Int J of Sci and Math Educ (2026) 24:63
https://doi.org/10.1007/s10763-026-10687-7

Relationships Between Opportunity to Learn and Class Prior Attainment in Mathematics

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Received: 16 March 2025 / Accepted: 25 May 2026

Abstract

Students' opportunity to learn (OTL) in mathematics in terms of the curriculum they experience in school has largely been examined in relation to subsequent student attainment, with less attention paid to whether prior attainment is itself associated with later OTL. Furthermore, existing international studies have operationalised OTL in various ways, yet the relationship between prior attainment and OTL remains underexplored across these operationalisations and educational contexts. This study examines whether class-average prior attainment is associated with different operationalisations of OTL in mathematics. Secondary data analysis was conducted using data from the Global Teaching InSights video study of the teaching of quadratic equations across seven countries and jurisdictions. This analysis drew on student-reported, teacher-reported, and observational measures of OTL, focusing on content coverage and instructional quality. Multilevel and linear regression models were used to explore patterns of association between class composition and OTL. Associations between class-average prior attainment and OTL were modest and varied across contexts and operationalisations of OTL. Relationships with prior attainment differed between student-reported OTL, teacher-reported and observational measures, while class heterogeneity was more strongly associated with instructional quality than with content coverage. These findings highlight the importance of considering multiple operationalisations of OTL and suggest that relationships between prior attainment and OTL are context-dependent.

Keywords International comparison study · Mathematics attainment · Opportunity to learn (OTL) · Quadratic equations

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Published online: 03 June 2026

Introduction

Students within education systems can experience differentiated opportunities to learn (OTL). These differences may arise from various structures and policies within the system, from cultural expectations about what students should or could learn, or from variations in the decisions made by individual teachers. In this article, I aim to examine the relationship between OTL and mathematics attainment by providing new evidence from an international study of mathematics teaching, the Global Teaching InSights Video Study (TVS), which took place across eight countries and jurisdictions[1]. The design of TVS allows us to analyse the relationship between class-level prior attainment and OTL, specifically how class average prior attainment relates to the implemented and experienced curriculum. This addresses this opportunity through three research questions: (1) to what extent is average prior attainment of a mathematics class associated with OTL in the lessons that follow? (2) are there particular measures of OTL that are more strongly related to class prior-attainment than others? (3) Do relationships between class attainment and OTL depend on class heterogeneity?

To begin, I outline the conceptualisation of OTL before reviewing the literature on the association between OTL and student attainment in mathematics. The methodology section describes the data and variables used within this article, taken from the TVS dataset, alongside measures specifically derived for the analysis, which are subsequently described. The findings are then presented, discussed and conclusions are drawn.

Conceptual Framework

In the literature, distinctions are often made between the intended curriculum, the implemented curriculum, the attained curriculum, and the experienced curriculum (Bokhove et al., 2019; Schmidt & McKnight, 1995). The intended curriculum is specified by the country, state, or school as the content that needs to be addressed. The implemented curriculum is the content that is actually taught by a teacher, the attained curriculum is what students actually learn, usually as measured on tests (Schmidt & Maier, 2009; Travers & Westbury, 1989), while the experienced curriculum is measured through students' perspectives on what they learned (Bokhove et al., 2019). The concept of OTL is frequently used to operationalise and measure the implemented, experienced and attained curriculum, and to explore the relationship between these (Travers & Westbury, 1989). This concept rests on the idea that students are more likely to learn the content that they are taught. Early conceptualisations focused exclusively on time spent on instruction (Carroll, 1963). With the introduction of large-scale international assessments and the necessity to take into account differences in curricula across countries, measures of OTL began to also include content coverage (Husén, 1967), the cognitive demand of this content (Porter, 2002), as well as the quality of teaching (e.g., Kyriakides et al., 2013).

[1] For brevity, the term "countries" is used to refer to the TVS participating countries and jurisdictions.

OTL has been shown to be strongly associated with student attainment in these large-scale assessments (Klieme, 2013; Kurz et al., 2020; Schmidt & McKnight, 1995). Four types of OTL are currently used widely in research, initially distinguished by Stevens (1993): content coverage; content exposure; content emphasis; and the quality of instructional delivery. Content coverage refers to the curriculum topics covered. Content exposure refers to the time teachers allocate to cover the content. Content emphasis makes a distinction between topics that are treated as a major focus and those that are treated as a minor focus within the content. Quality of instructional delivery refers to how coherently and effectively teachers engage students with the content so that they can achieve.

Content coverage and exposure dominate the exploration of the associations between measures of OTL and mathematics attainment in most international studies, such as the OECD's Programme for International Student Assessment (PISA) and the IEA's Trends in International Mathematics and Science Study (TIMSS) (Cogan & Schmidt, 2015; Schmidt & Maier, 2009; Schmidt & McKnight, 1995; Wang et al., 2024). The measurement of OTL varies considerably, with studies like TIMSS focusing on teacher reports of content coverage and time spent on different topics at the classroom level, and PISA concentrating on student reports of content coverage and the quality of teaching at the individual student level (Cogan & Schmidt, 2015; Wang et al., 2024). Both PISA and TIMSS also include student- or teacher-reported measures of the quality of instructional delivery. Each of these measures has been used to examine the effect of OTL on mathematics attainment.

TVS combines these measurement types from PISA and TIMSS, with many items based on those developed in these studies. In addition, TVS includes observational data from videoed lessons and lesson materials. The design of TVS thus addresses all four aspects of Stevens (1993) conceptualisation of OTL. Furthermore, the longitudinal design enables this study to address a gap in the existing research that focuses on the effects of OTL on mathematics attainment by considering the effects of prior attainment on OTL.

Literature Review

OTL and Mathematics Attainment

In recent years, several meta-analyses and large-scale cross-sectional studies have examined the relationships between OTL and mathematics attainment (Luyten, 2017; Rolfe et al., 2021; Scheerens, 2017). The majority of these studies have reported a positive association between OTL and attainment, in particular that "more curriculum coverage of a topic area … is related to larger gains in that same topic area" (Schmidt et al., 2001, p. 261). Scheerens' (2017) overview of 51 studies focusing on OTL showed a moderate average effect size ($d = 0.30$) of OTL on student attainment, but highlighted the variation of effect sizes depending on the conceptualisation and operationalisation of OTL in the individual study. For example, in contrast to the significant association found using the PISA data by Schmidt and colleagues, Luyten's (2017) study showed very little association between teacher-reported OTL and

students' mathematics attainment using the TIMSS data. Zhu's (2017) analysis of the same PISA data also found that OTL focused on content showed stronger correlations with mathematical attainment than teaching-related OTL. Similarly, Rolfe and Teig (2025) showed that how OTL is operationalised affects both the strength of relationships with mathematics attainment and interpretability. The study by Gamoran et al. (1997) focused specifically on attainment gain, and found the strongest correlations between OTL and attainment gain when they combined measures of OTL focused on the topic and measures focused on cognitive demand in comparison to considering each measure on its own, suggesting a more complex relationship between OTL and student attainment. These studies all focus on the effect of OTL on mathematics attainment, rather than on the effect of attainment on OTL, which is the focus of this study.

International studies have shown that there is a considerable variation between countries in the strength and the nature of the relationship between OTL and attainment (Rolfe et al., 2021; Schmidt & Maier, 2009; Schmidt et al., 2001). However, much of the research to date examining OTL has either been based within the US or has been subject to issues with the measurements used (Hansen & Strietholt, 2018; Rolfe et al., 2021). The student reports of their OTL in terms of their content exposure used in PISA and the teacher reports of what they have taught used in TIMSS have both been challenged in terms of their validity as measures of OTL (Luyten & Scheerens, 2022). For example, Schmidt et al. (2021) argue that student-reported measures of OTL are preferable since they more accurately reflect the content learned rather than taught, while Hansen and Strietholt (2018) raise the issue that student-reported measures include students' self-evaluation of their own competence in mathematics as well as their OTL, though after adjusting analyses to take into account students' mathematics self-concept, Hansen and Strietholt still found that OTL had both a direct effect on mathematics attainment and mediated an indirect effect of SES on mathematics attainment.

One particular area of research into the relationship between OTL and attainment has focused on the influence of other factors, such as students' socioeconomic status (SES), gender, ethnic background, or special educational needs (e.g., Schmidt et al., 2024). Schmidt et al. (2015) showed that social inequalities in student attainment evident in the PISA data were perpetuated by the different OTL students have, partly depending on their SES, showing that high-SES students tend to receive more rigorous OTL. In contrast, Bokhove et al.'s (2019) analysis, focusing on geometry specifically, did not find that including OTL in models based on TIMSS 2011 data affected the influence of SES. Schmidt et al. (2015), Lin (2018), and Hansen and Strietholt (2018) all showed that OTL has both a direct effect on mathematics attainment and mediates the effect of SES through an additional indirect effect in the majority of countries that participated in PISA or TIMSS. However, Rolfe et al. (2021) also showed that the associations between the OTL measures in TIMSS only mediated the effect of SES in particular contexts, largely in wealthy countries where English was the language of instruction. Measurement invariance across countries is seldom assessed in these large-scale assessments, and both teacher and student-reported measures of OTL can have culture-specific interpretations (Rutkowski & Svetina, 2014). Cross-country comparisons need to take into account these complexities, and

are therefore not the focus of this study. Furthermore, while these studies highlight important relationships between students' backgrounds and OTL, and the mediating role of OTL on mathematics attainment, the impact of mathematics attainment on OTL is underexplored.

OTL in the Context of Class Heterogeneity

The third research question in this study focuses on the role of class heterogeneity in associations between prior attainment and OTL. One of the key influences on the heterogeneity of classes within a country is the various ways in which students are grouped or tracked, for example, by prior attainment. Grouping students between and within schools often favours students with higher SES, and often results in the offer of a different curricula for the different groups (Oakes, 2005; Taylor et al., 2019), with Schmidt and McKnight (1995) concluding that systematically less demanding content was offered to lower-income students. These differences in OTL can be exacerbated by selection or self-selection into schools and practices such as grouping by prior attainment within schools, both of which are often related to students' socioeconomic and ethnic background (Kutnick et al., 2005; Taylor et al., 2019; Wiliam & Bartholomew, 2013). Across the eight countries that participated in TVS, there is a wide variety of ways in which students are grouped both between and within schools. These variations in grouping practices raise questions about the impact of class heterogeneity on OTL.

Previous Related Findings From TVS

The final study report on OTL within TVS (Organisation for Economic Co-operation and Development [OECD], 2020a) highlights the variation in the time spent on teaching quadratic equations both within and between countries, with most teachers spending less time teaching the topic than suggested by the intended curriculum. Additionally, the report also described the variation between countries in which solution method was emphasised, with a focus on the two methods considered more demanding, "completing the square" and "finding roots of a quadratic function". However, no relationships between the study's outcome measures (attainment, interest in mathematics, self-efficacy) and the teacher-reported OTL measures were reported (OECD, 2020a), but some student-reported OTL measures had positive effects on these outcome measures. In particular, the student-reported reasoning measure was a positive predictor of attainment in BMV-Chile and England, of personal interest in mathematics in Colombia, England, and Mexico, and of self-efficacy in Colombia, England, Germany, and Shanghai, after controlling for students' associated pre-scores and demographic characteristics.

Methodology

This study examines whether class average prior attainment and heterogeneity are associated with different operationalisations of OTL using the TVS dataset. In TVS, the measures of OTL used had a similar design to both those used in PISA and TIMSS, but focused on the topic of quadratic equations, and, importantly, the study included measures of student attainment *before* the topic was taught as well as after. These measures of OTL included student- and teacher-reported OTL focused specifically on quadratic equations. This design enables analysis of the relationship between mathematics attainment and OTL *following* the assessment, using both student-reported and teacher-reported measures of OTL, as well as the OTL observed in videoed lessons and lesson materials.

In this study, I estimate associations between class-average prior attainment and the different operationalised measures of OTL used in TVS. The design of TVS allows us to draw on both student-reported OTL and teacher-reported OTL, as well as OTL measures derived from the standardised ratings of the lesson videos and materials for a specific sequence of lessons on quadratic equations. The longitudinal design also enables an analysis of associations between prior attainment and OTL, in addition to the associations between OTL and maths attainment in the post-test examined in the study report (OECD, 2020a).

In this section, the TVS design is briefly described, including the nature of the sample in each participating country. Details of the variables and measures used in this study are then provided, followed by an outline of the analysis. The variables and analysis used were chosen to address the study's three research questions: (1) to what extent is average prior attainment of a mathematics class associated with the OTL in the lessons that follow? (2) are there particular measures of OTL that are more strongly related to class prior attainment than others? (3) do relationships between class prior attainment and OTL depend on class heterogeneity?

The TVS Dataset

The data and variables used in this article are taken from the OECD Global Teaching InSights Video Study (TVS) (OECD, 2020a), an international longitudinal study of the teaching of quadratic equations in eight education systems. These countries and economies were Bíobio, Metropolitana and Valparaíso in Chile (hereafter BMV-Chile), Colombia, England (UK), Germany, Kumagaya, Shizuoka and Toda in Japan (hereafter KST-Japan), Madrid (Spain), Mexico and Shanghai (China). Madrid is excluded from the analysis because of the large amount of missing data at the student level and from the teacher logs.

The study collected data in 2018 from between 50 and 103 teachers and one of their classes in each education system. TVS used a stratified two-stage probability sampling design. Schools in each education system were selected using systematic random sampling with probability proportional to size within explicit strata relevant to the system's context. Among those teachers who would be teaching quadratic equations in the sampled school, one or two were randomly selected from those teaching quadratic equations, with that class being selected if a sufficient number of students

consented to participate. The age of the students varied across and within the education systems, ranging from 13 years old to 16 years old. Further details of the sample are available in the supplementary materials (Table 1.1).

The final samples in England and Japan were not fully representative of the education system from which they were drawn, due to some deviations made from the sampling design in order to recruit sufficient teachers. The sample in Germany was a convenience sample of volunteer schools, drawing largely from the academic programme schools (OECD, 2020a). Full details of the study design are given in the TVS technical report (OECD, 2021). The data in TVS come from student pre- and post-tests, student and teacher pre- and post-questionnaires, and video recordings of two lessons, along with the accompanying lesson materials for those two lessons and two other lessons within the topic. Full details of the instruments used in the data collection for TVS are given in the study technical report (OECD, 2021).

Variables

The dependent variables for this study were selected from the TVS dataset to reflect the different ways in which the four types of OTL identified by Stevens (1993) were operationalised in TVS. These variables are summarised in Table 1. Full details of the derivation of these variables are described in the TVS Codebook (OECD, 2020b) and descriptives of each of these variables and correlations between the different OTL measures used in TVS are reported in the final study report (OECD, 2020a) with the relevant references listed in Table 1, and additional descriptives are given in Sect. 1.3 of the supplementary materials. These different OTL variables enable examination of relationships between prior attainment and OTL across its various operationalisations.

TVS partly controlled for content coverage through focusing specifically on the topic of quadratic equations, but also identified four key subtopics (Algebra, Functions, Reasoning, and Applications), and four solution methods (factorising, using the quadratic formula, completing the square, and finding roots in a graphical representation). Coverage of these subtopics and solution methods was measured through teacher-reported logs of the content taught, coding of the lesson materials and through questions in the student post-questionnaire. Content exposure and emphasis for each of these subtopics and solution methods were also measured using teacher-reported logs and lesson materials. One of these subtopics and one of the solution methods, functions and finding roots, are taught separately from quadratic equations in KST-Japan and Shanghai, according to both the intended official curriculum and as observed in the TVS analysis (OECD, 2020a). Furthermore, solving quadratic equations by completing the square or using the quadratic formula is only in the intended curriculum for higher-attaining students in England.

In TVS the students are all from the same class and consequently, the class-average student reported OTL takes into account variations in the implemented curriculum within a class, and students' experiences of the concepts outside of their formal mathematics lessons and can be considered a valid and reliable measure of the implemented curriculum (Marsh, 1987). Teacher logs are also a cost-effective way of collecting data on the implemented curriculum (Rowan et al., 2004) that have been

Table 1 Measures of OTL taken from TVS

OTL measure source	Variable Name	Reported by	Nature	Description	Descriptives location in TVS report
Lesson material ratings	OTL_AR OTL_AR_FUNCTIONS OTL_AR_ALGEBRA OTL_AR_REASONING OTL_AR_APPLIED	Coded by trained raters	Content coverage	Whether lesson materials included aspects of the 4 subtopics.	Annex Table 5.B.1–12.
Teacher logs	OTL_TL_FUNCTIONS	Teacher	Content coverage, exposure and emphasis	Coverage of the 4 subtopics	Annex Table 6.A.1–4
	OTL_TL_ALGEBRA			Time spent on each of the 4 subtopics	
	OTL_TL_REASONING			Whether a subtopic was a major or minor focus in the lesson	
	OTL_TL_APPLIED				
Student post-questionnaire	OTL_SQB/SB_OTL OTL_SQB_FUNCTIONS OTL_SQB_ALGEBRA OTL_SQB_REASONING OTL_SQB APPLIED	Students	Content coverage	Coverage of the 4 subtopics	Annex Table 6.A.1–4
Video ratings:	VDOMAIN_CE	Coded by trained raters (Scale 1 to 4)	Quality of instructional delivery	The extent to which observed lessons offered opportunities for students to engage in cognitively demanding mathematics.	Annex Table 5.A.1
	VDOMAIN_QS			The extent to which observed lessons included mathematical connections and explicit patterns and generalisations.	Annex Table 5.A.2

shown to be reliable and valid across several research studies (Edgerton & Desimone, 2019). .

TVS used a range of measures of instructional quality related OTL. This study uses two of these measures that represent the mathematics-specific instructional domains, the average video domain score for cognitive engagement and for the quality of subject matter. These two scores aggregate different components at a theoretically-grounded domain level, improving the reliability of the measures for the analysis described below. Further details of the rating and aggregation process for these measures used are detailed in the TVS technical report and codebook (OECD, 2020b, 2021).

Mathematics prior attainment was used as the independent variable using the scores from the specifically designed pre-test. This pre-test addressed general mathematical topics common across the participating countries' curricula, but with a focus on questions targeting content considered a prerequisite for learning quadratic equations (OECD, 2021). There are also differences between the countries in the variation in student and class average pre-test scores, with the standard deviations in the pre-test scores in BMV-Chile and England larger than in the other countries. However, there was a ceiling effect in the pre-test scores for KST-Japan and Shanghai. Descriptives of the pre-test scores for each country can be found in the supplementary materials, Table 1.2. This pre-test will also capture some of the historical effects of prior OTL, as well as the well-established impact of student characteristics, such as socioeconomic status, on their attainment (Ingram et al., 2020). To address these and to reduce the influence of extraneous variables, this study controlled for both student gender and socioeconomic background using the provided measures of gender, home possessions and parental education (OECD, 2021). The descriptive statistics for the student background variables are provided in Table 23.2 of the technical report (OECD, 2021).

In Shanghai and KST-Japan the topic of quadratic functions was not included in the study meaning that there are differences in the construction of some of the overall measures of OTL compared to the other participating countries. Furthermore, the ceiling effects in the pre-test mean that class prior-attainment effects cannot be estimated reliably due to the reduced variance in the pre-test scores. Consequently, Shanghai and KST-Japan were excluded from the regression models. However, this excluded countries that represent contexts with high overall attainment and comparatively low between-class variation.

Analysis

Initially, descriptive statistics were calculated for each OTL measure grouped by the data source: lesson materials, teacher logs, student post-questionnaire, and observed lessons. These descriptives provided an initial overview of the variation in OTL experienced or reported by students across classes. The first research question focuses on whether some of this variation can be explained by the class average prior attainment. Where there were noticeable differences in standard deviations between countries within each OTL data source, Levene's test was used to determine whether these differences were statistically significant, as many of the OTL measures were skewed

in some countries or economies. In addition, scatter plots for each OTL measure and class-average prior attainment in each country were generated and used to identify potential relationships, which were further explored using Kendall's non-parametric correlation, provided in Table 1.4 in the supplementary materials.

There were a large number of potential variables provided in the TVS dataset. To minimise the impact of errors arising from multiple testing, only variables that support a coherent analytical focus aligned with the research questions were included in the regression modelling. The rarity of certain subtopics in some countries meant there was little variation in these individual OTL measures. Consequently, aggregated OTL variables from the lesson materials and video observations were used to ensure sufficient within-country variation.

For the student-level dependent variable (SB_OTL), where students were nested within classes, to understand the proportion of variance at the class level and the country level, an interclass correlation coefficient (ICC) was estimated using a random-intercept variance decomposition model with the lmer4 package in R (Bates et al., 2015). While the between-country variation (0.54) was larger than the between-class variation within countries, substantial between-class variation remained (0.38). This supported further examination of class-level factors associated with student-reported OTL within specific country contexts using multilevel models (Snijders & Bosker, 2012). These models used the standardised class all-but-one mean pre-test score, combined with the deviation of individual pre-test scores from the associated class mean, as measures of prior attainment. This approach reduces collinearity and supports a clearer interpretation of compositional effects. In addition, the explanatory variables included student-level measures of gender, home possessions, and parental education.

For the class-level dependent variables (OTL_AR, VDOMAIN_CE, and VDOMAIN_QS), the variance between countries ranged from 0.14 to 0.41, indicating that most of the variance remains within countries. To investigate this variation within countries at the class level, linear regression models were used. For these models, the standardised class mean scores on the pre-test, aggregated from the individual student scores, were used to facilitate the interpretation and comparison of coefficients across models. Continuous predictors aggregated at the class-level were also standardised to improve model convergence and facilitate the interpretation of coefficients.

While cross-country comparisons are possible with the TVS dataset, the original TVS was not designed to support these without strong additional assumptions. In particular, the OTL constructs used may not be invariant across countries. Furthermore, this study's focus on the relationships between class prior attainment and OTL, alongside the well-documented challenges of cross-country comparisons (e.g., Rutkowski et al., 2010; Rutkowski & Svetina, 2014) supported analysing countries separately. All analyses were conducted using R (v.4.5.1, R Core Team, 2021), along with the tidyverse (Wickham et al., 2019) lme4 (Bates et al., 2015) and rstatix (v.0.7.2, Kassambara, 2023) packages. For the class-level dependent variables, four models were used: a baseline model that only included the class-average pre-test score; a second model including both the class-mean pre-test score and the class-level background characteristics; a third model which used the standard deviation of the class pre-test score and the class-level extraneous variables; and a final model that exam-

ined the interaction between the mean and the standard deviation of the class pre-test score. The third and fourth models were used to address the third research question of whether relationships between class prior attainment and OTL depend on class heterogeneity. For the student-level dependent variable (OTL_SB), two multilevel models were used: a baseline model that included only measures of prior attainment, and a second model that also included student-level background characteristics. Full details of the models used are given in the supplementary materials, Sects. 2 and 3.

Assumptions of the ordinary least squares regression and multilevel models (linearity, no endogeneity, normality, or homoscedasticity of the error term, no autocorrelation, no multicollinearity, and independence of residuals) were visually checked using the performance package (Lüdecke et al., 2021) before the analysis and deemed satisfactory. Due to concerns over multiple comparisons given the different measures of OTL involved, adjusted *p*-values using Benjamini-Hochberg were calculated for statistically significant findings. Furthermore, reporting focuses on patterns across measures rather than single statistically significant results.

Results

This section begins by reporting the descriptive statistics for each country separately for each type of OTL measure. These descriptives are used to identify where there were significant variations in OTL between classes within each of the countries.

Variations in OTL Across Countries

TVS measured OTL in multiple ways, as outlined in Table 1. The means and standard deviations for each measure of OTL in each country are shown in Table 2. Across the lesson materials, the variation in standard deviations suggested distinct patterns in content coverage. For example, Levene's test indicated that the variance differed significantly for the OTL algebra measure between BMV-Chile and England ($F(1, 177) = 13.40$, $p < 0.001$) and for the OTL reasoning measure between BMV-Chile and Mexico ($F(1, 195) = 5.32$, $p = 0.02$). A similar variation can be observed in the teacher-reported logs of content coverage, the video observation ratings of instructional quality, and the student-reported measures of content coverage. Levene's test indicated that the variance differed significantly for the student-reported OTL reasoning measure between KST-Japan and England ($F(1, 172) = 7.13$, $p = 0.008$). These measures suggest that some contexts show much greater between-class variation in OTL, particularly for some subtopics, but also that the pattern of variation depends on how OTL is measured. This variation between classes is central to the subsequent analyses and supports further analysis that considers both countries and the different measures of OTL separately.

For the four solution methods, in addition to the findings in the TVS report (OECD, 2020a), factorising was taught in almost all classes except in Mexico, and this did not vary according to class-average prior attainment. The quadratic formula was taught in almost all classes except in England. In England, there are large differences in the solution methods taught to classes with different average prior attainment, with 34%

Table 2 Means and standard deviations for each OTL measures, for each data source, and each country

Lesson materials								
Country	Functions		Algebra		Reasoning		Applied	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
BMV-Chile	0.10	0.19	0.36	0.28	0.26	0.23	0.29	0.31
Colombia	0.24	0.20	0.34	0.15	0.15	0.14	0.23	0.25
England	0.26	0.22	0.47	0.17	0.06	0.09	0.18	0.21
Germany	0.42	0.25	0.43	0.17	0.19	0.13	0.39	0.30
KST-Japan	-	-	0.59	0.16	0.00	0.02	0.47	0.33
Mexico	0.09	0.16	0.24	0.16	0.15	0.17	0.50	0.34
Shanghai	-	-	0.49	0.17	0.31	0.13	0.20	0.25
Teacher logs								
Country	Functions		Algebra		Reasoning		Applied	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
BMV-Chile	2.48	2.17	4.00	2.54	3.92	3.02	3.02	2.79
Colombia	1.39	1.20	1.67	1.00	2.29	1.54	1.42	1.52
England	1.71	1.51	2.42	1.00	2.10	1.81	0.85	0.93
Germany	3.89	2.16	4.27	1.85	3.30	2.07	3.04	2.06
KST-Japan	-	-	2.69	1.27	0.91	1.11	3.61	1.69
Mexico	1.31	1.90	2.28	1.66	2.97	2.41	2.91	2.40
Shanghai	-	-	3.65	1.24	4.37	2.11	1.81	1.89
Student questionnaires								
Country	Functions		Algebra		Reasoning		Applied	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
BMV-Chile	1.59	0.26	4.63	0.25	1.82	0.14	0.96	0.37
Colombia	1.65	0.19	4.19	0.34	1.62	0.20	1.09	0.33
England	1.34	0.29	4.07	0.38	1.41	0.32	0.48	0.25
Germany	1.77	0.30	4.71	0.17	1.39	0.17	1.05	0.42
KST-Japan	-	-	4.70	0.22	1.35	0.23	0.59	0.35
Mexico	1.67	0.20	4.29	0.30	1.74	0.17	1.43	0.25
Shanghai	-	-	4.80	0.14	1.91	0.08	0.60	0.19
Lesson observations								
Country	Cognitive Engagement		Quality of Subject Matter					
	Mean	SD	Mean	SD				
BMV-Chile	1.47	0.24	1.36	0.22				
Colombia	1.50	0.26	1.40	0.20				
England	1.86	0.39	1.77	0.36				
Germany	1.81	0.35	1.51	0.22				
KST-Japan	2.11	0.40	1.71	0.29				
Mexico	1.63	0.28	1.54	0.36				
Shanghai	1.70	0.26	1.97	0.22				

of lower-attaining classes not being taught how to complete the square and 21% not being taught to use the quadratic formula, compared to 6% and 5% for higher-attaining classes. In BMV-Chile, completing the square was not taught to 8% of higher-attaining classes and 19% of lower-attaining classes. Full details are included in Sect. 1.5 of the supplementary materials.

These descriptives and correlations also show that some measures of OTL were rarely observed in certain country contexts or in classes with lower class-average

prior attainment. In particular, the teacher logs indicate that content exposure and emphasis were placed on functions in Germany, whereas there was little content exposure or emphasis on applications of quadratic equations in England. For these subtopics, the patterns of emphasis and exposure were similar across the different measures.

As the focus of this study is patterns in relationships between prior attainment and different measures of OTL, results from models in one country context for selected measures of OTL are shared to illustrate specific patterns of association. Full details of all the models for all countries are included in the supplementary materials and described in relation to how similar they are to the relationship illustrated by one of the country cases below. To answer the first question, the models from England for the student-reported measure of OTL are used to illustrate a context where class prior attainment is associated with OTL for this measure. For the third research question, the models from Mexico for one of the video ratings are used to illustrate a context where the heterogeneity of a class is associated with instructional quality.

Associations Between Class-Level Student Prior Attainment and OTL

To address the first research question of the extent to which OTL was associated with the average prior attainment of the mathematics class they belong to, linear regression models for the class-level measures of OTL and multilevel models for the student-level measures of OTL were constructed. Across the multilevel models focused on student-reported OTL, students' socioeconomic background was more consistently associated with OTL than class-average prior attainment, although the overall proportion of variance explained by the fixed effects was modest. In all countries, students' relative attainment in relation to the class average score on the pre-test was not associated with differences in student-reported OTL after controlling for students' gender and socioeconomic background. In Table 3 the results from the modelling of student-reported OTL in England are reported. England is used here to illustrate an instance where class compositional effects exist but only explain a modest proportion of variation in student-reported OTL. In this country, mean class pre-test score was significantly associated with student-reported OTL, and this association remained after controlling for students' gender and socioeconomic back-

Table 3 Variables associated with student-reported OTL in England

	Baseline Model	Model 1
Mean class pre-test[a]	0.37*** (<0.01)	0.34*** (<0.01)
Student relative score	0.14* (0.03)	0.11 (0.09)
Female		-0.23* (0.01)
Home possessions[b]		0.15** (<0.01)
Parental education		-0.02 (0.33)
Between-class variance	0.56	0.56
Within-class variance	1.73	1.74
Number of observations	1753	1614
R^2 Marginal	0.034	0.039
R^2 Conditional	0.125	0.129
ICC	0.1	0.1

*$p<0.05$, ** $p<0.01$, *** $p<0.001$

[a]standardised all-but-one class mean of pre-test scores

[b]index constructed using IRT

ground. However, roughly 10% of the variation in student-reported OTL lies between classrooms, with most variation occurring between students within classrooms. Furthermore, the marginal R^2 indicates that the fixed variables explain only a limited proportion of the total variation in student-reported OTL, while the conditional R^2 indicates that class composition is associated with student-reported OTL after taking into account prior attainment, gender and socioeconomic background. A similar pattern was observed in Germany, while in BMV-Chile, Colombia and Mexico, a different pattern was observed where class-average prior-attainment was not associated with student-reported OTL.

Linear regression models were used to examine the extent to which average prior attainment of a mathematics class was associated with the overall OTL observed in the lesson videos and materials. For the lesson materials, in the majority of countries there was no association between any of the variables and OTL observed. In countries where there was a significant association between class prior-attainment and the OTL in the lesson materials, this remained significant after controlling for the average class SES and the proportion of female students in the class. Two different patterns of association emerge with class-average prior attainment more strongly associated with OTL than the average class socioeconomic background in some countries (e.g., England), while average class socioeconomic background was more strongly associated in others (e.g., Colombia). However, after adjusting for multiple testing, these associations were no longer significant, suggesting they are not robust. Furthermore, as with the student-reported OTL, only a modest amount of the variation in OTL observed in the lesson materials was explained by the class-average prior attainment and other compositional variables.

Models with the OTL measures of instructional quality as rated in the lesson videos show similar patterns to the two identified with the lesson materials, but again the associations were not robust under multiple testing corrections. Table 4 shows the regression models in Mexico with video ratings for cognitive engagement as the dependent variable, which illustrates a common pattern of no clear associations between the explanatory variables and instructional quality.

Associations Between Class Heterogeneity and OTL

For the third research question, exploratory regression analysis that considered the interaction between class mean pre-test score and the standard deviation of that pre-test score was used to examine whether these patterns in OTL were associated with class heterogeneity, using the standard deviation of class pre-test score as a measure of class heterogeneity. In these models, two further patterns of association arise. The results of the regression models in Mexico are used here to illustrate the pattern where the heterogeneity of a class was associated with the observed instructional quality, as shown in Table 4. The standard deviation of the class average pre-test score is significantly associated with the average rating for cognitive engagement and remains significant after adjusting for multiple testing ($p = 0.018$). This association also remains after controlling for the average class pre-test score. This pattern of association was only observed with the instructional quality measures of OTL in

Table 4 Variables associated with cognitive engagement as measured in the lesson videos in Mexico

	Base			Full Model			SD Model			Interaction Model		
Variables	β	SE	*p*	β	SE	*p*	β	SE	*p*	β	SE	*p*
Class mean pre-test score[a]	0.06	0.05	0.178	0.11	0.06	0.091				0.31	0.17	0.068
Proportion of females				0.11	0.25	0.665	0.07	0.24	0.780	0.07	0.24	0.770
Class mean home possessions				0.12	0.10	0.248	0.07	0.10	0.469	0.08	0.11	0.427
Class mean parental education				-0.06	0.03	0.024	-0.05	0.03	0.077	-0.06	0.03	0.047
Class pre-test standard deviation							0.42	0.14	0.003	0.42	0.15	0.006
Class mean pre-test score[a]*Class pre-test standard deviation										-0.28	0.16	0.087
Number of observations	114			114			114			114		
R^2	0.02			0.06			0.12			0.14		
Adj. R^2	0.01			0.03			0.08			0.1		

[a]Standardised at the country level

Mexico. In general, class heterogeneity was not associated with OTL both in terms of class-average prior attainment and the class-average socioeconomic composition.

Discussion

This study sought to address three research questions, and in this section, the findings for each are discussed before the overall conclusions are drawn.

Associations between the average prior attainment of a mathematics class and the observed, teacher-reported, and student-reported OTL during the lessons that followed were modest, varied across the countries considered, and left substantial variation unexplained. Statistically robust associations were found between class-average prior attainment and student-reported OTL in some countries, which remained after controlling for students' gender and socioeconomic backgrounds. However, this was not the case for the content coverage observed in the lesson materials or for the instructional quality as observed in the videoed lessons. For these two operationalisations of OTL, associations with class-average prior attainment were found in few countries and were not robust to multiple-testing adjustments. Differences in student-reported OTL were also not associated with students' relative attainment within their class.

Most of the variation in OTL remains unexplained, with class-average prior attainment and class composition accounting for only a modest proportion. However, the rarity of some teacher-reported and lesson-material-based measures of OTL subtopics in some countries meant that these measures lacked the variation necessary for further modelling and restricted the interpretation of the aggregated overall measures. Yet, the descriptive statistics and correlations suggested differences in the content coverage associated with class-average prior attainment. Some of this variation may reflect differences in national curricula, but there are also additional between-class differences in content coverage within countries. The observed variation may also be a consequence of how the curriculum is sequenced at a country or class level, as a topic that may be revisited and developed over time. Similarly, some aspects of the measured OTL within quadratic equations may connect to other topics within the curricula, such as graphing functions or factorising expressions, and students may therefore experience more content coverage, exposure and emphasis on the different subtopics than is captured in TVS. These patterns raise questions about whether students in different classes experience quadratic equations through different solution methods, subtopics and mathematical representations in ways that are associated with prior attainment in some countries.

The second research question explored whether particular operationalisations of OTL were more strongly related to class-average prior attainment than others. Similar patterns of association were observed between the content coverage in the lesson materials and that reported by students for the aggregated OTL measures. However, many of these patterns were not statistically robust for the lesson materials. Importantly, in some country contexts, observed OTL was more strongly associated with class prior attainment than socioeconomic background. Yet for student-reported OTL, the association with a student's socioeconomic background was more strongly

associated than class prior attainment across all countries. This supports Luyten's (2017) argument that the student-reported and teacher-reported measures may measure two different aspects of OTL, which may also vary across country contexts.

The models addressing research question 3 examined whether relationships between class attainment and OTL depended on class heterogeneity also suggest further differences depending on the operationalisation of OTL. Where there was an association between OTL and class heterogeneity, it was stronger for instructional quality, as observed in the lesson videos, than for content coverage, as observed in the lesson materials.

Conclusion

This study has shown that class-average prior attainment and heterogeneity may shape OTL in different ways. This article focused on OTL as operationalised through student-reported, teacher-reported and observed measures, revealing different patterns of association between OTL and class-average prior attainment. These findings raise some further questions about how prior attainment in mathematics influences subsequent OTL, and the country-level and class-level factors that influence these associations.

The analysis in this article also addresses some of the limitations of earlier studies that rely on a single source for the measure of OTL; student-reported OTL (Schmidt et al., 2015) or teacher-reported OTL (Rolfe et al., 2021). However, it is also limited by the availability of the data from TVS, which involves smaller sample sizes than studies like PISA and TIMSS, and variations in the sampling methods within each country.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s10763-026-10687-7.

Acknowledgments The author is grateful for the contribution of Tiarnach McDermott who contributed to the preliminary analysis of the OTL measures in the TVS study that this article builds on.

Funding This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

Data Availability The data that support the findings of this study are openly available from the OECD at https://www.oecd.org/education/school/global-teaching-insights-technical-documents.htm.

Declarations

Ethics Approval BERA ethical guidelines have been followed in the present research study. Ethical approval for the analysis in this paper was not required by the author's institution.

Competing interests The authors declare that there is no conflict of interest.

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