Interrelationship Between Inquiry-Based Learning and Instructional Quality in Predicting Science Literacy

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Abstract

Recent international comparison studies such as the Programme for International Student Assessment (PISA) repeatedly argued that inquiry-based learning (IBL) indicated a negative effect on science literacy (SL). However, those studies included two limitations in revealing the relationship between IBL and SL as they did not consider (1) instructional quality and (2) different types of IBL. Accordingly, this study aimed to explore relationships between two types of IBL (open and guided) and SL, and how four types of instructional quality (classroom management, adaptative teaching, teacher–student relationship, and teacher support) moderated the relationships between IBL and SL. For this purpose, a PISA 2015 Finnish sample was used and analyzed by latent moderated structural equation modeling in order to explore the latent interaction between IBL and the quality of instruction. The results of this study presented that the teacher–student relationship was the most potent predictor of SL and moderated the effects of guided and open inquiry on SL. Classroom management also indicated moderation effects for both guided and open inquiry. Also, this study showed the overruling effect of open inquiry on guided inquiry in predicting SL.

Keywords Inquiry-based learning · Moderation effect · Instructional quality · PISA · Teacher–student relationship

Introduction

Inquiry-based learning (IBL), which stimulates and reflects scientists’ authentic work among students, becomes the keystone of science education for the last decades. It is a less teacher-directed step-by-step instruction, rather, a more student-centered way of learning, which

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encourages to use learners' own experiences. IBL has been recognized as a salient pedagogical method not only enhancing students' interest and achievement but also providing students with a chance to discover how scientific knowledge has been constructed and developed by following scientists' authentic work (Lee and Songer 2003). That is, through the IBL process, students can learn and develop higher-order thinking skills consisting of problem-solving, inferring, estimating, predicting, generalizing, and creative thinking skills, so that they are prepared as lifelong learners and scientifically literate citizen armed with a comprehensive understanding of the processes and products of science (Madhuri et al. 2012). Therefore, having more chances to experience IBL at school is necessary for every student, whether or not they want to be a scientist in the future.

Surprisingly, however, a recent international comparison study, the Program for International Student Assessment (PISA) 2015, reported that students' experiences related to the inquiry cycle had been negatively correlated with students' science achievement in most of the participating countries (The Organisation for Economic Co-operation and Development (OECD), 2016a). That is, more IBL implementation leads to lower academic achievement in science. Subsequently, this issue has been debated in recent respected national and international science education conferences, distinguished researchers like Sjøberg (2017) have raised the question of whether inquiry-based science education should be sacrificed in order to get better achievements in PISA, and the voice was echoed to the public and policymakers (e.g., Gibb 2020).

However, there are two limitations of the current PISA report regarding the effect of IBL. First, it does not consider different types of IBL, while several studies using the PISA IBL scales repeatedly reported that they found two types (or constructs) of IBL such as teacher-directed guided inquiry and student-directed open inquiry (Aditomo and Klieme 2020; Kang and Keinonen 2018; Lau and Lam 2017). Therefore, using the PISA IBL scale as one construct as was reported by the PISA 2015 may provide erroneous results. Second, the PISA IBL scale measured only the frequency (quantity) of IBL rather than the quality; thus, several studies pointed out the limitation of using only the frequency data in measuring the effect of IBL activities on achievement (Kang and Keinonen 2018; Oliver et al. 2019). Accordingly, this study aimed to analyze the relationship between IBL and science literacy taking different types of IBL and instructional quality into account.

Instructional Quality and IBL

A large portion of student outcomes can be explained by teachers' instructional quality (Kyriakides et al. 2013). Accordingly, it becomes an important topic for teachers' professional development. Although the definition may differ by studies, I use *instructional quality* as an umbrella term for teaching strategies (Caro et al. 2016), instructional behavior (Holzberger et al. 2014), disciplinary climate (Chi et al. 2018), or effective teaching (Kyriakides et al. 2013) that all point out similar elements of instructional quality such as classroom management and supportive climate that are widely accepted in recent instructional quality studies (Fauth et al. 2019). In particular, *classroom management* refers to handling of disruptions and misbehavior in order to maximize learning time. Therefore, students who are in effectively managed classrooms can spend more time on learning tasks and activities so that they may gain more knowledge on the subject-related content than those who are in less efficiently managed classrooms. (Lipowsky et al. 2009). Classroom management can be seen as a critical prerequisite for IBL since this student-centered approach asks more time and engagement than traditional methods (Chi et al. 2018; Fauth et al. 2019). *Supportive climate* refers to specific

aspects of teacher–student relationships and interactions such as giving constructive feedback, respecting students’ ideas and questions, adapting the lesson and providing extra support when needed, and caring students’ emotion (Houtveen et al. 1999; Kyriakides et al. 2013; Lipowsky et al. 2009). A warm and caring atmosphere between a teacher and students foster the experience of relatedness; this positive relationship supports students’ motivation to engage with the content, and thus, it moderates the relationships between students’ interest and achievement (Lipowsky et al. 2009). Supportive climate is a vital element of IBL, which demands high teacher–student interactions and constructive feedback during the inquiry process. According to the review by Fauth et al. (2019), classroom management has indicated positive relationships with student achievement, while supportive climate has been connected to students’ motivational and interest development.

PISA and IBL

PISA is one of the comprehensive international assessments to measure students’ capabilities not only in their content knowledge but also in their use of knowledge in order to meet and solve real-life challenges (OECD 2016a). One subject among reading, mathematics, and science literacy is focused on triennially in randomly selected groups of 15-year-old students. PISA 2006 was the first assessment, and PISA 2015 is the latest assessment focusing on science literacy. In the PISA science assessment, science literacy is defined as “the ability to engage with science-related issues, and with the ideas of science, as a reflective citizen” (OECD 2016c, p. 19) focusing on three competencies: *to explain phenomena scientifically*, *to evaluate and design scientific inquiry*, and *to interpret data and evidence scientifically*. Although all three competencies require knowledge, it demands different kinds of scientific knowledge. Specifically, while the first competency emphasizes more on “knowledge of the content of science,” the latter two competencies require more “procedural knowledge” and “epistemic knowledge” that are closely connected to and generated through scientific inquiry processes and experiences. Therefore, the PISA Science underlines the importance of the use of IBL in science education in order to equip students with science literacy competencies so that they are willing to engage in reasoned discourse about science and technology in the future. In addition to measuring students’ science literacy, PISA also measures teaching approaches that are related to IBL that students experienced at school. As presented in Table 1, students were asked to answer how often these nine IBL-related approaches were used in science class.

IBL is accounted for in various ways by the amount of autonomy given to learners in designing and investigating experiments (Kang and Keinonen 2018; Sadeh and Zion 2009). However, since several definitions exist and are used in different studies, it is hard to simplify the levels of inquiry (Bunterm et al. 2014). In general, many researchers agreed that guided inquiry “helps students learn science content, master scientific skills, and understand the nature of scientific knowledge” (Sadeh and Zion 2012, p. 833), while open inquiry helps students increase procedural and epistemological scientific understanding and engage in higher-order thinking (Madhuri et al. 2012; Zion et al. 2013). Accordingly, both approaches may enhance students’ nature of science (NOS) views. Moreover, it is important that NOS content is introduced in the context of IBL proposals in an explicit and reflective manner (Khishfe and Abd-El-Khalick 2002). That is, learners are to be “first explicitly introduced to certain NOS aspects and then provided multiple structured opportunities to reflect on these aspects” (p. 554) during the inquiry process to promote their understandings of NOS.

Table 1 Description of factors and items

Factor	Item	Item description
Guided inquiry	GI1 ^a	Students are given opportunities to explain their ideas.
	GI2	Students spend time in the laboratory doing practical experiments.
	GI3	Students are asked to draw conclusions from an experiment they have conducted.
	GI4	The teacher explains <school science> idea can be applied
	GI5	The teacher clearly explains relevance <broad science> concepts to our lives.
Open inquiry	OI1	Students are required to argue about science questions.
	OI2	Students are allowed to design their own experiments.
	OI3	There is a class debate about investigations.
	OI4	Students are asked to do an investigation to test ideas.
Classroom management	CM1	Students do not listen to what the teacher says.
	CM2	There is noise and disorder.
	CM3	The teacher waits long for students to quiet down.
	CM4	Students cannot work well.
	CM5	Students do not start working for a long time after.
Supportive climate	Teacher support	TS1 The teacher shows interest every students learning.
		TS2 The teacher gives extra help.
		TS3 The teacher helps students with their learning.
		TS4 The teacher continues teaching/students understand.
		TS5 Teacher gives an opportunity to express opinions.
	Adaptative teaching	AI1 The teacher adapts the lesson to my class needs and knowledge.
		AI2 The teacher provides individual help when a student has difficulties
	Teacher–student relationship	AI3 The teacher changes the structure of the lesson on a topic
		RE1 Teachers called on me less often than they called on other students.
		RE2 Teachers graded me harder than they graded other students.
		RE3 Teachers gave me the impression that they think I am less smart than I really am.
		RE4 Teachers disciplined me more harshly than other students.
		RE5 Teachers ridiculed me in front of others.
		RE6 Teachers said something insulting to me in front of others.
		INT1 I have fun when I am learning <broad science>
Interest	INT2	I like reading about <broad science> topics.
	INT3	I am happy working on <broad science> topics.
	INT4	I enjoy acquiring new knowledge in <broad science>.
	INT5	I am interested in learning about <broad science>.

^a For the latent moderated analysis, GI1 was excluded based on the results of EFA and CFA

Interestingly, several studies using both PISA 2006 and 2015 indicated that the PISA IBL-scale presented two constructs such as teacher-directed guided inquiry and student-directed open inquiry. For instance, Kang and Keinonen (2018) using the PISA 2006 Finnish data found two factors—guided and open inquiry. Their findings suggested that guided inquiry indicated positive relationships, whereas open inquiry was negatively related to science literacy. Similarly, Lau and Lam (2017) using data of ten top-performing countries in PISA 2015 found two distinctive factors from the PISA IBL scale as interactive investigation and interactive application. According to the results, interactive application indicated a positive association with performance in all ten countries, while interactive investigation was found negatively associated in all regions. Aditomo and Klieme (2020) also separated the IBL scale into two factors as guided and independent inquiry based on several factor analyses using

twenty PISA 2015 participating countries. Their study reported that guided inquiry indicated a positive relationship with science literacy, while independent inquiry was negatively associated across sixteen countries. On the other hand, in case all nine PISA IBL items were used as a single factor, the relationship between IBL and science literacy was negative as reported by OECD (2016a) (e.g., Chi et al. 2018; Oliver et al. 2019). Therefore, it is assumed that the effect of open inquiry overrules the effect of guided inquiry when these two types of inquiry are used as a single construct. Accordingly, it is recommended to differentiate and measure the effects of different types of IBL on achievement separately when using the PISA datasets.

Aims and Research Questions

As reviewed, each dimension of instructional quality is closely connected to successful practices of IBL. However, to my knowledge, only one study took this perspective when investigating the effect of IBL for low socioeconomic status (SES) students' science achievement in China (Chi et al. 2018). This Finnish study therefore aimed to provide further insights into the moderation effect of instructional quality on the relationships between IBL and learning outcomes applying *latent moderated structural equation modeling* using PISA 2015 data. Also, in exploring the relationships, different levels of IBL such as guided and open inquiry will be considered. To this end, this study tried to answer the following research questions:

RQ1. Does instructional quality moderate the relationship between IBL and learning outcomes? How does each dimension of instructional quality affect differently on this relationship?

RQ2. How does the moderation effect of instructional quality lead to different learning outcomes depending on the types of IBL?

Based on the review of the literature, I hypothesized that classroom management moderates the effect of guided (first hypothesis, H1) and open inquiry (H2) on science literacy. In contrast, supportive climate may not work as a moderator on the relationships of guided (H3) and open inquiry (H4) with science literacy. Concerning the relationships between inquiry and science interest, on the other hand, classroom management may not moderate the effect of guided (H5) and open inquiry (H6), but supportive climate may show a significant interrelationship with guided (H7) and open inquiry (H8) in predicting science interest.

Method

For this study, I used data collected for PISA 2015. As mentioned, PISA 2015 is the latest assessment focusing on science literacy among 15-year-old students. The data cover not only students' science achievements but also attitudes towards science and learning experiences such as IBL. The Finnish sample was chosen because previous studies continuously have revealed that the Finnish PISA sample indicated two types of IBL as guided inquiry, which is predominant in the curriculum and widely implemented by Finnish teachers, and open inquiry, which had been rarely used, but emphasized in the new 2016 national core curriculum (Lavonen and Laaksonen 2009; Kang and Keinonen 2017, 2018). The sample comprised 5882 students (48.7% female) from 168 schools, and most of them were 9th graders (87%).

Measures

All variables except the science literacy score were derived from PISA 2015 Student Questionnaire data. The PISA Student Questionnaire used a four-point Likert scale between one and four, and some variables were coded or recoded as the high point indicated higher levels of agreement with the asked concepts. Table 1 describes each item and factor in detail.

Moderator Variable: Instructional Quality

Based on the previous literature and availability of data, four instructional quality factors were chosen from the PISA 2015 student questionnaire—*classroom management*, *teacher support*, *teacher–student relationship*, and *adaptive teaching*. Regarding *classroom management*, students were asked how well their teachers managed certain disruptive situations with five items ($\alpha = 0.91$). Regarding *teacher support*, students were asked how often teachers give extra help for or show interest in every student learning with five items ($\alpha = 0.91$). The *teacher–student relationship* was measured with six items by asking if teachers treated students equally at school during the past 12 months ($\alpha = 0.84$). The items of *adaptive teaching* asked students how often teachers adapted or changed the structure of the science lesson based on students' diverse needs and knowledge with three items ($\alpha = 0.81$).

Independent Variable: IBL Experiences

Based on the previous literature and preliminary factor analyses (see Table S1), the nine PISA IBL items were grouped into two types of IBL as teacher-directed guided inquiry (from here guided inquiry) and student-directed open inquiry (from here open inquiry). Open inquiry included four items representing the high autonomy of students in selecting a research topic and in designing experimental work ($\alpha = 0.82$). The items in this factor refer to student-directed inquiry activities without involving explicit teacher guidance. On the other hand, guided inquiry items included five activities led by both teachers and students including practical hands-on activities ($\alpha = 0.76$). Especially, studies by Lavonen and Laaksonen (2009) and Kang and Keinonen (2018) confirmed that these guided inquiry variables were closely related to the traditional inquiry practice in Finland emphasizing the importance of teachers' guidance during the inquiry process.

Dependent Variable: Science Literacy and Interest

Students' scientific literacy scores and science interest were used as dependent variables. In reporting proficiency of science, PISA uses plausible values that are multiple imputations of proficiency values based on information from the test items. Briefly, in order to minimize participants' response burden, the full set of test items is organized into several booklets and each student receives only one among them; based on data from individuals, PISA produces plausible values representing the range of the students' science proficiency of the population. In PISA 2015, ten plausible values were calculated as science proficiency scores (see PISA 2015 Technical Report for more detail (OECD 2017b)). Regarding science interest, students were asked how much enjoyment and fun they have in learning science with five statements ($\alpha = 0.95$).

Analyses

To explore the latent interaction between IBL and instructional quality as shown in Fig. 1, the latent moderated structural equation modeling (LMS) was used (Klein and Moosbrugger 2000). Compared with manifest analyses, LMS indicates some advantages in analyzing moderation effects such as controlling for measurement errors and accounting for the non-normality of the variables by providing robust standard errors. As shown in Tables 5 and 6, latent regression models were estimated first, and then latent interaction terms were entered into the latent regression models to measure the moderation effect of each instructional quality on IBL. For this, Mplus 7.4 was used with the maximum likelihood with robust standard errors and a chi-squared estimator (MLR), which is robust to non-normality. In measuring the goodness of model fit for regression models, traditional cutoff values were applied: RMSEA (the root-mean-square error of approximation) below 0.08, CFI (comparative fit index) above 0.90, and TLI (Tucker–Lewis index) above 0.90. Currently, however, Mplus does not offer fit indices for the LMS. A students' final weight offered by PISA was used in order to correct for selection bias, and missing data were estimated using full information maximum likelihood estimation (FIML) throughout the analysis processes. For LMS, all items were standardized in order to enhance the interpretability of the results except science literacy scores.

Result

Preliminary Analyses

The means and standard deviations are presented on the diagonal with italics in Table 2. Finnish students achieved 531.57 points at the PISA science test (the OECD average score was 500 with a standard deviation of 100), and their interest in science was 2.57. Regarding the quality of instruction, the average scores of classroom management (2.84), teacher support (3.16), and the teacher–student relationship (3.42) were above the mid-point 2.5, but adaptive teaching (2.37) was below 2.5. In addition, while the teacher–student relationship presented a higher correlation with science literacy (0.29) than other instructional quality factors, teacher support and adaptive teaching indicated high correlations with interest (0.29 and 0.32, respectively). As expected, guided inquiry was positively associated with science literacy score (0.18), whereas open inquiry indicated negative relationship and its coefficient was much

Fig. 1 Hypothesized model of this study. Effect of gender and ESCS (economic, social, and cultural status) has been controlled

Table 2 Descriptive statistics as well as bivariate correlations

	1	2	3	4	5	6	7	8
1 Science literacy	531.57 (91.93)							
2 Science interest	0.35	2.57 (0.7-3)						
3 Classroom management	0.14	0.21	2.83 (0.68)					
4 Teacher support	0.15	0.29	0.25	3.16 (0.7-2)				
5 Adaptive teaching	0.18	0.32	0.20	0.54	2.37 (0.7-5)			
6 Teacher–student relationship	0.29	0.19	0.26	0.33	0.16	3.42 (0.6-3)		
7 Guided inquiry	0.18	0.32	0.10	0.51	0.44	0.13	2.30 (0.6-5)	
8 Open Inquiry	−0.30	0.08	−0.05 <i>p</i> = .017	0.17	0.16	−0.16	0.65	1.48 (0.61)

higher (−0.30); thus, we could easily assume that when the PISA-IBL variables were used as one factor, the negative effect of open inquiry-related variables might overrule the positive effect of guided inquiry-related variables on the science literacy score. In addition, while guided inquiry indicated a positive correlation with interest moderately (0.32), the correlation coefficient of open inquiry and interest was very small (0.08). Thus, the positive correlation between the PISA-IBL scale and interest reported by OECD (2016a) was mainly due to the strong positive relationship between guided inquiry and interest, not open inquiry. Interestingly, open inquiry was negatively correlated with the teacher–student relationship (−0.16). Therefore, it was assumed that this negative relationship may affect the moderation relationship between open inquiry, teacher–student relationship, and science literacy. All factors were correlated significantly at the 0.001 level, except the correlation between management and open inquiry ($p = 0.017$).

CFA was conducted for the four dimensions of instructional quality and the two types of IBL separately, and the CFA model fits for both were satisfactory as shown in Table 3. Also, each variable was gathered into the expected factors with sufficient factor loadings greater than 0.4 (see Table 4). However, the loading of the item GI1 was continuously low similar to the EFA results (see also Table S2). Therefore, the item GI1 was omitted from the guided inquiry factor for further analyses.

Table 3 CFA results for instructional quality and IBL models

	χ^2	<i>df</i>	RMSEA	CFI	TLI
Instructional quality	2669.355	146	0.055 (0.053, 0.056)	0.946	0.936
IBL	952.383	26	0.080 (0.075, 0.084)	0.932	0.905

Table 4 CFA factor loading

	Inquiry		Instructional quality			
	GI	OI	CM	TS	AT	TSR
GI1	0.462					
GI2	0.588					
GI3	0.703					
GI4	0.742					
GI5	0.628					
OI1		0.731				
OI2		0.673				
OI3		0.816				
OI4		0.702				
CM1			0.789			
CM2			0.845			
CM3			0.846			
CM4			0.766			
CM5			0.817			
TS1				0.748		
TS2				0.861		
TS3				0.894		
TS4				0.787		
TS5				0.763		
AT1					0.783	
AT2					0.732	
AT3					0.804	
TSR 1						0.515
TSR 2						0.599
TSR 3						0.697
TSR 4						0.697
TSR 5						0.806
TSR 6						0.809

GI guided inquiry, *OI* open inquiry, *CM* classroom management, *TS* teacher support, *AT* adaptive teaching, *TSR* teacher–student relationship

Moderation Effects of Instructional Quality

After conducting CFA, I estimated four latent regression models (see Tables 5 and 6; Models M 1.1, M 2.1, M 3.1, M 4.1) and then entered the latent interaction term in each of the models (see Tables 5 and 6; Models M 1.2, M 2.2, M 3.2, M 4.2) in order to test the hypotheses. As presented in the second row in Table 5, guided inquiry kept showing positive relationships with science literacy in all models. In addition, classroom management ($b = 13.27, p < .001$), adaptive teaching ($b = 12.52, p < .001$), the teacher–student relationship ($b = 47.20, p < .001$), and teacher support ($b = 9.88, p < .001$) showed positive relationships with science literacy as well. Particularly, the teacher–student relationship indicated the highest coefficient compared with other instructional quality factors as well as control variables such as ESCS.

In terms of the moderation effect, significant interactions between guided inquiry and classroom management ($b = 8.01, p < .05$), the teacher–student relationship ($b = 19.75, p < .001$), and teacher support ($b = -9.01, p < .001$) were substantiated when predicting science literacy. Therefore, H1, which assumed the moderation effect of classroom management, was confirmed, while H3, which predicted no interrelationships between guided inquiry and supportive climate (including the teacher–student relationship and teacher support), was

Table 5 Regression on science literacy with guided inquiry, instructional quality, and moderators

Variable	Model							
	M 1.1	M 1.2	M 2.1	M 2.2	M 3.1	M 3.2	M 4.1	M 4.2
Guided inquiry	19.23***	25.66***	14.51***	17.53***	16.42***	20.77***	15.67***	19.07***
Classroom management	13.27***	14.00***						
Guided inquiry × classroom management		8.01*						
Adaptive teaching			12.52***	12.40***				
Guided inquiry × adaptive teaching				1.99				
Teacher–student relationship					47.20***	48.56***		
Guided inquiry × teacher–student relationship						19.75***		
Teacher support							9.88***	7.50**
Guided inquiry × teacher support								−9.01*
Gender	−19.02***	N/A	−18.20***	−18.16***	−13.25***	−13.00***	−18.79***	N/A
ESCS	37.98***	N/A	37.87***	37.85***	37.79***	37.59***	38.40***	38.87***
R ²	0.14	0.05	0.14	0.14	0.19	0.20	0.14	0.13
Model fit								
χ ²	1182.46		835.52		2670.83		1316.96	
df	185		148		205		185	
RMSEA	0.030		0.028		0.045		0.032	
CFI	0.992		0.994		0.980		0.991	
TLI	0.991		0.993		0.977		0.990	

The multiplication sign indicates the interaction effect between two variables. *** $p < .001$; ** $p < .005$; * $p < .05$

N/A not applicable

Table 6 Regression on science literacy with open inquiry and instructional quality, and moderators

Variable	Model							
	M 1.1	M 1.2	M 2.1	M 2.2	M 3.1	M 3.2	M 4.1	M 4.2
Open inquiry	– 35.37***	– 36.26***	– 40.46***	– 40.32***	– 31.92***	– 33.49***	– 39.92***	– 41.73***
Classroom management	13.00***	12.27***						
Open inquiry × classroom management		5.89**	23.34***	23.38***				
Adaptive teaching				– 1.57				
Open inquiry × adaptive teaching								
Teacher–student relationship								
Open inquiry × teacher–student relationship					43.71***	45.39***		
Teacher support						– 7.67*		
Open inquiry × teacher support							22.22***	22.52***
GENDER	– 8.16**	N/A	– 6.32*	– 6.33*	– 3.63	N/A	– 7.45**	2.77
ESCS	39.97***	40.12***	38.68	38.69	39.58	39.61	39.32	N/A
R ²	0.20	0.20	0.22	0.22	0.24	0.25	0.22	0.22
Model fit								
χ ²	1049.61		709.21		2453.16		1138.60	
df	185		148		205		185	
RMSEA	0.028		0.026		0.043		0.03	
CFI	0.993		0.995		0.982		0.993	
TLI	0.992		0.995		0.979		0.992	

The multiplication sign indicates the interaction effect between two variables. *** $p < .001$; ** $p < .005$; * $p < .05$

N/A not applicable

rejected. Again, the moderation coefficient of the teacher–student relationship was high and significant. That is, when students think that they have a good relationship with their teachers, guided inquiry becomes more effective in enhancing students' science literacy. Interestingly, while a significant positive interaction was found between guided inquiry and classroom management, a significant negative interaction was presented between guided inquiry and teacher support. This result indicates that guided inquiry can be more successful when it is conducted by teachers who can manage and control the learning environment efficiently, rather than those who try to support all individual students that may cause disorder during inquiry process.

Opposite to the guided inquiry, open inquiry continuously indicated a significant negative effect on science literacy in all models as shown in the second row in Table 6. Regarding moderation effect, a significant positive interaction between open inquiry and classroom management was found in predicting science literacy ($b = 5.89$, $p < .005$). In addition, a significant negative interaction between open inquiry and the teacher–student relationship was substantiated ($b = -7.67$, $p < .005$). Thus, H2, which hypothesized the moderation effect of classroom management on science literacy, was confirmed, whereas H4, which speculated no interrelationship between open inquiry and supportive climate (including the teacher–student relationship), was rejected. These findings indicate that when teachers can organize their classroom well, open inquiry will result in better performance. On the other hand, when teachers have a good relationship with students, the effect of open inquiry on science literacy becomes worse. As shown in Table 2, open inquiry was negatively correlated with the teacher–student relationship and this negative correlation may affect this moderation effect. A possible interpretation of this result is discussed in the next section.

On the other hand, non-significant or very low moderation effects of instructional quality on the relationships between inquiry and interest were found (see Supplementary Material Table S3 and S4). Thus, these findings confirmed H5 and H6, which predicted no interrelationships between classroom management and inquiry approaches in predicting science interest. However, these results rejected H7 and H8, which hypothesized significant moderating effects of supportive climate on the relationships between inquiry approaches and science interest.

Besides, as also presented in Supplementary Material, when the all nine PISA-IBL scales were used together as one factor, it indicated a negative relationship with science literacy, but a positive relationship with interest (see the second row in Table S5 and the second row in Table S6, respectively). This result showed that the negative correlation of open inquiry with science literacy overrides the positive effect of guided inquiry on science literacy.

Discussion

IBL has played a pivotal role in science education for last decades as one of the effective teaching approaches enhancing students' science literacy and interest. However, recent studies using PISA data reported controversial results as IBL experiences were negatively associated with science literacy for all PISA participating countries (OECD 2016a). However, to my knowledge, no studies have considered instructional quality and different types of IBL in analyzing the relationship between IBL and science literacy. Therefore, this study aimed to investigate whether instructional quality moderated the effect of IBL on science literacy considering two types of IBL as guided and open inquiry.

Effect of Instructional Quality on Science Literacy and its Moderation Effect on IBL

According to the results, all four types of instructional quality indicated positive relationships with science literacy. In particular, the teacher–student relationship was revealed as the most powerful predictor of science literacy. This result is in line with previous studies indicating the positive relationship between achievement and the teacher–student relationship (e.g., Mason et al. 2017). Also, this finding is interesting since the effect size of the teacher–student relationship towards science literacy was more than three time higher than the other instructional quality factors. This teacher–student relationship factor focused on students' perception on how fairly their teachers treated pupils, and the Finnish sample showed very positive responses on this question. According to the PISA report (OECD 2017a), the teacher–student relationship indicated a high correlation with students' sense of belonging at school, which affects their school performance and life satisfaction. Thus, the teacher–student relationship might affect directly and indirectly science literacy during school years.

In addition to this significant correlation with science literacy, the teacher–student relationship moderated the effect of IBL on science literacy. Interestingly, while it indicated the positive moderation effect for guided inquiry, the teacher–student relationship moderated the effect of open inquiry on science literacy negatively. Also, this open inquiry scale was negatively correlated with the teacher–student relationship. Although there may be a debate on how to interpret this result, a possible explanation for this might be that when teachers practice more open inquiry, the teacher–student relationship may go worse. Considering the teacher–student relationship questions in Table 1, we can assume that students who frequently experienced open inquiry may feel that a teacher calls a few selected students who were good at open inquiry; students could not get good marks after open inquiry; students get stressed and nervous during open inquiry process; in the end, the teacher–student relationship becomes negative after the open inquiry practice. This result is in line with the argument of Kirschner et al. (2006) emphasizing that a minimal guidance during IBL might cause high cognitive load and stress that may be detrimental to learning. Also, as Kang and Keinonen (2018) and Lavonen and Laaksonen (2009) argued, while open inquiry is the most complex level of IBL and emphasized in the Finnish national curriculum, it has not been practiced often at the Finnish lower secondary school yet. Therefore, it can be assumed that the Finnish teachers who practiced open inquiry did not have sufficient skills and experiences in conducting open inquiry properly; it caused low quality of the open inquiry practice and led to an unhealthy relationship with their students. At last, students' open inquiry experiences were negatively associated with science literacy and the teacher–student relationship. However, although this negative result may attribute to teachers' lack of readiness for conducting open inquiry and without doubt, science teachers should be prepared well to conduct open inquiry first, this study did not explore whether open inquiry itself is proper for lower secondary school students. In some countries like Korea, conducting open inquiry has become mandatory for Grade 3 to Grade 10 since 2010 (MOE 2007), and some countries like Finland have recommended to conduct open inquiry for lower secondary school students (FNAE 2014). However, up to date, there are not enough evidences regarding to whom and in what age open inquiry is effective for enhancing science literacy. Considering its level of complexity and difficulty, open inquiry seems proper and better for upper secondary school students for those who are willing to take it as an optional course like the Netherlands (van Rens et al. 2010) or Israel (Sadeh and Zion 2009) set out. However, since this topic is beyond this research aims, further research is needed to investigate the proper age for the open inquiry practice.

In addition to the teacher–student relationship, classroom management and teacher support also indicated positive relationships with science literacy. This finding is consistent with previous research showing positive relationship of science literacy with classroom management (Fauth et al. 2019) and teacher support (Lipowsky et al. 2009). Also, classroom management and teacher support were positively associated with students' interest. Considering that interest is known to be a strong enhancer of achievement (Kang and Keinonen 2018), these dimensions of instructional quality will affect science literacy indirectly via interest. Therefore, this study reassures the importance of supportive climate and well-managed learning environment in enhancing students' science literacy. In addition, these two types of instructional quality moderated the effect of IBL on science literacy. Specifically, while classroom management interacted with guide inquiry positively, teacher support negatively moderated the effect of guide inquiry on science literacy. Thus, teachers who can handle disruptions and misbehavior properly during inquiry process will make students' learning more effective since students are likely to have more time on inquiry activities than those who are in less effectively managed classrooms. However, when teachers try to support and listen to all individuals during inquiry, guided inquiry will be less effective since it may cause disruption in class. Taken together, teachers should support individual student' needs during science lesson and it will improve students' science literacy. However, during IBL, it is better to focus on managing their classroom without disorder rather than on satisfying all students' needs that may cause disorder.

In line with previous studies (Houtveen et al. 1999; OECD 2016b; Oliver et al. 2019), adaptive teaching indicated positive correlations with science literacy and interest. However, students indicated that their teachers did not often adapt science lessons based on student needs and knowledge. Also, not like the other instructional quality factors, adaptive teaching did not show any interactions with IBL in predicting science literacy. This result shows that once the structure of the lesson has been decided at the beginning of school years, Finnish teachers may hesitate to change them during their lessons. However, as this study presented, adapting their lessons does not harmful to students' learning; rather, it fosters students' knowledge gaining. Also, as reviewed, adaptation of lesson might play an important role in conducting inquiry effectively because in nature IBL is exploratory that might demand a more flexible learning environment than traditional approaches. Therefore, it is recommended for teachers to adapt their lessons without hesitation when they recognize that the level of their prepared lessons or inquiry process is too high and difficult for their students to understand. This approach will increase not only students' science literacy and interest but also the impact of IBL.

Types of Inquiry and their Different Relationships with Literacy

In line with those of previous studies (Aditomo and Klieme 2020; Kang and Keinonen 2018; Lau and Lam 2017; Lavonen and Laaksonen 2009), while guided inquiry indicated the positive relationship, open inquiry showed the negative association with science literacy. In addition, when these two scales were used together as one factor in predicting science literacy, the correlation between IBL and science literacy became negative. Thus, this result confirms that the negative effect of open inquiry overrides the positive effect of guided inquiry. Therefore, it should be avoided to use the nine PISA-IBL variables together as one IBL factor that might provide erroneous results regarding the effect of IBL on science literacy. To answer to the Sjøberg's (2017) question, inquiry-based science education does not have to be sacrificed to get better achievements in PISA, because some PISA-IBL variables belonging to guided inquiry still indicate positive relationship with science achievement. However, as discussed in the previous section, some IBL activities related to open inquiry should be examined thoroughly whether those activities are effective not only for

enhancing science knowledge but also for improving the teacher–student relationship. In case open inquiry gives rise to the negative teacher–student relationship, it may affect students' well-being and life satisfaction at school as reported by PISA (OECD 2017a).

Limitations

Since this study used the secondary data, there are some limitations such as survey designs. First, although previous studies indicated some teacher level factors such as teachers' self-efficacy that affect instructional quality significantly (Burić and Kim 2020), this study could not control or involve those teacher level factors. Indeed, PISA 2015 gathered data from teachers including their self-efficacy using the Teacher Questionnaire. However, they did not provide the link that connects student and teacher datasets. Therefore, for future PISA studies, it is recommended to offer the linking variable that might widen research horizons in learning and instruction. Second, the definitions of guided and open inquiry in this study do not fully correspond with some classical classifications of the levels of inquiry such as four levels of inquiry (e.g., Banchi and Bell 2008). According to the PISA 2015 Framework, the PISA IBL items were derived from a broad perspective of IBL approaches such as students' engagement in the cognitive dimensions of inquiry, teacher-led inquiry activities, or scientific argumentation (OECD 2016c, p. 114). Therefore, the items themselves were not likely to match with specific steps of the inquiry process that distinguish the four levels of inquiry. However, I argue that each item representing open and guided inquiry in this study indicated some explicit features of teacher-directed guided and student-directed open inquiry in general. Third, since it is cross-sectional, this study does not allow causal inferences to be made. Therefore, in order to capture dynamic interplay between IBL, instructional quality and learning outcomes, and longitudinal studies following students through primary and secondary education should be conducted.

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