variables have included more than one item. A measurement model was created for each latent variable and factor loadings of each item were carefully examined (Table 3). Convergent validity is supported by three indicators: (1) each factor loads significantly into a latent variable, with a standardized factor loading of 0.7; (2) a composite reliability (CR) of above 0.7; (3) an average variance extracted (AVE) of above 0.5 (Hair et al. 2010). Items were deleted such that CR and AVE reached 0.7 and 0.5 respectively.

Model fit indices were investigated for each measurement model. The model fit indices were computed and compared using the Root Mean Square Error of Approximation (denoted as RMSEA, good fit with values less than 0.08 (Loehlin and Mahwah 2004), the Standardized Root Mean Square Residual (denoted as SRMR, good fit with values less than 0.08) (Brown 2014; Hu and Bentler 1999), the Confirmatory Fit index (CFI, good fit with values above 0.95) and the Tucker-Lewis Index (TLI, good fit with values above 0.95). To improve model fit indices, the measurement models were revised by correlating residuals between items. As shown in Table 3, all latent variables reached various indices of model fits. After specifying measurement models, structural models were specified such that the direct effects and indirect effects of instructional factors on students' achievement in different cognitive domains can be calculated. In TIMSS, there are five plausible values for achievement of each cognitive domains. We created five data files for each plausible values, and the function TYPE=IMPUTATION can combine effect sizes of all five plausible values and their standard errors in calculating path coefficients. More importantly, with consideration of complex sampling in TIMSS data collection, the School ID was specified as the cluster and total student weight was taken as the sampling weight (Wan, Zhan, and Zhang 2023). The Mplus function TYPE=COMPLEX was used

Table 2. Zero-order correlation of the study's latent variables.

	Mean	SD	ES	IM	SC	FP	CI	KS	AS	RS
Enjoyment of science (ES)	2.96	.768	1.000							
Instrumental Motivation (IM)	2.85	.775	.644***	1.000						
Self-concept (SC)	2.60	.741	.774***	.616***	1.000					
Frequency of practical work	3.51	.651	.134***	.100***	.096***	1.000				
Clarity of instruction (CI)	3.05	.81	.664***	.501***	.573***	.131***	1.000			
Achievement of Knowing science (KS)	501.80	102.02	.244***	.201***	.238***	.127**	.114*	1.000		
Achievement of Applying Science (AS)	502.24	101.59	.215***	.197***	.183***	.119***	.092*	.896***	1.000	
Achievement of Reasoning Science (RS)	504.49	96.64	.194***	.185***	.162***	.142***	.086	.866***	.928***	1.000

*Significant at $p \leq 0.05$ level, **Significant at $p \leq 0.01$ level, ***Significant at $p \leq 0.001$.

Table 3. Standardized estimates factor loadings of the study's latent variables.

	Attitudes towards science			Reliability indices	
Items	Enjoyment of science (ES)	Instrumental Motivation (IM)	Self-concept (SC)	Composite Reliability (CR)	Average Variance Extracted (AVE)
BSBS22A	.856			.935	.743
BSBS22D	.774				
BSBS22E	.908				
BSBS22F	.878				
BSBS22I	.883				
BSBS25B		.755		.944	.709
BSBS25C		.881			
BSBS25D		.903			
BSBS25E		.836			
BSBS25F		.838			
BSBS25G		.874			
BSBS25I		.782			
BSBS24A			.791	.888	.666
BSBS24D			.872		
BSBS24E			.870		
BSBS24F			.738		
Chi^2/df	8.36	25.37	34.17		
CFI	.993	.958	.981		
TFI	.986	.937	.945		
RMSEA	.048	.087	.101		
SRMR	.010	.022	.014		

to compute the cluster-robust standard errors (Wan, Zhan, and Zhang 2023). In the output of MPlus software, the model fit indices were then compared with those in the literature. All regression coefficients were reported as both independent variables and dependent variables of each effect were standardised.

5. Results

5.1 Model fits

After examining the model fits of the measurement models of latent variables, we built different structural equation models and tested their model fit indices. Initially, we constructed simple models which specified the relationships between attitudes toward science and students' achievement in different cognitive domains. We then included an instructional factor in the model each time and found that the model fit indices increased from simple regression models to latent mediating models. Finally, we included both instructional factors, frequency of teachers' use of practical work and clarity of instruction in the model. The final model fit indices were as follow: SRMR (0.040), RMSEA (0.046), CFI (0.965), TFI (0.957). These four indices indicated a good model fit.

5.2 Effects of two instructional factors on students' achievement in cognitive domains

The patterns of the direct effects of clarity of instruction and frequency of teacher's use of practical work had opposite effects. Clarity of instruction had a direct significantly negative effect on the domain of knowing ($effect = -.12$, $SE = .06$, $p < .001$), applying ($effect = -.12$, $SE = .05$, $p < .001$) but not reasoning ($effect = -.10$, $SE = .06$, $p > .05$). By contrast, frequency of teachers' use of practical work had a direct significant positive effect on students' achievement in knowing (*effect*= .10, *SE* = .03, $p < .01$), applying (*effect* = .09, *SE* = .03, $p < .01$) and reasoning (*effect*=.12, *SE* = .04, $p < .01$). The coefficients with standardised independent and outcome variables were shown in Figure 2. Clarity of instruction seems to negatively predict students' achievement in knowing and applying science, while more frequent use of practical work by teachers seems to have a direct effect on students' achievement in all cognitive domains.

5.3 Effects of practical work and clarity of instruction on students' attitudes toward science

Both clarity of instruction and frequency of practical work had a significantly positive effect on two types of attitudes toward science, enjoyment of science and instrumental motivation in science. Clarity of instruction had a statistically significant positive effect on enjoyment of science (*effect* = .66, *SE* = .02, $p < 0.001$) and instrumental motivation (*effect* = .50, *SE* = .03, $p < 0.001$), while frequency of teachers' use of practical work had a statistically significant effect on enjoyment of science (*effect* = .05, *SE* = .02, $p < 0.01$) and students' instrumental motivation in science (*effect* = .04, *SE* = .02, $p < 0.05$). Clarity of instruction seems to have a stronger effect than frequency of teachers' use of practical work on the two types of attitudes toward science. Moreover, clarity of instruction had a positive significant effect on students' self-concept in science (*effect* = .56, *SE* = .03, $p <$ 0.001), but frequency of teachers' use of practical work did not have any significant effect on students' self-concept in science (*effect* = .03, *SE* = .02, $p > .05$).

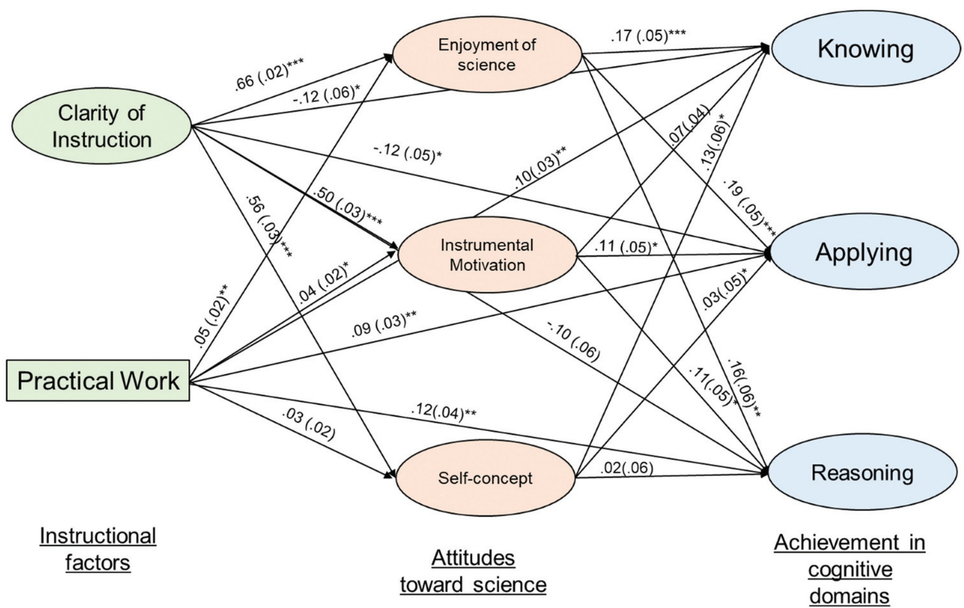

Figure 2. Standardized estimates for relations among instructional factors, attitudes toward science and different cognitive domains. Note: the dashed lines represent insignificant relationship. *Significant at $p \leq 0.05$ level, **Significant at $p \leq 0.01$ level, ***Significant at $p \leq 0.001$ (model fit indices: $\chi 2/df = 73.15$, SRMR = .40, RMSEA = .046, CFI = .965, TFI = .957).

5.4 Effects of students' attitudes towards science on students' achievement in cognitive domains

Enjoyment of science had a positive significant effect on students' achievement in all three cognitive domains (knowing: *effect* = .17, *SE* = .05, $p < .001$; applying: *effect* = .19, *SE* = .05, $p < .001$; reasoning: *effect* = .16, *SE* = .06, $p < .01$). Instrumental motivation also had a positive significant effect on students' achievement in only applying (*effect* = .11, *SE* = .05, $p < .05$) and reasoning (*effect* = .11, *SE* = .05, $p < .05$). Students' self-concept in science only had a positive significant effect on students' achievement in knowing (knowing: *effect* = .13, *SE* = .06, $p < .05$) and applying science (*effect* = .03, *SE* = .05, $p < .05$) but was not significantly associated with reasoning (*effect* = .02, *SE* = .06, $p > 0.05$).

5.5 Indirect effects of frequency of practical work and clarity of instruction on students' achievement in different cognitive domains

Enjoyment of science had a mediating role between clarity of instruction and students' achievement in different cognitive domains. The estimates of indirect effects and standard errors were shown in Table 4. Enjoyment of science had a significantly positive mediating effect between clarity of instruction and knowing (*effect* = .113, *SE*= .031, $p < .001$), applying (*effect* = .125, *SE*= .032, $p < .001$) and reasoning (*effect* = .107, *SE*= .040, $p < .001$). More importantly, intrinsic motivation has a significantly positive mediating role between clarity of instruction and applying (*effect* = .055, *SE*= .023, $p < .05$) and reasoning science (*effect* = .055, *SE*= .023, $p < .05$). Self-concept had a significant mediating effect between clarity of instruction and knowing science (*effect* = .071, *SE*= .033, $p < .05$).

Students' enjoyment in science had a mediating role between frequency of teachers' use of practical work and students' achievement in different cognitive domains, knowing (*effect* = .009, *SE*= .004, $p < .05$), applying (*effect* = .010, *SE*= .004, $p < .05$), and reasoning (*effect* = .009, *SE*= .004, $p < .05$). The mediating effect estimates of enjoyment of science on the relationship between clarity of instruction and students' achievement in three cognitive domains was smaller than that between frequency of teachers' use of practical work and students' achievement in three cognitive domains. The other two types of attitudes towards science, instrumental motivation and self-concept, did not play a significant mediating role between frequency of teachers' use of practical work and students' achievement in all three cognitive domains.

6. Discussion

In this study, we examined the interrelationships among students' self-reported instructional factors, students' attitudes toward science and students' achievement in different cognitive domains. Although previous studies have shown that instructional factors were related to students' overall science achievement (Kang 2020; Liou 2020; Liou and Ho 2016), it was unknown whether two instructional factors examined (frequency of practical work and clarity of instruction) were differentially related to different science cognitive domains, knowing, applying and reasoning. Additionally, the results of this study also reveal if different types of students' attitudes toward science play a mediating role between students' achievement in each cognitive domain and the two instructional

Table 4. Indirect effects of components of frequency of practical work on students' achievement in different cognitive domains.

Path	Estimate	*SE*
PW → ES → Knowing	.009*	.004
PW → ES → Applying	.010*	.004
PW → ES → Reasoning	.009*	.004
PW → IM → Knowing	.003	.002
PW → IM → Applying	.004	.003
PW → IM → Reasoning	.004	.003
PW → SC → Knowing	.003	.003
PW → SC → Applying	.001	.001
PW → SC → Reasoning	.000	.002
CI → ES → Knowing	.113***	.031
CI → ES → Applying	.0125***	.032
CI → ES → Reasoning	.0107**	.040
CI → IM → Knowing	.034	.020
CI → IM → Applying	.055*	.023
CI → IM → Reasoning	.055*	.023
CI → SC → Knowing	.071*	.033
CI → SC → Applying	.017	.028
CI → SC → Reasoning	.009	.032

PW: frequency of practical work; CI: Clarity of Instruction ES: enjoyment of science; IM: intrinsic motivation; SC: Students' self-concept in science.

*Significant at $p \leq 0.05$ level, **Significant at $p \leq 0.01$ level, ***Significant at $p \leq 0.001$.

factors. In this section, the two main contributions will be discussed, followed by a discussion of limitations and suggestions for future research.

6.1 *Effects of frequency of practical work and clarity of instruction on different cognitive domains*

The finding shows that clarity of teachers' instruction yielded a significantly negative direct effect on students' achievement in knowing and applying science. Students' achievement in cognitive domains cannot be enhanced by simply improving teachers' clarity of instruction, such as easy to access to subject matter knowledge. This could be attributed to that Hong Kong students adopt a Chinese style of learning which focuses on memorisation instead of knowing, applying, and reasoning scientific knowledge (Lau 2014; Wong 2004; Yeung 2009). Though previous studies showed that teacher-directed practice was significantly related to students' science achievement (Liou and Ho 2016), a high clarity of instruction embedded in science instruction did not necessarily enhance students' achievement in knowing, applying and reasoning scientific knowledge. There could be two plausible explanations accounting for this. The learning culture of the region might influence how a learners' cognitive domains is affected by teachers' clarity of instruction. Another plausible explanation is that learners' interest and motivation to learn science could mediate the relationship between clarity of instruction and students' achievement in cognitive domains.

On the other hand, the results indicated that teachers' frequent use of practical work had a significant positive effect on students' achievement in all three cognitive domains, knowing, applying and reasoning. This resonates with previous finding that a more frequent use of practical work enhanced students' science achievement (Achor and Agambar 2016). Embedding practical work in science lessons could be an effective mean in enhancing students' cognitive outcomes (Abrahams and Millar 2008).

6.2 Interrelationships among teachers' instructional practices, attitudes toward science and students' achievement in different cognitive domains

As students' attitudes toward science were important mediating roles on their academic achievement (Jo and Seo 2021; Liou 2020), we studied the mediating roles of enjoyment of science, instrumental motivation and self-concept on students' achievement in science cognitive domains. Similar to the finding by Liou (2020), enjoyment of science exerted a significantly positive mediating effect between two instructional factors and different science cognitive domains. This was to some extent concurrent with his interpretation that enhancing students' intrinsic motivation could lead to a deeper learning as well as academic performance (Simons et al. 2004). The activities that students participate, such as conducting practical work, shaped their interest and hence their ways of knowing and reasoning claims (Shaffer 2006). However, there was not any large difference in mediating effects of enjoyment of science on three cognitive domains in our findings, despite the fact that the domains of reasoning and applying are more cognitively demanding than the domain of knowing (Huitt 2011).

More importantly, our findings further demonstrated that practical work did not have both direct and indirect effects on students' self-concept. It might be because practical work in school science was administered in a way that did not improve their perception of their ability in doing science (Pun and Cheung 2023; Cheung and Pun 2023). According to Jansen, Schroeders and Lüdtke (2014), self-concept in science was commonly found to be positively correlated with academic achievement. However, based on our findings, practical work might not play an important role in building students' self-concept that led to their achievement in cognitive domains. One possible explanation was that students might not have enough support during practical work activities.

6.3 Limitations and future research

It should be noted that this study has some limitations which warrant further investigations. Scales of instructional factors were self-reported by the students. TIMSS did not carry out observational studies on teachers, instead it administered self-reported e-surveys to students. The actual instructional factors, such as the frequency of teachers' use of practical work, might mismatch with those being reported by students. Students' subjective perception of teachers, such as whether they like the teachers, affected their rating of teachers' clarity of instruction and their frequency of using practical work in science lessons. Another limitation is that the TIMSS data is cross-sectional in nature, which means that experimental design was not carried out to verify the cause-and-effect relationships (Chen 2014; Liou 2020). The instructional factors, students' attitudes toward science and students' achievement in cognitive domains were measured concurrently. As students' attitudes toward science take time to develop, examination of mediating roles of attitudes toward science requires empirical longitudinal studies.Also, students' achievement in various cognitive domains can be influenced by different factors, such as linguistic backgrounds (Pun, Fu and Cheung 2023) and exposure to socioscientific issues (Chan, Cheung and Erduran 2023; Cheung, Chan and Erduran 2023). Lastly, this study did not take within-class and between-class variance of attitudes toward of science into account, so there might be contextual effects affecting these predicators of students' achievement in cognitive domains. Future studies can investigate the multilevel structural equation models (Rabe-Hesketh, Skrondal, and Zheng 2007) of their interrelationships.

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Ethical statements

It draws on secondary data analysis from large-scale assessment databases. Hence, ethical approval is not applicable.

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