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Research Article

Impact of conceptual understanding, teaching experience, and parental education on science achievement: TIMSS data analysis

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ABSTRACT

This quantitative study examined the impact of teachers' self-reported use of instructional practices for conceptual understanding, teaching experience, and parental education on eighth-grade students' science achievement scores in Australia, England, Japan, South Africa, and the United States, using data from TIMSS 2015 and TIMSS 2019. The data were subjected to descriptive statistical analyses and multiple regression modeling to investigate the extent to which teachers' use of conceptual understanding practices, teaching experience, and parental education affects students' science achievement. The findings revealed that teaching for conceptual understanding practices did not always contribute to improved students' science achievement scores. However, teachers' teaching experience and parental education could have a positive effect on students' science achievement scores. The findings also showed that science teachers' teaching for conceptual understanding practices weakly accounted for differences in students' science achievement scores in the five countries, although a large percentage of teachers self-reported using conceptual understanding practices in their classrooms. The authors posit that such practices are beneficial for students' achievement in science and STEM and that establishing a universal characterization of "teaching for conceptual understanding" would enhance the conduction of cross-national studies.

Keywords: conceptual understanding practices, teaching experience, parental education, science achievement, science education, STEM education, TIMSS

INTRODUCTION

The need for personnel to fill the science, technology, engineering, and mathematics (STEM) pipeline has become increasingly pertinent globally, and science education is tasked with helping fill this critical gap (Marginson et al., 2013). In recent decades, the calls for educational reforms that produce conducive teaching and learning environments geared towards improving science and mathematics education have dominated the discussion on science education (Darling-Hammond et al., 2020). Notwithstanding the importance of scientific knowledge and technological developments to a nation's economic development, many children seem to be losing interest in science (Cheryan et al., 2015; Wigfield et al., 2015). The declining enrollment in

STEM fields of study and employment is an international phenomenon of growing concern (Marginson et al., 2013). In their attempt to address the challenges mentioned earlier, the global response has been multifaceted; England, Germany, and the USA have invested in world-class STEM educational programs to equip students for the Fourth Industrial Revolution (Penprase, 2018).

South Korea has implemented a science, technology, engineering, arts, and mathematics (STEAM) program, which incorporates the arts to foster students' creativity and design thinking to improve achievement in STEM (Kang, 2019). Japan has turned to tougher content requirements and more stringent STEM standards to enhance the quality of students for future STEM careers (Marginson et al., 2013). To improve students' science achievement and advance scientific literacy in general, the USA has undertaken considerable restructuring in science education (Beatty & Schweingruber, 2017). The most prominent result of these restructuring processes is the birth of the next generation science standards (NGSS) (Bybee, 2014). This new science education standard offers disciplinary science content, scientific practices, and crosscutting concepts across all the science disciplines to provide pre-collegiate (or K-12 in the USA) students with an internationally benchmarked K-12 science education (NGSS Lead States, 2013).

Educational leaders across multiple countries are implementing measures to tackle the lack of students and workers in the STEM fields. These measures cannot be completed without investigating what happens in science classrooms worldwide. In this regard, the authors set out to investigate perceived teaching practices that seek to promote conceptual understanding of science/STEM concepts across five industrialized countries in some geographical regions of the world, like Africa, Asia, Europe, Oceania, and North America. The selection of the industrialized countries was based on the United Nations Industrial Development Organization (UNIDO) competitive industrial performance (CIP) report 2020. UNIDO measures industrial competitiveness using the CIP index by ranking countries using a composite index based on the following dimensions: capacity to produce and export manufactured goods; technological deepening and upgrading; and world impact (UNIDO, 2021).

The authors selected the countries based on their regional leadership according to the CIP index and the availability of trends in international mathematics and science study (TIMSS) study data. The authors selected Australia, representing the geographical region of Oceania, England (Europe), Japan (Asia), South Africa (Africa), and the USA (North America) based on the criteria stated above. England is the exception in that it is not the most industrialized country in Europe; data from the country's TIMSS study was used because of its global stature. In Asia, though China is the most industrialized country based on the CIP index, the authors used Japan in this analysis because Japan is equally industrialized, and the TIMSS 2019 data for mainland China were not available, which is why Japan was used in the data analysis. Based on the above criteria and justifications, TIMSS 2015 and TIMSS 2019 grade 8 data from students and their science teachers in Australia, England, Japan, South Africa, and the USA were in the investigation of the effect of perceived teaching practices on students' conceptual understanding. Note that in this article as the authors describe teaching practices, they are describing perceived, self-reported teaching practices.

Students declare an interest in science and other STEM-related subjects based on their preference for teaching techniques and how they perceive science's usefulness in their everyday life (Hasni & Potvin, 2015). Constructivist teaching approaches, such as the conceptual change model, place students in an environment to build their understanding and apply their deep understanding of scientific concepts to everyday phenomena (Addido et al., 2022, Cairns, 2019). Several factors have been connected to students' achievement in STEM courses; amongst them are teachers' instructional practices. Though not a prominent factor, it is worth looking at the relationship between teachers' instructional practices and students' achievement as well as other factors (Han et al., 2021; Larsen & Jang, 2021) because instructional practices that enhance conceptual understanding have been connected to student achievement (Eriksson et al., 2019; O'Dwyer et al., 2015).

Focusing on the global STEM skills crunch and the need for science education to help proffer solutions, it's crucial to look at international comparison studies such as the TIMSS. The literature points out that students lack interest in science and STEM-related fields partly due to teaching practices that disconnect science concepts from students' daily lives (Anggoro et al., 2019; Bigozzi et al., 2018), and some studies show how the real-world connection makes the STEM interest stronger (Bicer & Lee, 2023; Burrows et al., 2014, 2018).

Therefore, looking at how teachers across the world implement teaching practices to create interest in science and promote conceptual understanding of science concepts will help to proffer empirically based solutions.

Research Purpose

The authors examined the effect that teaching for conceptual understanding practices had on grade 8 (middle school pupils aged 14-16) students' science achievement scores in the TIMSS 2015 and TIMSS 2019 tests. The objective was to ascertain how the variable of interest (teaching for conceptual understanding) correlates with and predicts students' science achievement scores. Additional variables (socioeconomic status [SES], gender, parental education, and teacher years of teaching) were included to help understand how significant the variable of interest is in affecting students' science achievement. Conceptual understanding entails equipping students with the requisite skills to develop the ability to deeply understand and transfer knowledge gained on a topic, build on it, and become creative with knowledge in a relevant way (Moser & Chen, 2016); it also includes the ability of students to apply learned scientific concepts to phenomena and problem-solving in everyday life (Syuhendri, 2017).

The TIMSS data allows for studying the factors that affect students' achievement in the teaching and learning context within individual countries (Mohtar et al., 2019). The authors used the TIMSS data to compare teaching for conceptual understanding practices in the five industrialized countries and also ran multiple regression analyses to investigate how teaching for conceptual understanding practices correlated and predicted science achievement scores. The following research questions guided the study:

1. How do science teachers' self-reported conceptual understanding teaching practices differ across Australia, England, Japan, South Africa, and the USA?
2. What effect does the perception of teaching for conceptual understanding, home possessions, and parental education have on students' science achievement in TIMSS across Australia, England, Japan, South Africa, and the USA?
3. How do teacher experience, parental education, and home possessions predict students' science achievement in the selected countries?
4. To what extent do teaching for conceptual understanding practices explain variations in science achievement scores compared to other factors such as SES and teacher experience?

LITERATURE REVIEW

Teaching for Conceptual Understanding

The theoretical perspective of constructivism guided this study as a philosophy of learning. Constructivism is the belief that learners construct knowledge instead of merely receiving it. In a constructivist classroom, students are not just given information via a textbook but are expected to repeat explanations of scientific concepts. Instead, they have the liberty to explore the concepts and construct a peculiar understanding of the topic through personal discoveries (Deliberto, 2014). Teaching for conceptual understanding is one principal objective of science education (Duit & Treagust, 2003; Syuhendri, 2017); the challenge is how to teach for conceptual understanding. A significant barrier to teaching conceptual understanding is the penchant to employ direct instruction in teaching science concepts (Ullah & Iqbal, 2020).

Student-centered instruction that allows students to work collaboratively in designing activities and knowledge construction positively contributes to conceptual understanding (Schwortz & Burrows, 2021; Vosniadou, 2013). Not everyone supports this instructional approach, and some are of the view that this method of teaching science concepts can alienate low achievers, and it also lacks the rigor of real science learning (Lu & Zhang, 2013; Sampson & Blanchard, 2012). The authors claim that this assertion ignores that the ability to work in teams is a 21st century skill set that students need to acquire to thrive in a STEM environment (Moore et al., 2020). When students share their thinking with peers, they build confidence in their ideas and allow others to consolidate their understanding (Mills, 2019).

Instructors' teaching practices constitute essential variables in explaining differences in students' disciplinary achievement at both the class and school levels. However, establishing a concrete relationship between specific teaching practices and student achievement is challenging. The difficulty stems from the lack of data on students' prior achievement, which can help to infer that a particular teaching approach improves achievement scores or because there are high-achieving students in the class (O'Dwyer et al., 2015). However, some studies have provided evidence to link teaching practices to student achievement. In their research that investigated the effects of expert scaffolding in science-related professional development, PD for elementary school teachers found that teachers' instruction was a substantial mediator of student achievement (Kleickmann et al., 2015). Others found that teachers' skills used in teaching mathematics are positively connected with improvements in students' mathematical achievement (Abdul Hamid & Kamarudin, 2021).

Teachers instructional practice measures examined in their analysis had statistically significant associations with student achievement after controlling for other school-level and student-level characteristics (Richman et al., 2019). The teaching practices referred to in the literature are fundamental for developing students' positive educational outcomes (Mohtar et al., 2019). Specifically, the authors of this study investigated science teaching practices that promote students' conceptual understanding based on teacher responses to the "How often" item in the 2015 and 2019 TIMSS teacher questionnaires. The authors focused on what TIMSS 2015 and TIMSS 2019 data would reveal about the connections between teachers' instructional practices and student achievement across five countries (Australia, England, Japan, South Africa, and the USA).

Possible Predictors of Science Achievement

Students' achievement in science is affected by multiple factors. The literature that examines students' science and math achievement lists factors such as SES, gender, parental education, and teacher years of teaching as some of the factors that feature prominently in determining achievement in science and math (Ersan & Rodriguez, 2020; Harju-Luukkainen et al., 2020; Kudari, 2016). In this study, the factors listed were used in regression analysis to ascertain the predictive power of each predictor with regard to students' science achievement scores. In the sections below, an in-depth review of the literature is carried out on the possible predictors of students' science achievement.

Socio-economic status

SES is commonly considered among the main variables in student performance (Gobena, 2018; Takashiro, 2016). Students with higher family SES are found to have much higher educational achievement than those having poorer family resources and vice versa (Caponera & Losito, 2016; Harju-Luukkainen et al., 2020; Tomul & Savasci, 2012). Data from the TIMSS study provides information on SES pointers connected to student achievements, such as home possessions, the number of books at home, and parental education. The analysis of TIMSS data has shown positive connections between student achievement and SES variables (Bouhlila, 2015; Byun & Kim, 2010; Takashiro, 2016). However, some studies show that the relationship between SES and student achievement is insignificant (Gobena, 2018; Koban Koc, 2016). It is worth noting that most studies show SES to be a significant variable in terms of student achievement in TIMSS (Harju-Luukkainen et al., 2020). Despite these findings, some definite variables within the SES spectrum have been analyzed using TIMSS data. The results show that the number of books, home resources, and parental education (as student SES variables) had a positive influence on student mathematics and science achievement (Geesa et al., 2019; Hojo, 2011; Martin et al., 2016; Takashiro, 2016).

Home possessions

Home possessions as a variable in analyzing TIMSS data is a recent development (Takashiro, 2017), but its gaining popularity among educational researchers. Studies show that different home possessions are positively related to student scores (Geesa et al., 2019; Hojo, 2011; Yoshino, 2012). This justifies the usage of home possession as a variable since it includes digital devices such as tablets, mobile phones, and gaming systems which are integral items in the teaching and learning of STEM subjects in the 21st century classroom. Consequently, the effect of home possessions on students' science achievement was included and investigated in this study.

Parental education

In the literature, most international studies show connections between parental educational levels and students' achievement in science and mathematics (Sanchez et al., 2013; Tomul & Savasci, 2012; Wang & Shi, 2014; Zhao & Hong, 2012). One shows that parents' educational level and students' gender had a significant effect on students' science achievement in some selected East Asian countries (Trinh, 2020). Parents with higher education certificates can support the schoolwork of their school-going wards, thereby helping them improve their academic abilities (Takashiro, 2017). With this concept in mind, the variable 'parental education' from the 2015 and 2019 TIMSS data was included to investigate its effect on students' science achievement.

Teacher years of experience

Teacher experience has a statistically significant effect on students' science achievements, and the number of years a teacher has been in the classroom positively affects the performance of students in science and mathematics assessments (Atar & Atar, 2012; Polly et al., 2022; Şahin & Öztürk, 2018). A synthesis research study established that more experienced teachers significantly affected students' achievement scores (Kini & Podolsky, 2016). Another study found a significant relationship between teaching experience and students' mathematics achievement (Wiswall, 2013). Hong's (2012) analysis of TIMSS data from 1995 to 2007 showed that teaching experience positively affects mathematics achievement in unindustrialized nations.

METHODS

Data Collection

This is a quantitative study, and data used for this research were from TIMSS 2015 and TIMSS 2019 data across Australia, England, Japan, South Africa, and the USA. The instruments used are the achievement test for science, the student questionnaire, and the teacher questionnaire. TIMSS 2015 and TIMSS 2019 studies measured students' achievement in mathematics and science. The authors downloaded the relevant datasets for the respective countries from the IEA website. The TIMSS data provides population estimates of the mathematics and science performance of students in grade 4 and grade 8 in participating countries. The student and teacher responses were explicitly obtained from students who completed the study and their teacher (Foy, 2017). Therefore, the teachers and students do not represent the entire student population of the countries in this research but are a sample representation of the students and teachers in these countries (Bowd et al., 2021). The results of this research should be treated as a sample based on an analysis of students' and teachers' data and not a representation of all students and teachers in the selected countries.

Sample

The final analysis sample for each country was based on cleaned data files using the following criteria. First, students were matched with science teachers who completed the questionnaire. So, if a teacher did not complete the questionnaire, all students linked with that particular teacher were deleted from the data for analysis. Second, students with missing cases on the student-level variables (i.e., home possession and parental education) were removed from the analysis sample. Raw data are the uncleaned data of students who wrote the science achievement test in each country and the teachers who taught those students. The student IDs and achievement scores were linked with their home possession and parental education data and their science teachers, and the authors of this study deleted all duplicated cases.

Third, science teachers include all teachers teaching various science disciplines such as biology, physics, chemistry, and earth science. Fourth, students with more than one science teacher were removed from the analysis sample. This step ensured that only students whose science achievement scores could be linked with one science teacher were included in the analyses, an essential prerequisite for investigating the relationship between teachers' instructional practices and students' science achievement.

With these criteria, the total 2015 TIMSS grade 8 (middle school pupils aged 12-13) science student sample for all countries was 8,082 for Australia, 3,583 for England, 4,607 for Japan, 10,889 for South Africa, and 8,178 for the USA. The student sample for 2019 TIMSS were 7,167 for Australia, 2,034 for England, 4,312 for Japan, 19,929 for South Africa, and 8,178 for the USA. **Table 1** contains the statistics about the samples.

Variables

Using the TIMSS 2015 and TIMSS 2019 international database, the authors analyzed students and teachers based on the following variables: science achievement scores, home possessions, parental education,

Table 1. Statistics of students and teacher sample for TIMSS 2015 and TIMSS 2019

		Students				Teachers			
Country	Year	Raw data (N)	Removed data (N)	Analysis data (N)	Percentage removed (%)	Raw data (N)	Removed data (N)	Analysis data (N)	Percentage removed (%)
Australia	2015	10,338	2,256	8,082	21.82	1,037	272	765	26.23
	2019	9,060	1,893	7,167	20.90	739	140	599	18.95
England	2015	4,814	1,231	3,583	25.57	777	212	565	27.29
	2019	3,365	1,331	2,034	39.55	141	57	84	40.43
Japan	2015	4,745	138	4,607	2.91	171	4	167	2.34
	2019	4,446	134	4,312	3.01	155	1	154	0.65
South Africa	2015	12,514	1,922	10,592	15.36	319	9	310	2.82
	2019	20,829	900	19,929	4.32	536	9	527	1.68
USA	2015	10,221	2,043	8,178	19.99	530	110	420	20.75
	2019	8,698	1,900	6,798	21.85	468	49	419	10.47

Item	
a	Relate the lesson to students' daily lives
b	Ask students to explain their answers
c	Ask students to complete challenging exercises requiring them to go beyond the instruction
d	Encourage classroom discussions among students
e	Link new content to students' prior knowledge
f	Ask students to decide their own problem-solving procedures
g	Encourage students to express their ideas in class

Figure 1. Science teacher question items categorized as teaching for conceptual understanding (Figure created by the authors)

instructor teaching experience, and teaching for conceptual understanding. The student background questionnaire had items on the use of computers or tablets at home for homework, ownership of computers or tablets, sharing of computers/tablets, and having a desk, room, internet connection, mobile phone, and gaming system, which were grouped to form the "home possessions" variable. The "parental education" variable was created from the items "highest level of education of mother" and "highest level of education of father" in the student background questionnaire.

The "science achievement scores" variable is the mean of five plausible science test scores. From the science teacher questionnaire, the stand-alone item of "years been teaching" was used as the "teacher teaching experience" variable. The seven items under the section "about teaching the TIMSS class/class with the TIMSS students" in the science teacher questionnaire formed the teaching for conceptual understanding variable (**Figure 1**). The dependent was science achievement scores, and the four independent variables were home possessions, parental education, instructor teaching experience, and conceptual understanding.

Data Analysis

Data analysis was conducted with IBM SPSS statistics (version 28) software to run a series of multiple linear regression analyses. This was done to investigate the effect of home possessions, parental education, teacher experience, and teaching for conceptual understanding on students' science achievement. The authors used the hierarchical regression method to select the independent variables based on past research. Then the authors entered known predictors (independent variables) of student science achievement before adding the "teaching for conceptual understanding" variable into the model in SPSS. TIMSS employs a stratified two-stage cluster sample design so that sample statistics can represent the population appropriately. Several sampling weights are calculated for data analysis (Martin et al., 2013).

When using a large-scale dataset for analysis, the importance of using sample weights has been well documented (Arıkan et al., 2020). In this research, all plausible values, the student weight, the science teacher sampling weight, student weight, school weight, and the house weight were all applied to produce correct estimates of the sample (Foy, 2017). The independent variables were selected based on past research and have a solid theoretical basis, as explained in the literature review of this study. The analysis to answer the first research question involved the calculation of descriptive statistics for teachers' responses to the seven items on teaching for conceptual understanding.

The correlation analysis was used to answer the third research question. Multiple regression analyses were used to answer the second and fourth research questions. It is important to note that the authors assigned numerical scores to the teacher's responses with a value of 1 for the first response option (on the opinionnaire scale) and a value of 4 to the fourth option.

Thus, the lower the score, the more likely that the teacher reported consistently using that particular practice of teaching, and conversely, the higher the score, the less likely that the teacher reported consistently using that particular practice of teaching.

RESULTS

The results of this research study are presented in multiple forms. One is a graphical presentation of teachers' responses to how often they used the seven measures of teaching for conceptual understanding in the respective countries. Descriptive statistics are also presented to show how teachers' approaches to teaching for conceptual understanding compare across the five countries of interest. Lastly, tables are presented on the output from the multiple regression analysis.

In the TIMSS 2015, the results show that a large percentage of teachers in the five countries implemented the seven items on the teacher questionnaire every or almost every lesson, except in Japan. Specifically, the science teachers' response to teaching for conceptual understanding shows that a greater percentage of teachers reported that they encouraged students to express their ideas in class (63.66% in Australia, 68.14% in England, 54.19% in South Africa, and 64.76% in the USA) in every or almost every lesson. The exception was in Japan, where science teachers reported that they only encouraged students to express their ideas in about half the lessons (50.30%) instead of in every or almost every lesson (22.16%).

Overall, the results showed that a large percentage of teachers in the five countries implemented the seven items on the teacher questionnaire in every or almost every lesson, except in Japan, where most teachers report that they implemented teaching for conceptual understanding items in about half or some lessons.

Figure 2 provides details of the teachers' responses for each country. As a reminder, the teachers' practices discussed are the teachers' self-report of their practices.

The results from the TIMSS 2019 generally followed a similar trend to the TIMSS 2015. Teachers reported that they linked new content to students' prior knowledge in every or almost every lesson (63.60% in Australia, 69.05% in England, 66.41% in South Africa, and 73.75% in the USA). Once again, except for Japan, teachers in the four countries reported that they only link to prior knowledge in half the lessons or some lessons (74.03%) more than every or almost every lesson (25.97%). The teaching activity that instructors implemented the least was asking students to complete challenging exercises that required them to go beyond the instruction (3.90%).

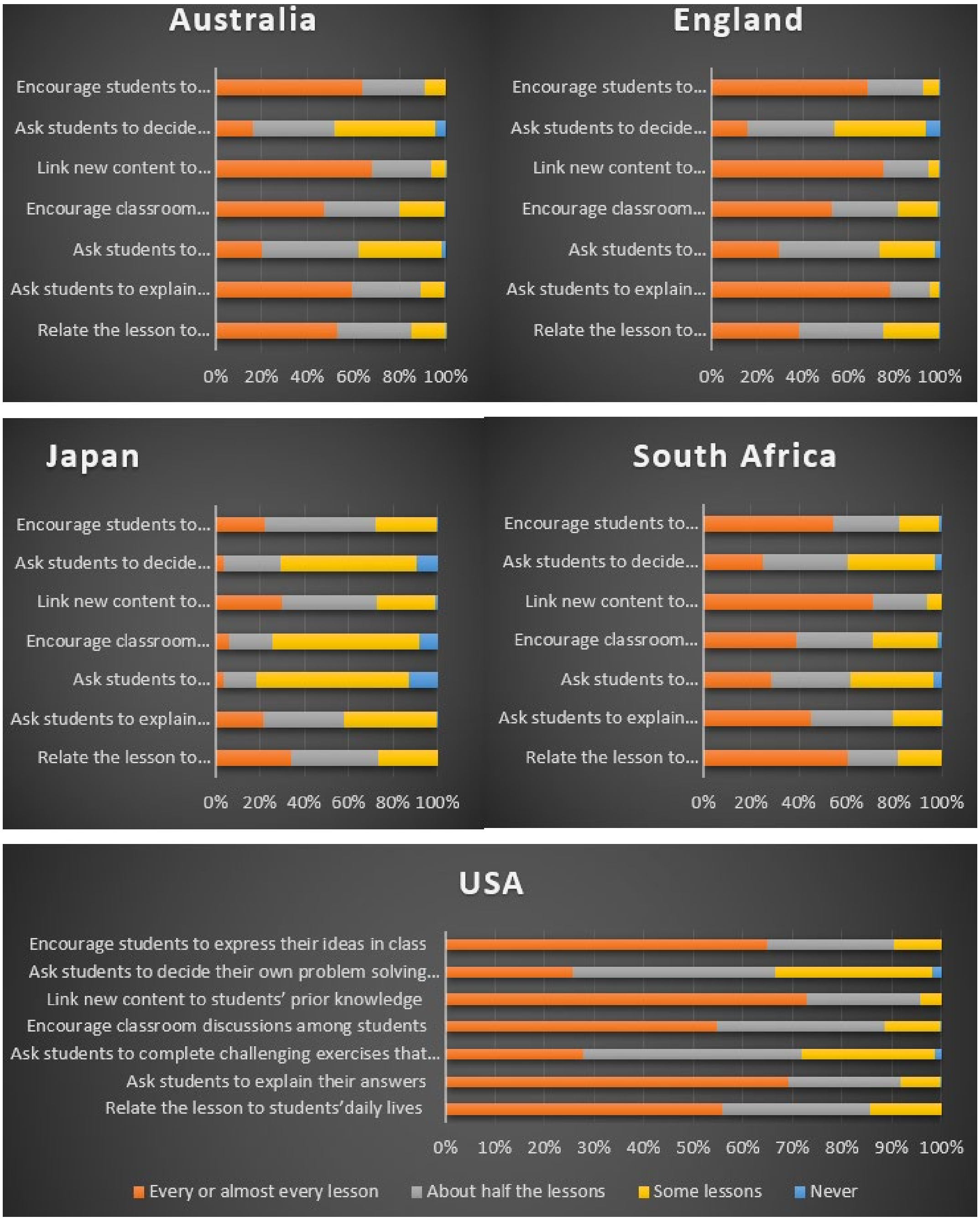

Figure 2. Science teachers teaching for conceptual understanding in TIMSS 2015 (Figure created by the authors)

Figure 3 details a country-by-country comparison. The descriptive statistics in **Table A1** and **Table A2** in **Appendix A** show that even when science teachers in different countries implemented a teaching for conceptual understanding item in large percentages, there were differences in their mean approaches. In TIMSS 2015, science teachers in most of the countries reported in high percentages that they asked students to explain their answers, but it was in England (mean [M] = 1.27, standard deviation [SD] = 0.547) that students encountered this in every or almost every lesson closely followed by USA (M = 1.40, SD = 0.645), Australia (M = 1.52, SD = 0.689), and South Africa (M = 1.76, SD = 0.782), respectively.

The results from TIMSS 2019 were generally not different from the 2015 TIMSS. Teachers in the USA report more frequently how their science teaching involved all seven items on the questionnaire. Even on items that teachers report that they do not frequently implement in their classrooms, teachers in the USA reported doing it more regularly than their colleagues in other countries.

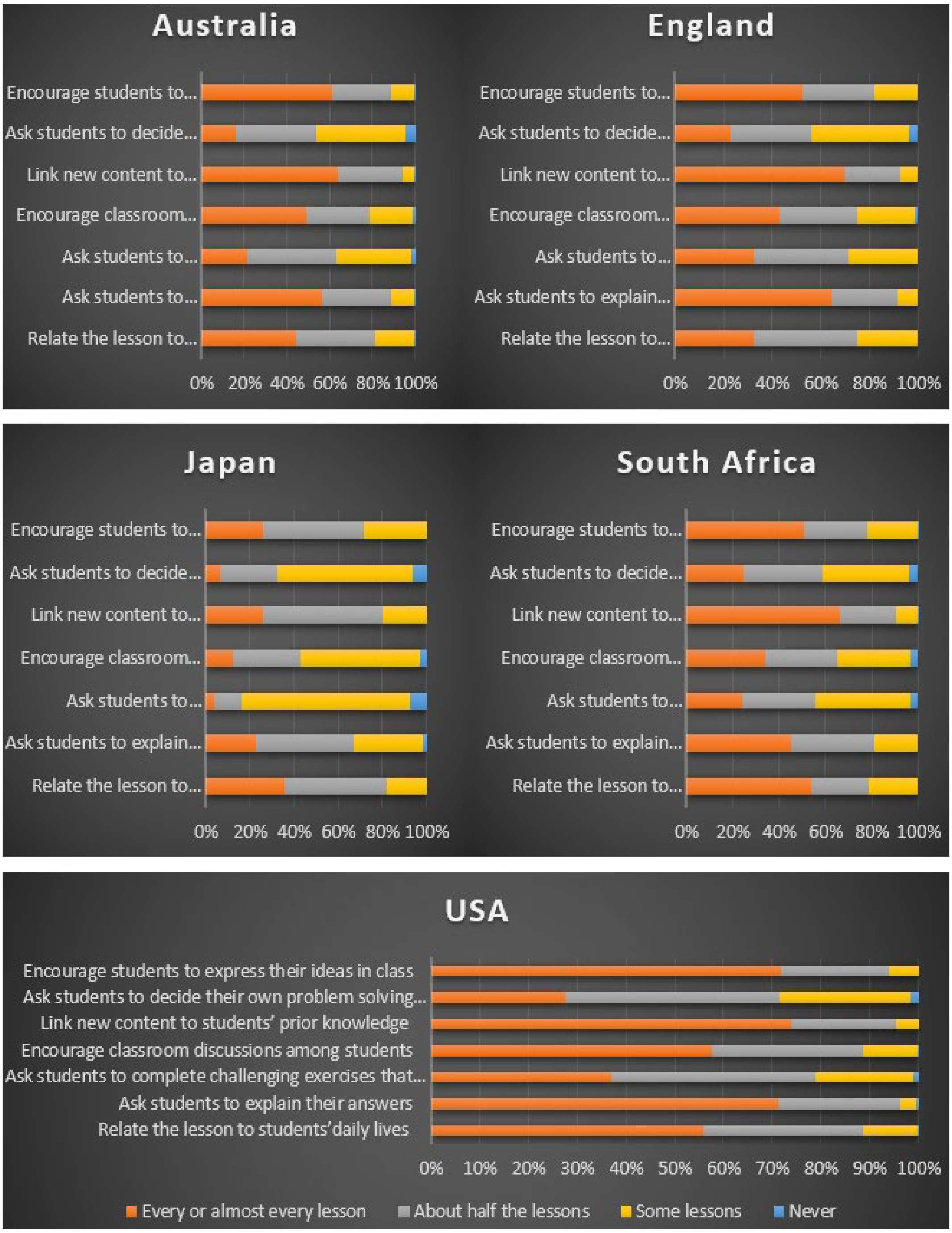

Figure 3. Science teachers teaching for conceptual understanding in TIMSS 2019 (Figure created by the authors)

In this research study, the authors used the hierarchical regression method of the multiple linear regression model (Field, 2014). All assumptions were checked and met, e.g., independent observations (used SPSS 'identify duplicate cases' to ensure that the sample for each country's observations applied to a different student or teacher), no independent errors (Durbin-Watson), normality (histogram and P-P plots), multicollinearity (variance inflation factor [VIF] values), homoscedasticity and linearity (scatterplot of residuals versus predicted values) (Field, 2014).

The correlation matrix is valuable in providing a general idea about the relationships between the independent variables and the dependent variable.

Table 2 and **Table 3** provide details on the Ms, SDs, and Pearson correlation for all the variables used in the analysis.

Table 2. Ms, SDs, and Pearson correlations between the dependent and independent variables in TIMSS 2015

		1. Science achievement scores	2. Teaching for conceptual understanding	3. Home possessions	4. Parental education	5. Teacher years of teaching
Australia	N	8,082	8,082	8,082	8,082	8,082
	M	523.233	1.741	1.142	6.142	13.280
	SD	80.501	.486	.154	1.882	10.182
	1	1.000	-.084*	-.170*	.072*	.082*
England	N	3,583	3,583	3,583	3,583	3,583
	M	544.870	1.680	1.113	6.543	11.340
	SD	74.815	.459	.128	1.816	9.393
	1	1.000	-.147*	-.174*	-.106*	.116*
Japan	N	4,607	4,607	4,607	4,607	4,607
	M	571.678	2.408	1.220	5.614	17.700
	SD	70.746	.447	.180	1.757	11.953
	1	1.000	-.048*	-.019	.022	-.038**
South Africa	N	10,592	10,592	10,592	10,592	10,592
	M	363.277	1.792	1.474	4.717	14.320
	SD	95.599	.529	.255	2.121	9.660
	1	1.000	-.036*	-.324*	.226*	.031*
USA	N	8,178	8,178	8,178	8,178	8,178
	M	530.780	1.627	1.154	5.489	13.220
	SD	76.5181	.473	.163	1.959	9.027
	1	1.000	-.018	-.171*	.101*	-.007

Table 3. Ms, SDs, and Pearson correlations between the dependent and independent variables in TIMSS 2019

		1. Science achievement scores	2. Teaching for conceptual understanding	3. Home possessions	4. Parental education	5. Teacher years of teaching
Australia	N	7,167	7,167	7,167	7,167	7,167
	M	548.554	1.761	1.066	6.092	12.770
	SD	81.47709	.49769	.131	1.831	10.777
	1	1.000	-.105*	-.156*	.057*	.043*
England	N	2,034	2,034	2,034	2,034	2,034
	M	524.176	1.837	1.118	6.393	11.690
	SD	86.893	.514	.142	1.923	7.323
	1	1.000	-.039**	-.091*	-.077*	.021
Japan	N	4,312	4,312	4,312	4,312	4,312
	M	570.608	2.287	1.170	5.833	14.830
	SD	67.926	.454	.141	1.734	11.906
	1	1.000	-.050*	-.055*	.004	.009
South Africa	N	19,929	19,929	19,929	19,929	19,929
	M	392.720	1.844	1.327	5.051	15.090
	SD	99.550	.572	.238	2.037	10.394
	1	1.000	.085*	-.375*	.210*	.050*
USA	N	6,798	6,798	6,798	6,798	6,798
	M	532.084	1.547	1.109	5.696	13.140
	SD	92.455	.438	.145	1.998	8.769
	1	1.000	-.107*	-.230*	.144*	.164*

A look at **Table 3** for TIMSS 2015 data showed that Pearson's correlation coefficient between teaching for conceptual understanding and science achievement scores is a negative correlation for Australia (r = -.084), England (r = -.147), Japan (r = -.048), South Africa (r = -.036), and the USA (r = -.018). Students' parental education had a positive correlation with science achievement scores in four countries; Australia (r = .072, p < .001), Japan (r = .022, p < .072), South Africa (r = .226, p < .001), and the USA (r = .101, p < .001) but a negative correlation in England (r = -.106, p < .001).

In TIMSS 2019 (**Table 3**), the correlation results were similar to 2015, with most countries having a negative correlation between teaching for conceptual understanding and science achievement scores. In Australia (r = -.105, p < .001), England (r = -.039, p < .05), Japan (r = -.050, p < .001), and the USA (r = -.107, p < .001), the correlations were negative, but South Africa (r = .085, p < .001) bucked the trend with a positive correlation. The education of parents had a positive correlation with students' science achievement scores in Australia

Table 4. Regression model summary of all countries for TIMSS 2015

Model		R	R^2	R^2_{adj}	F	df1	df2	p	Durbin-Watson
1	Australia	.222*	.049	.049	105.048**	4	8,077	< .001**	1.598
	England	.274*	.075	.074	72.492**	4	3,578	< .001**	.830
	Japan	.065*	.004	.003	4.813**	4	4,602	< .001**	1.712
	South Africa	.372*	.138	.138	425.211**	4	10,587	.000**	1.103
	USA	.193*	.037	.037	78.733**	4	8,173	< .001**	1.064

* Predictors: (Constant), teaching for conceptual understanding, home possessions, parental education, teacher years of teaching
** Dependent variable: Science achievement scores

Table 5. Regression model summary of all countries for TIMSS 2019

Model		R	R^2	R^2_{adj}	F	df1	df2	p	Durbin-Watson
1	Australia	.199*	.039	.039	73.491**	4	7,164	< .001**	1.703
	England	.129*	.017	.015	8.528**	4	2,029	< .001**	1.681
	Japan	.075*	006	005	6.024**	4	4,307	< .001**	1.845
	South Africa	.416*	.173	173	1,044.284**	4	19,924	< .001**	1.457
	USA	.312*	.097	.097	182.563**	4	6,793	< .001**	1.657

* Predictors: (Constant), teaching for conceptual understanding, home possessions, parental education, teacher years of teaching
** Dependent variable: Science achievement scores

(r = .057, p < .001), Japan (r = .047, p < .001), South Africa (r = .210, p < .001), and the USA (r = .144, p < .001) but a negative correlation in England (r = -.077, p < .001).

Table 4 and **Table 5** show the overall summary model output for all the five countries of interest in this research. The multiple regression reveals that for Australia (R = .222), the model predicts 22.2% of students' science achievement. The R^2 value of 0.049 indicates that 4.9% of the variation in science achievement scores can be explained by the model using the independent variables teaching for conceptual understanding, home possessions, parental education, and instructors' years of teaching.

The models explained 7.5%, 0.4%, 13.8%, and 3.7% of the variation in science achievement scores for England, Japan, South Africa, and the USA, respectively. The TIMSS 2019 results showed that for Australia (R = .199), England (R = .129), Japan (R = .075), South Africa (.416), and the USA (.312), the model predicted 19.9%, 12.9%, 7.5%, 41.6% and 31.2% of students' science achievement scores, respectively. The results show that in Australia, parental education (B = 3.031) and teacher years of teaching (B = .751) have a positive relationship with science achievement scores(See supplementary material).

The decrease in science achievement scores as teaching for conceptual understanding increases by a unit is an occurrence across all countries. The t-statistic showed that in Australia, teaching for conceptual understanding is t(8077) = -8.829, p < .001, in England, it's t(3578) = -9.443, p < .001, in Japan it's t(4602) = -2.908, p = .004, in South Africa it's t(10587) = -2.749, p = .006, and in the USA, it's t(8173) = -1.912, p = .056. The 2019 TIMSS data analysis showed that the independent variable of interest in this research, teaching for conceptual understanding, had a negative relationship with science achievement scores in all countries except South Africa (see **Appendix A**).

DISCUSSION

The authors of this research study examined two main issues. First, the study focused on how teaching conceptual understanding differs across five major industrialized countries on different continents. Secondly, it investigates the effect of teaching for conceptual understanding on middle school students' science achievement scores. The researchers analyzed data from two TIMSS studies, 2015 and 2019. The results showed that science teachers across four countries of interest generally employed teaching conceptual understanding practices in teaching their students that participated in the TIMSS study. However, Japanese teachers whose responses were used in this research did not use teaching for conceptual understanding practices in their classrooms. These results align with other studies (O'Dwyer et al., 2015) in their study that looked at the relationship between teachers' instructional practices and students' achievement in mathematics across four countries.

The results also showed that the various teaching practices categorized as teaching for conceptual change varied across countries. Analysis from the 2015 TIMSS data revealed that teachers in Australia, England, South

Africa, and the USA encouraged their students to express their ideas in class. However, teachers in Australia, England, and the USA employed this practice 10% of the time more than their counterparts in South Africa. This variation in the employment of perceived teaching practices across countries is supported by the study of O'Dwyer et al. (2015). As a reminder, the authors discuss teaching practices, and are referring to the self-reported, perceived teaching practices. Considering this, the pattern of variability in the usage of teaching practices for conceptual understanding can be seen in the 2019 TIMSS data results. The findings again question the significance of teaching conceptual understanding practices to students' science achievement scores.

In investigating the effect of teaching for conceptual understanding on students' science achievement, Pearson's correlation coefficient results indicated a negative correlation between perceived teaching for conceptual understanding and science achievement scores in the five countries. This result contradicts the conclusions from the studies of Kleickmann et al. (2015), Abdul Hamid and Kamarudin (2021), and Richman et al. (2019). However, it supports the position of O'Dwyer et al. (2015) when they asserted that it is difficult to infer that a particular teaching approach improves achievement scores. Students' home possessions correlated negatively with science achievement scores for all countries, which contradicts studies that showed home possessions positively correlated with student scores (Geesa et al., 2019; Hojo, 2011; Yoshino, 2012).

The authors posit four main areas for the negative correlation that require further study. First, the authors believe that teaching (and assignments that lead to achievement scores) is more fact-based than conceptually based. Thus, there is a mismatch of how teachers instruct versus how they assess student learning (rote, siloed understanding versus conceptual understanding). Secondly, teaching for conceptual understanding necessitates more instructional time and student interactions to solidify new information. This additional time requirement may negatively impact on student achievement scores, as students may not have sufficient opportunity to become familiar with standardized test questions or to fully grasp the concepts being taught.

Thirdly, if there is a misconception in the conceptual understanding, then it could be exacerbated or applied incorrectly when recalling information. Fourthly, students might mistakenly think that preparing for a test is easier with conceptual understanding and might spend less time studying for conceptual understanding assessments as well as regular assessments. Therefore, following a unit or lesson focused on conceptual understanding, students may benefit from having basic facts explicitly outlined, additional time for reflection and comprehension, opportunities to address misconceptions, and clear guidance on the distinction between what conceptual understanding is and what it is not.

Parental education positively correlated with science achievement scores in four countries; Australia, Japan, South Africa, and the USA, but negatively correlated in England. The correlation between parental education and student achievement in South Africa ($r = .210$, $p < .001$) reflects a small to moderate effect size. Although this is statistically significant, the effect size indicates that parental education alone explains only a small portion of the variation in students' science achievement. This suggests that other factors, such as school resources or teacher quality, may play a larger role in determining student outcomes. This is in line with the studies done by Sanchez et al. (2013), Tomul and Savasci (2012), Wang and Shi (2014), and Zhao and Hong (2012). They concluded that parental education is positively connected to students' achievement. However, the result from England is difficult to explain and may require further investigation to come up with a plausible reason.

The multiple regression coefficients buttressed the interpretation of the result from the correlation coefficients. The B values for almost all countries indicated that when teaching for conceptual understanding increased by one point, science achievement scores decreased by some units when the other independent variables were held constant. The regression model for Australia in TIMSS 2015 shows that teaching for conceptual understanding, home possessions, parental education, and teacher experience together explain only 4.9% of the variance in science achievement ($R^2 = 0.049$). This small effect size indicates that the model does not capture many other factors likely influencing student performance, such as school resources, student motivation, or instructional quality. Therefore, the practical significance of these findings is limited, and further research is needed to identify stronger predictors of science achievement.

The results from this research demonstrate that the factors that influence student achievement are numerous and diverse; hence there is no single silver bullet solution. A multifaceted approach addressing all possible variables would lead to more productive results. Results indicate those science teachers in Australia, England, South Africa, and the USA are similar in their perceived teaching approaches. The teachers from Japan who reported predominantly that they did not employ these teaching practices have their students performing better than similar industrialized countries (Takashiro, 2017). It would be worth investigating how teachers in Japan interact with their students pedagogically to find out how it influences their science achievement. In Japan, responses about using teaching practices that support conceptual understanding varied significantly from that of the other four countries. This is quite surprising because, in past TIMSS studies, such as in TIMSS 1999, Japanese teachers reported using teaching for conceptual understanding practices in greater percentages such practices (Mullis et al., 2000; O'Dwyer et al., 2015). However, the data from the stacked bar charts in this research study indicate that Japanese teachers' teaching for conceptual change may have changed.

The excellent performance of Japanese students in international standardized tests such as TIMSS means the teaching practices of Japanese teachers have been of interest to experts in the educational field. The research on the teaching practices of Japanese teachers points to building a shared knowledge base about instruction, interest in students' scientific thinking, and enhancing teacher content knowledge through lesson study (Corcoran, 2011; Lewis & Hurd, 2011; Lewis & Takahashi, 2013). The lesson study creates an opportunity for teachers within a district to meet and work on how to teach a science topic over many years, using feedback from colleagues to improve teaching in their schools (Lewis & Takahashi, 2013). A significant feature of the lesson study is that teachers work together by studying teaching materials and examining what is currently known about teaching and learning a particular topic of interest (Burrows & Borowczak, 2019; Lewis et al., 2011).

The authors infer that lesson study, an approach to collaborative teaching, makes Japanese teachers see themselves as implementers of collaboratively designed teaching practices rather than carrying out individual teaching items as listed in the TIMSS science teacher questionnaire. This could be why science teachers in Japan responded in low percentages to the items that constitute teaching for conceptual understanding.

Teachers' years taught correlated positively and predicted students' science achievement scores across all countries. This result is supported by the findings of Atar and Atar (2012), Polly et al. (2022), and Şahin and Öztürk (2018). In science education, policymakers and governments could incentivize teachers for the length of their teaching careers. The current high attrition rate amongst teachers in the USA, some due to poor conditions, events such as COVID-19, and other factors, should be addressed as a matter of national urgency to bolster the school-to-STEM career pipelines.

In interpreting the results presented in this study, a number of limitations should be considered. The first limitation is that the TIMSS questionnaire data are based on self-reported data (perceived teaching practices), and there could be incorrect responses from students and teachers. Secondly, because of the difference in the raw and analyzed samples, bias may have been introduced with the deletion of students' and teachers' cases due to missing data or duplication. Third, another limitation is that findings cannot be used to make declarations of causality regarding the relationships between teachers' teaching for conceptual understanding and students' science achievement scores. Fourth, the authors do not intend to overstate the significance of the findings, as more systematic research on verifiable observational data on how teaching conceptual understanding practices affects learning outcomes. Fifth, there are published critical analyses of the limitations of using a mean score to represent a set of opinionnaire responses (even if one can claim that all the items are addressing the same dimension). The individual items might vary in the extent to which they affect the dependent variable (Sullivan & Artino, 2013).

The authors acknowledge that the reliance on self-reported teaching practices, although acknowledged in limitations, could be further problematized, especially regarding cross-cultural validity. As such, the validity of self-report data across diverse cultural settings remains an open methodological challenge.

This research contributes to the literature in several ways. The authors used TIMSS data from two different years to compare how instructors perceive teaching conceptual change practices across five industrialized countries. The authors present results on how teaching for conceptual understanding predicts students' science achievement compared to other variables from the literature. Another factor to consider is that given the large number in the mass data sets, it is not surprising that low statistical results can be declared statistically significant. However, it is necessary to clarify for the reader that the statistical significance only indicates that the results are not likely due to chance and that this does not necessarily indicate the magnitude of the results. Several of the correlation results are low in value and can only possibly indicate that there is no definable relationship between teachers' perceived practices and achievement score outcomes (as the results for the correlation are effectively 'zero').

The study used multiple regression models to examine how teaching conceptual understanding, along with other factors such as teacher experience and parental education, influenced students' science achievement scores. Despite the statistical significance of many of the relationships, the effect sizes were generally small, indicating that these factors accounted for only a modest amount of the variance in student outcomes. For instance, the regression analysis revealed that in Australia, the model explained only 4.9% of the variance in science achievement scores. Similarly, for England, the variance explained was 7.5%, and for Japan, it was only 0.4%. This suggests that while the model identifies factors that influence science achievement, the actual impact of these factors, as reflected by the R^2 values, is relatively small.

A key finding was the negative relationship between teaching for conceptual understanding and science achievement. For example, in Australia, the correlation between teaching for conceptual understanding and science achievement was negative ($r = -.084$), and even though it was statistically significant, the small effect size ($r = -.084$) suggests that the practical impact of this relationship is minor.

This pattern was observed across most countries, with teaching for conceptual understanding having little practical significance despite its statistical significance. In summary, the study has found connections between teaching methods and student performance. However, the small impact suggests that these methods only account for a small part of the variations in science achievement. Therefore, other factors like school resources and student motivation are probably more influential in determining student success. Future research should investigate these additional factors.

Thus, the results presented in this research can contribute to the knowledge of the science education community by further explaining the effect of instructors' perceived teaching practices on students' science learning and achievement.

CONCLUSION

This research aimed to assess the effect of the teaching practices categorized as 'teaching for conceptual understanding' on grade 8 students' science achievement scores using TIMSS 2015 and TIMSS 2019 data from Australia, England, Japan, South Africa, and the USA. The analysis samples included 75264 students' and 4010 teachers' data across the five countries of interest. The authors used descriptive statistics and graphical presentations to show teachers' responses to how often they used the seven measures of teaching for conceptual understanding in the respective countries. Multiple regression analyses were employed using the variables; teaching for conceptual understanding, home possessions, parental education, and teacher years of teaching to predict students' science achievement scores. The results showed that teaching conceptual understanding correlated negatively with students' science achievement scores and weakly predicted science achievement scores.

Instructors' teaching experience, however, correlated positively with students' science achievement scores and strongly predicted students' science achievement across all countries in both TIMSS 2015 and TIMSS 2019. The results also showed that instructors' teaching practices weakly accounted for the difference in students' science achievement scores in the five countries, even though a more significant percentage of teachers reported that they employed teaching for conceptual understanding practices in their classrooms. This study has implications for the teaching of science for conceptual understanding and student preparation to meet the global STEM challenges of the 21st century. This study provides insights into how teachers in some of the major industrialized countries engage in teaching practices that seek to promote conceptual understanding of science concepts. It is important to note that although statistical significance has been established, the practical impact of the predictors is modest. Thus, teachers and teacher educators across the globe should take these implications with an understanding of the potential limitations of the magnitude of the results. This clarification seeks to provide a more balanced understanding of the results.

The findings also have implications for how teaching practices for conceptual understanding are characterized by teachers in different countries. The case of Japan, where teachers seem to employ teaching practices that promote conceptual understanding but did not respond in the affirmative in answering the questionnaire queries, raises the question, "What constitutes teaching practices that promote conceptual understanding?" This study points to important further research on using mass data sets as predictors of classroom science achievement, but it also exhibits some of the limitations such data represent when the research instrument (i.e., opinionnaire used by the TIMMS) might be a weak proxy for the actual classroom practice that the researchers do not have access to study in such large numbers. Overall, there is a need to develop a universally accepted description of teaching practices that can be depicted as promoting conceptual understanding, which could help ensure that self-reported data on such teaching practices will be consistent, valid, and very useful to the conduction of comparative research studies.

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Data availability: Data generated or analyzed during this study are available from the authors on request.

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APPENDIX A

Table A1. Multiple regression coefficients for predicting science achievement scores TMSS 2015

		Constant	Teaching for conceptual understanding	Home possessions	Parental education	Teacher years of teaching
Australia	B	622.235	-16.119	87.137	-3.031	.751
	SE	7.773	1.826	5.669	.464	.087
	β	-	-.097	-.167	.071	.095
	t	80.048	-8.829	-15.371	-6.532	8.617
	p	.000	< .001	< .001	< .001	< .001
England	B	713.396	-24.765	-100.921	--3.807	.907
	SE	12.323	2.622	9.505	.663	.128
	β	-	-.152	-.171	-.092	.114
	t	57.892	-9.443	-10.618	-5.738	7.077
	p	.000	< .001	< .001	< .001	< .001
Japan	B	595.857	-6.834	-7.455	.855	-.194
	SE	9.633	2.350	5.771	.593	.088
	β	-	-.043	-.019	.021	-.033
	t	61.854	-2.908	-1.292	1.442	-2.208
	p	.000	.004	.197	.149	.027
South Africa	B	492.048	-4.515	-110.907	8.071	.328
	SE	6.517	1.642	3.426	.412	.090
	β	-	-.025	-.296	.179	.033
	t	75.506	-2.749	-32.373	19.596	3.657
	p	.000	.006	< .001	< .001	< .001
USA	B	607.618	-3.363	-76.549	3.354	-.110
	SE	7.348	1.759	5.109	.426	.092
	β	-	-.021	-.163	.086	-.013
	t	82.687	-1.912	-14.982	7.877	-1.194
	p	.000	.056	< .001	< .001	.232

Note. Dependent variable: Science achievement scores

Table A2. Multiple regression coefficients for predicting science achievement scores TMSS 2019

		Constant	Teaching for conceptual understanding	Home possessions	Parental education	Teacher years of teaching
Australia	B	660.787	-17.250	-93.945	2.360	.305
	SE	9.074	1.899	7.210	.516	.088
	β	-	-.105	-.151	.053	.040
	t	72.820	-9.084	-13.029	4.576	3.475
	p	.000	< .001	< .001	< .001	< .001
England	B	622.999	-7.166	-57.871	-3.571	.158
	SE	18.847	3.750	13.546	.995	.263
	β	-	-.042	-.094	-.079	.013
	t	33.056	-1.911	-4.272	-3.587	.599
	p	< .001	.056	< .001	< .001	.549
Japan	B	615.605	-7.319	-26.229	.262	.060
	SE	10.531	2.276	7.333	.596	.087
	β	-	-.049	-.054	.007	011
	t	58.458	-3.216	-3.577	.439	.693
	p	.000	.001	< .001	.661	.488
South Africa	B	521.181	10.039	-146.295	8.185	.389
	SE	4.820	1.136	2.719	.317	.062
	β	-	.058	-.350	.168	.041
	t	108.124	8.839	-53.798	25.795	6.232
	p	.000	< .001	.000	< .001	< .001
USA	B	658.392	-21.270	-128.985	5.249	1.505
	SE	9.960	2.436	7.428	.538	.122
	β	-	-.101	-.202	.113	.143
	t	66.102	-8.732	-17.364	9.753	12.328
	p	.000	< .001	< .001	< .001	< .001

Note. Dependent variable: Science achievement scores