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Does Team Work Make the Dream Work? (And Other Claims of Student-Oriented Mathematics Instruction)

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AEI Economics Working Paper 2024-10

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Does Team Work Make the Dream Work? (And Other Claims of Student-Oriented Mathematics Instruction.)

By Andrew G. Biggs and John Mantus

6/14/2024

Abstract

There is much public concern over the poor math performances of U.S. students compared to other developed countries. In this paper, we consider the role of instruction style in student performance on the math literacy portion of the OECD's PISA exam, specifically looking at the increasingly-popular student-oriented style of classroom instruction versus the more traditional teacher-directed instruction style. The 2012 PISA exam is unique in including a student questionnaire with questions pertaining to how math is taught in their classroom. We first enhance the robustness of question-level results produced by the OECD in Echazarra et al. (2016), confirming their finding that traditional teacher-directed instruction style is superior to student-oriented instruction, regardless of question difficulty. These results contradict the OECD's conclusion in Weatherby (2016) that the 2012 PISA data justify the employment of both math instructional philosophies.

We then study overall exam data at both an international- and student-level and find strong evidence that student-oriented instruction is associated with lower math scores and teacher-directed instruction with higher ones. At the country level, the United States' greater use of student-oriented math instruction accounts for roughly one quarter of the 2012 PISA score difference between the U.S. and Korea, which had the second highest average score in the 2012 exam and the highest use of teacher-directed instruction. At the student level, a one standard deviation increase in the use of student-oriented mathematics instruction correlates with a decline in PISA exams scores of 0.27 standard deviations, while a one standard deviation increase in teacher-directed instruction corresponds with a 0.19 standard deviation increase in math scores. These effects are comparable in size to a one standard deviation increase in a student's socioeconomic status or the student living with both parents rather than a single parent. These results imply that mathematics instructional methods result in differences in mathematics proficiency that are not only statistically significant but meaningful in size.

These results contradict the teaching recommendations provided by the OECD and suggest that increased utilization of teacher-directed instructional methods could potentially improve U.S. math performance.

1. Introduction

U.S. students have long struggled with mathematics achievement, in particular relative to students in other countries. In 2000, the first year the PISA was administered, U.S. students earned an average score of 493, slightly below the OECD average of 500. This score placed the United States 19th out of 27 countries participating in the program. In the latest exam results for 2022, U.S. students achieved an average score of 465. This figure, likely affected by school disruptions during the COVID pandemic, was down 13 points from the previous exam in 2018.

Over this same period, a debate has occurred in the United States (and other countries) regarding the most effective methods of mathematics instruction. Traditional teacher-led pedagogy, in which the classroom teacher leads lessons, explains new procedures, and models with worked examples has been challenged by so-called “student-oriented” instruction, which places less emphasis on memorization and practice and greater emphasis on students working together to discover mathematical logic and procedures. Piirimees (2020), et al. distinguish the two approaches in this way: “the student-centered approach is a way of teaching which sees a teacher as a facilitator of the students’ learning processes, whereas the teacher-centered approach is a way of teaching in which students are more or less the passive recipients of the information that is transmitted from the teachers to the students.”¹ Defenders of teacher-centered instruction would counter that their preferred approach includes an emphasis on teacher-student interaction, in particular with the teacher providing explicit instruction in mathematical procedures, modeling worked examples of those procedures being employed, and students practicing problems on their own to build mathematical fluency. Nevertheless, this description accurately characterizes the stronger leadership role of the classroom teacher in teacher-centered learning.

According to Walters et al. (2014), student-oriented math instruction includes, among other things, “instructional activities that actively engage students in sense-making by building on their prior learning and connecting to personal experience, often through collaborative group work,” and “a focus on the individual through differentiation, scaffolding, and opportunity for choice.”² Proponents of student-oriented instruction sometimes summarize the distinction by saying that a teacher should be a “guide on the side, not a sage on the stage.”

The debate over student-oriented versus teacher-directed mathematics instruction mirrors the more developed debate in reading instruction between so-called balanced literacy and structured literacy. Balanced literacy places less stress upon explicit teacher instruction in

¹ Piirimees, A., et al. (2020). Teachers’ understanding of contemporary approaches to teaching and learning. European Proceedings of International Conference on Education and Educational Psychology, European Publisher.

² Walters, K., et al. (2014). "An Up-Close Look at Student-Centered Math Teaching: A Study of Highly Regarded High School Teachers and Their Students." Nellie Mae Education Foundation.

phonics while emphasizing students engaging with reading material that they enjoy, often in small groups. Structured literacy tends to place emphasis in an opposite direction, with more emphasis on phonics and greater whole-class instruction from the teacher.

To be clear, the common argument is that teacher-directed and student-oriented mathematics instruction lie on a continuum: even strongly teacher-directed instruction includes room for students to apply skills to unfamiliar problems, while even strongly student-oriented instruction allows the teacher to step in to provide guidance as needed. The distinction may lie in how the process is followed: in teacher-directed instruction the teacher provides explicit instruction and modeling first, followed by student application of learned techniques, while student-oriented instruction often begins with students working individually or in groups to attack unfamiliar problems, after which the teacher provides guidance and sums up the lesson.³

The fact that this debate continues indicates that one side of the argument has not yet persuaded the other. Our contribution is to utilize PISA exam data that link student achievement scores to student reports of the type and frequency of teacher- and student-oriented teaching methods that are employed in their classrooms. While this approach does not reach the gold standard of a randomized controlled trial (RCT), it is commonly used in other contexts and may supply useful information for those interested with mathematics pedagogy.

1. Literature Review

This study builds upon previous work in the field. Using the 2012 PISA, the OECD constructed indices of student-oriented (SO) and teacher-directed (TD) instructional techniques, based upon the researchers' perceptions of teaching methods that would be indicative of those broader instructional philosophies. Researchers at the OECD have studied the relationships between instruction styles and math performance on the PISA exam.⁴ Echazarra et al. (2016) find that exposure to TD instruction is associated with better performances and the opposite for SO instruction. Further, the effectiveness of TD instruction declines when questions are of intermediate or high difficulty while there appears to be no relationship between SO effectiveness and question difficulty. We believe this analysis can be improved in several ways, in the process generating more robust conclusions.

³ These differing instructional sequences are described in a science teaching context in Zhang, L. and J. Sweller (2024). "Instructional sequences in science teaching: considering element interactivity when sequencing inquiry-based investigation activities and explicit instruction." *European Journal of Psychology of Education*: 1-11.

⁴ Echazarra, A., et al. (2016), "How teachers teach and students learn: Successful strategies for school", OECD Education Working Papers, No. 130, OECD Publishing, Paris, <https://doi.org/10.1787/5jm29kpt0xxx-en>.

First, the OECD indices of student- and teacher-directed instruction were simple averages of student responses to Program for International Student Assessment (PISA) questions that were selected by the OECD researchers and assumed to correspond to different teaching philosophies. We use factor analysis to demonstrate that certain teaching practices indeed appear to be aligned with unobserved background methodologies consistent with student-oriented and teacher-directed instruction.

Second, the OECD analysis did not account for student-level demographic differences that might have affected the perceived performance of the two instructional approaches. We include controls for socioeconomic status, native language, and family structure, strengthening the analysis of teaching instructional approaches.

Third, we present evidence at the international-, student-, and question-level that the positive effects of teacher-directed mathematics instruction, and the negative impact of student-oriented instruction, are robust to different aggregation choices and are of sufficient size to be meaningful for the selection of instructional methods. Conversations regarding how to improve mathematics achievement should not ignore differences in instructional methodologies. This enhanced analysis provides a clearer view of how student-oriented and teacher-directed mathematics instruction corresponds with mathematics proficiency as measured in the PISA exam.

2. Data

In this study, we conduct a new and more in-depth analysis of the 2012 PISA exam data. The 2012 data are chosen over more recent exams because, in addition to the results of the PISA mathematics exam, the 2012 survey included extensive additional questions regarding classroom practices, including the degree to which students engaged in group work. This section provides additional background on the 2012 PISA dataset.

2.1. The PISA Exam

Since 2000, the OECD has administered the PISA exam across eighty countries to over three million 15-year-old students. The math exams, in particular, are designed to test mathematical literacy, which the OECD defines as follows:

Mathematical literacy is an individual's capacity to formulate, employ, and interpret mathematics in a variety of contexts. It includes reasoning mathematically and using mathematical concepts, procedures, facts and tools to describe, explain, and predict phenomena.⁵

⁵ OECD (2013), *PISA 2012 Assessment and Analytical Framework*, available at https://www.oecd.org/pisa/pisaproducts/PISA%202012%20framework%20e-book_final.pdf

Figure 1. An example of a mathematics question found on the PISA exam

FAULTY PLAYERS		
The <i>Electrix Company</i> makes two types of electronic equipment: video and audio players. At the end of the daily production, the players are tested and those with faults are removed and sent for repair.		
The following table shows the average number of players of each type that are made per day, and the average percentage of faulty players per day.		
Player type	Average number of players made per day	Average percentage of faulty players per day
Video players	2000	5%
Audio players	6000	3%

Question 1: FAULTY PLAYERS		PM00EQ01
Below are three statements about the daily production at <i>Electrix Company</i> . Are the statements correct?		
Circle "Yes" or "No" for each statement.		
Statement	Is the statement correct?	
One third of the players produced daily are video players.	Yes / No	
In each batch of 100 video players made, exactly 5 will be faulty.	Yes / No	
If an audio player is chosen at random from the daily production for testing, the probability that it will need to be repaired is 0.03.	Yes / No	

Source: PISA 2012 Released Mathematics Items

Relative to another prominent international exam, the Trends in International Mathematics and Science Study (TIMSS), the PISA is perceived to place greater emphasis on creativity and problem-solving skills, which are a focus of progressive mathematics instruction. The TIMSS, by contrast, is seen as placing greater emphasis on procedural fluency, which might be seen as favoring the more traditional teacher-directed instructional approach. Students taking the PISA mathematics exam are required to “formulate situations mathematically; employ mathematical concepts, facts, procedures and reasoning; and interpret, apply and evaluate mathematical outcomes” (Weatherby (2016)). Thus, one might expect that the PISA would be an exam where the broader sets of skills believed to be developed via student-oriented math instruction might reasonably be measured.

An example question can be found in Figure 1. PISA mathematics questions tend to require students not to merely solve a problem procedurally but first understand how a problem expressed in words can be modeled mathematically, then solved using the tools of algebra, probability, etc.

The anonymized results from the PISA’s exams and surveys are published online for public use with identifying information to map students to parents and schools. The primary strength of this dataset is the exam standardization across countries. Because PISA uses “strong quality assurance mechanisms for translation” and “measures to achieve cultural and linguistic breadth in the assessment materials,” differences in test scores are meaningful in that they can

be attributed to factors unrelated to the exam itself.⁶ In other words, the exam standardization allows researchers to examine the influence of, for instance, socio-economic status (SES), teacher instruction decisions, and school resources, in a student's mathematical abilities. The detailed survey data also allow us to study these factors at the student level in addition to the aggregate country level.

2.2. PISA questions on instructional approaches

In addition to assessing student skills, the PISA includes additional survey questions posed to students, parents, and school administrators regarding a variety of background topics, including students' home lives, school staffing and resources, curricula choices, and other topics. In particular, the 2012 PISA included a range of questions focusing on the ways in which mathematics is taught in the classroom.

For instance, the 2012 exam asked students the following question regarding group work:

Question 29. *How often do these things happen in your mathematics lessons? ... (g)*
The teacher has us work in small groups to come up with joint solutions to a problem or task, with the following possible responses: (1) *Every Lesson*, (2) *Most Lessons*, (3) *Some Lessons*, and (4) *Never or Hardly Ever*.

The questions listed in Table 1 below are from the 2012 Student Questionnaire Form C administered to students who took the PISA exam in that year.

For simplicity, the questions that *appear* to represent teacher-directed are grouped together, as are those that appear to represent a student-oriented teaching philosophy. A third category of instructional methods, termed Formative Assessment, is independent of both student-oriented and teacher-directed instruction and appears could co-exist with either instructional philosophy. We treat student responses to teacher-instruction questions as categorical variables.

3. Replicating and expanding Echazarra et al. (2016)

As described above, Echazarra et al. (2016) is cited by the OECD in their recommendation for math teachers to use a mix of both SO and TD instruction styles. In this analysis, we will replicate the primary results of Echazarra et al. (2016) and add additional control variables to test the robustness of their results.

For each question on the exam, the authors estimate a logistic regression where the outcome variable is an indicator representing whether the student answered the question correctly and the independent variables are the instruction style indices. They estimate

⁶ OECD (2013), *PISA 2012 Assessment and Analytical Framework*, available at https://www.oecd.org/pisa/pisaproducts/PISA%202012%20framework%20e-book_final.pdf

Table 1. PISA 2012 Student Questionnaire responses to questions about math instruction styles
(% of students)

		Every Lessons	Most Lessons	Some Lessons	Never or Hardly Ever	N/A	Invalid	Missing
Teacher-Directed Instruction	- The teacher sets clear goals for our learning	23.53	23.90	13.37	4.07	33.98	0.07	1.09
	- The teacher asks me or my classmates to present our thinking or reasoning at some length	15.09	21.40	19.11	9.13	33.98	0.07	1.21
	- The teacher asks questions to check whether we have understood what was taught.	26.80	21.53	12.39	3.93	33.98	0.09	1.27
	- At the beginning of a lesson, the teacher presents a short summary of the previous lesson.	15.07	16.37	20.38	12.89	33.98	0.09	1.21
	- The teacher tells us what we have to learn	29.03	22.13	10.58	2.90	33.98	0.09	1.29
Student-Oriented Instruction	- The teacher gives different work to classmates who have difficulties learning and/or to those who can advance faster.	8.95	11.49	15.05	29.17	33.98	0.12	1.23
	- The teacher assigns projects that require at least one week to complete	5.63	8.34	18.68	32.00	33.98	0.12	1.24
	- The teacher has us work in small groups to come up with joint solutions to a problem or task.	8.48	11.42	19.69	25.10	33.98	0.10	1.22
	- The teacher asks us to help plan classroom activities or topics	5.70	9.33	17.98	31.66	33.98	0.07	1.28
Formative Assessment	- The teacher tells me about how well I am doing in my mathematics class.	9.07	14.42	23.94	17.17	33.98	0.11	1.31
	- The teacher gives me feedback on my strengths and weaknesses in mathematics.	7.31	12.97	22.42	21.92	33.98	0.09	1.30
	- The teacher tells us what is expected of us when we get a test, quiz or assignment.	17.22	22.06	17.44	7.85	33.98	0.10	1.14
	- The teacher tells me what I need to do to become better in mathematics.	16.38	18.37	18.25	1.69	33.98	0.07	1.26

Source: 2012 PISA Exam

these regressions within each OECD country and take the average coefficient across countries. They interpret the coefficients as odds ratios and find that “on average, students in OECD countries perform better on easier items when receiving teacher-directed instruction,” but “on intermediate or very difficult items, the odds ratio of success are often less than 1 and are most often not statistically significant” (page 60). They also find that students exposed to SO instruction to be less likely to answer questions correctly, regardless of difficulty.

We enhance this model by layering in additional controls which are likely contribute to a student’s ability to perform on the math literacy portion of the exam. These include a student’s socioeconomic status (SES), whether the student speaks the language of the test in their home,

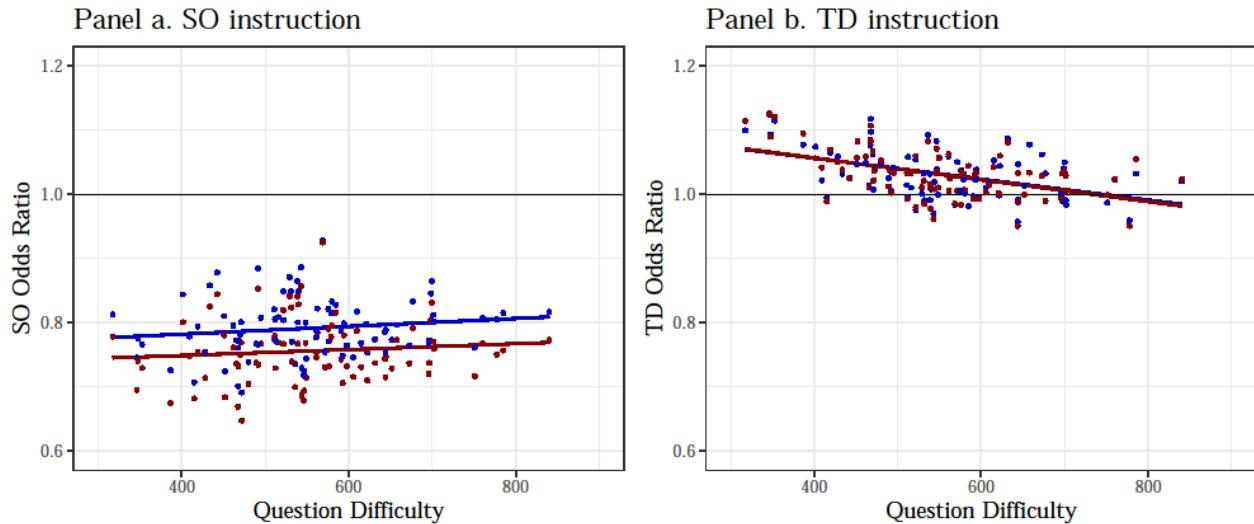
the immigration status of a student, and a student's family structure. The OECD estimates a student's SES using survey responses related to parental education and employment, as well as resources available in a student's home. Family structure indicates whether a student lives in a two-parent household, a one-parent household, or does not live with their parents. Immigration status categorizes students as either native (at least one parent born in resident country), second-generation, or first-generation. The PISA 2012 Technical Report provides more details on these variables. The variables representing family structure are coded such that increases correspond to an increase in the number of parents and the immigration status variable is coded such that one represents native-born, two represents second-generation, and three represents first-generation.

Figure 2 below shows the originally-estimated relationships between question difficulty and instruction methods which do not account for additional controls (red) and our estimates which do (blue). Panel a displays the relationship for SO instruction, Panel b shows TD instruction. For SO, we find that inclusion of the additional controls changes the results of the analysis only slightly. The disadvantage associated with exposure to SO instruction decreases slightly, from 25 percent less likely to answer the average question to 21 percent less likely, but the odds ratios remain strictly below zero. This means that exposure to student-oriented mathematics instruction is associated with poorer performances on all 84 PISA questions, regardless of difficulty. Similarly, the results for TD are robust to the inclusion of additional controls: while the effect is smaller in magnitude for more difficult questions, TD instruction is associated with better performances for 80 percent of questions. For the easiest 20 percent of questions, the average odds ratio is 1.06 while for the hardest quintile of questions the mean is 1.02.

This analysis adds robustness to the results presented by Echazarra et al. (2016) but sheds doubt on the practices endorsed by the OECD in Weatherby (2016). Weatherby, relying on Echazarra et al. (2016), cites only the analysis of teacher-direction instruction when contrasting the effectiveness of teacher-directed versus student-oriented instruction. Weatherby correctly reports that exposure to TD instruction increases the probability of correctly answering math questions, but that these benefits shrink as the exam questions grow more difficult.

But Weatherby incorrectly sums up this result as implying that “just as one teaching method is not sufficient for teaching a class of students with varying levels of ability, a single teaching strategy will not work for all mathematics problems, either”(page 15). If a reader assumed, reasonably enough by Weatherby referencing only teacher-directed instruction, that student-oriented instruction was the opposite of teacher-directed instruction, then at points at

Figure 2. Relationship between exposure to instruction styles and success on each math question, by difficulty of question



Source: 2012 PISA Exam & Student Questionnaire; Author's Calculations.

which the advantage of teacher-directed instruction grew small then presumably student-oriented instruction would be more effective.

But that is very clearly not what the data indicate. Our own question-level analysis, which produces results qualitatively similar to those of Echazarra et al. (2016), demonstrates the superiority of teacher-directed instruction over student-oriented for PISA math questions at all levels of difficulty. To be sure, the advantage of teacher-directed instruction over student-oriented instruction is not uniform over question difficulty, shrinking as questions grow more difficult. However, it is not the case that student-oriented instruction is beneficial for these harder questions, either relative to an absence of student-oriented instructional practices or to the presence of teacher-oriented instructional techniques. In fact, students exposed to student-oriented instruction are 20 percent less likely to correctly answer top-quintile-difficulty questions compared to students exposed to less SO instruction, and the gap is even larger relative to students exposed to teacher-directed instruction. The advantage of teacher-directed instruction over student-organized instruction exists across the entire spectrum of question difficulty. This analysis reveals there are no types of PISA math questions which students would be more likely to answer correctly if exposed to student-oriented rather than teacher-directed instruction.

4. Constructing Instruction Style Indices

We posit that responses PISA's instructional style questions are determined by unobserved, latent teaching philosophies used by math instructors in the classroom. However, we can't be sure that each teaching method necessarily is representative of a broader style or philosophy of instruction. For instance, it is possible that in both teacher-directed and student-oriented classrooms the teacher would begin a lesson by summarizing the previous lesson.

Table 2. Results of factor analysis on nine teaching style questions, PISA 2012

Factor	Eigenvalue	Difference	Proportion	Cumulative
Factor 1	3.40327	2.15413	0.3781	0.3781
Factor 2	1.24915	0.48820	0.1388	0.5169
Factor 3	0.76094	0.07949	0.0845	0.6015
Factor 4	0.68145	0.04485	0.0757	0.6772
Factor 5	0.63659	0.01800	0.0707	0.7479
Factor 6	0.61860	0.04977	0.0687	0.8167
Factor 7	0.56883	0.02650	0.0632	0.8799
Factor 8	0.54233	0.00348	0.0603	0.9401
Factor 9	0.53885		0.0599	1

Source: 2012 PISA Exam & Student Questionnaire; Author's Calculations.

To check, we use dimensionality-reducing factor analysis to quantify and estimate these teaching styles, where the number of latent variables is determined empirically. This differs methodologically from the OECD indexes, used above, which are simple averages of student responses to survey questions related to exposure to different instruction techniques, techniques which the OECD categorizes as SO or TD without empirical support. The results of our analysis are found in Table 2.

Consistent with Kaiser's Criterion, we choose only the first two factors, which are associated with eigenvalues greater than 1. We additionally perform Horn's Parallel Analysis (not shown) and find identical results. We then assess the extent to which each instruction question is related to each of the factors via their loadings, shown in Table 3.

We can see that the first five questions are most strongly related to Factor 1 and the next four questions are most strongly related to Factor 2. The content of the first five questions pertain to the extent of TD instruction while the next four pertain to SO instruction (this is consistent with the OECD's internal categorization of these questions). Hence, we use Factors 1 and 2 as measures of TD and SO learning, referring to them henceforth as TD Factor and SO Factor, respectively.

5. Applying Instructional Styles in An International Perspective

We begin with an international analysis of PISA math scores. We do so for several reasons. The international perspective provides additional context regarding how the U.S. compares to its OECD peers and other countries which participate in PISA, both in terms of instruction style and math performances. This perspective also informs theories on differential performances across countries. Public policy changes to improve math scores in the U.S. should be based on theories which can explain relevant global patterns, including the ones which we highlight.

Table 3. Factor analysis loadings for instruction-style questions

Variable	Loadings		Uniqueness
	TD Factor	SO Factor	
Sets Clear Goals	0.6102		0.5912
Encourages Thinking and Reasoning	0.4707		0.6481
Checks Understanding	0.6826		0.5588
Summarizes Previous Lessons	0.4429		0.6484
Informs about Learning Goals	0.6296		0.6778
Differentiates Between Students When Giving Tasks		0.5108	0.6755
Assigns Complex Projects		0.7220	0.5610
Has Students Work in Small Groups		0.5970	0.5809
Plans Classroom Activities		0.5696	0.6305

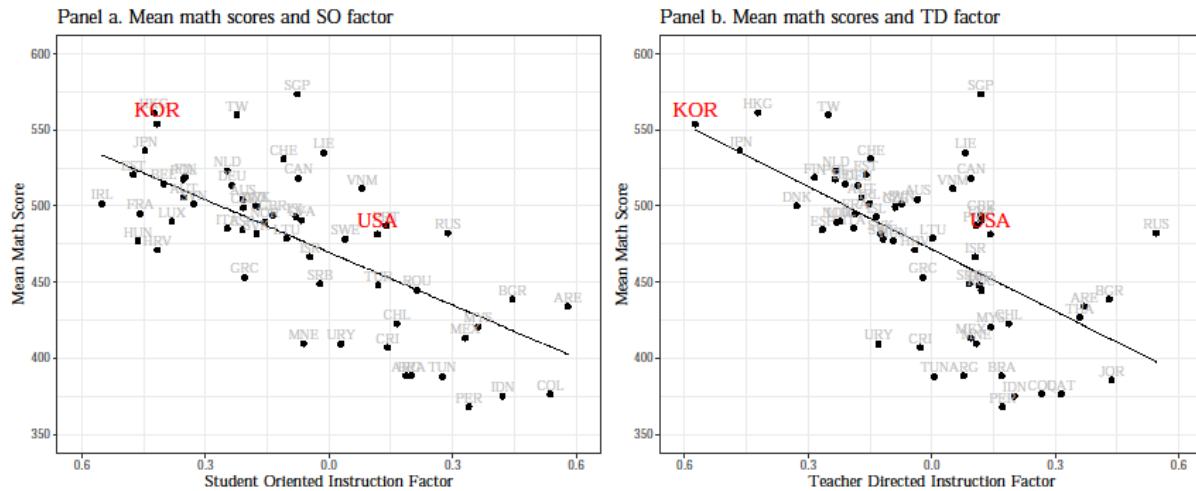
Source: 2012 PISA Exam & Student Questionnaire; Author's Calculations.

Of the 34 OECD member countries that participated in the 2015 PISA, the United States ranks joint first for use of student-oriented mathematics instruction, seventh in the use of teacher-directed instruction and twelfth in employing formative assessment. In the expanded sample of 62 countries that participated in the PISA, the U.S. ranked 12th in student-oriented instruction, 27th in teacher-directed instruction and 31st in formative assessment.

Prior to more sophisticated analyses, it is interesting to note that countries that are lauded for strong mathematics performance tend to employ student-oriented math instruction less intensively than the United States. For instance, the ten countries with the lowest composite scores for student-oriented mathematics instruction, followed by their ranks (out of 62) in the 2012 PISA, include: Korea (4), Japan (5), Finland (10), Luxembourg (27), Hong Kong (2), Switzerland (7), Netherlands (8), Estonia (9), Poland (11), and Belgium (13). Meanwhile, the ten countries with the highest scores for student-oriented mathematics instruction include: Peru (61), Russia (32), Malaysia (49), Colombia (58), United Arab Emirates (45), Thailand (47), Bulgaria (44), Jordan (57), Qatar (58) and Kazakhstan (46).

In Figure 3 below we plot each country's SO Factor (panel (a)) and TD factor (panel (b)) against math scores on the 2012 PISA for the full sample of participating countries.⁷ The U.S. (highlighted in red) is in the middle of the pack in terms of math performance amongst the 62 countries of this analysis. The average U.S. student earned 481 points on the PISA exam, 15 points below the OECD average and worse than 33 participating countries (see Table 5 below), though not all of these differences are necessarily statistically significant.

⁷ We exclude China-Shanghai, as well as the other sub-country observations, including U.S. state-level observations from Florida, Connecticut, and Massachusetts.

Figure 3. International math scores versus teaching styles, PISA 2012

Source: 2012 PISA Exam & Student Questionnaire; Author's Calculations.

A lower SO or TD factor value indicates less intensive use of that instructional approach. In the univariate cases, both teacher-directed and student-oriented instruction are associated with worse performances on the exam. Indeed, the instruction methods themselves are highly positively correlated with a coefficient of correlation equal to 0.88. In other words, countries which lean heavily on TD instruction *also* lean on SO instruction, so it is unclear which, if any, instruction style is driving worse performances in these countries.

Simple econometric methods can shed light on this question: holding the use of teacher-directed instruction constant, what is the relationship between student-oriented instruction prevalence and math scores (and vice versa)?

We can address this question using multiple linear regression (MLR). This provides us with estimates of the relationships between instruction styles and math performance which account for the other instruction style. That is, the regression coefficient on our TD Factor in a MLR setup is the expected change in math scores given an increase in TD instruction, holding SO instruction constant. Our estimates appear in Table 4 below. Columns (1) and (2) include just our SO and TD instruction factors, respectively. The third column includes both simultaneously, the fourth layers in a Formative Assessment (FA) index, a classroom instruction technique which differs from the more traditional “summative assessment” method and is distinct from either instructional approach, and the fifth column includes 2012 GDP per capita, gathered from the World Bank (thousands of 2012 U.S. dollars).

We offer several observations. First, the observed negative relationship between teacher-directed instruction and test scores is *not* robust to the inclusion of additional control variables. Specifically in Column (3), which controls for the use of SO instruction, we see that our TD Factor coefficient is not statistically significantly different from zero ($p = 0.96$). Further, in our full specification shown in Column (5), the coefficient for TO instruction is actually positive,

Table 4. Regression estimates of test scores on instruction styles

	(1)	(2)	(3)	(4)	(5)
SO Factor	-117.373*** (13.270)		-115.797*** (31.603)	-118.655*** (32.820)	-130.528*** (29.679)
TD Factor		-139.244*** (19.197)	-2.271 (41.264)	-10.331 (47.255)	42.365 (44.552)
FA Factor				-12.801 (35.684)	2.671 (32.343)
GDP per Capita					0.507*** (0.151)
Constant	470.397*** (4.481)	471.155*** (4.965)	470.409*** (4.524)	470.509*** (4.566)	452.481*** (6.499)
R-squared	0.566	0.467	0.566	0.567	0.645
N	62	62	62	62	61

Source: 2012 PISA Exam & Student Questionnaire; Author's Calculations.

Note: Standard errors in parentheses. Taiwan (labelled "Chinese Taipei" in the OECD database) does not have its own World Bank observation in 2012, hence there are only 61 observations.

* $p < 0.1$, ** $p < 0.05$, *** $p < .01$

though again statistically insignificant ($p = 0.35$). This suggests the negative relationship between test scores and TD instruction is largely driven by other factors, including SES and SO instruction. It is unclear whether the true relationship is positive or a well-estimated zero.

Second, the negative relationship between student-oriented instruction and math scores is robust to all specifications, suggesting this relationship is not spurious. This is consistent with the conclusion that student-oriented instruction is causally-related to lower PISA math scores. The estimates found in Column (5) imply that a one standard deviation increase in student-oriented instruction corresponds to a 44 point decrease in math scores, or about 84 percent of a standard deviation. For instance, a country that lies at the 75th percentile in the use of SO instruction style could expect PISA exam scores 61 points lower than a county at the 25th percentile, or about 1.2 standard deviations lower.

Third, we see that on an international-level, mathematics teaching styles have considerable explanatory power. Column (4) suggests teaching styles alone explain over 55 percent of the variance in math scores across countries.

As an additional exercise, we can use these model estimates to predict countries' performances given their observed characteristics. For example, considering the United States' economic conditions, how well do U.S. students perform? By estimating the univariate relationship between GDP per capita and PISA scores (not shown) and plugging the U.S. GDP per capita measure into that equation, we get an expected score of 485, 4 points higher than the

actual U.S. score. In other words, the U.S. *underperforms* in mathematics given its SES. In contrast, Korea *overperforms* by 90 points conditional on its GDP per capita.

What could explain these differences? Considering the evidence presented above, we suggest differing teaching styles could play a role. The U.S. heavily employs student-oriented instructional methods while Korea uses such methods only infrequently. For instance, 21 percent of U.S. students report doing group work in every mathematics lesson, while only 18 percent report never or hardly ever doing group work. By contrast, only 3 percent of Korean students do group work in every math lesson while 54 percent never or hardly ever use group.⁸

Using the estimates found in Columns (3) through (5) of Table 4, we can produce further math score predictions which include both SES and mathematics instructional style. In Table 5 below, we provide a series of predictions based upon the estimates found in Table 4. From left to right, we present a country's (1) name, (2) actual mean math score, (3-5) actual mean teaching style factors (SO, TD, and FA, respectively), (6) predicted math score using SES, (7) predicted math score using SES and teaching style factors, and (8) predicted math score using SES and *Korea's* mean teaching style factors. Rows are sorted from highest to lowest actual math scores.

Swapping every country to Korea's mathematics instruction style predicts a 22-point increase in the average score across these countries and a small 2-point increase in the OECD average. If the U.S. employed student-oriented instruction in the more limited level of Korean schools, the U.S. is predicted to score 19 points higher, closing over 25 percent of the mathematics test score gap between itself and Korea and placing its average score on par with that of Austria.

While instruction styles have considerable explanatory power, it is important to note that the U.S. and Korea have nearly the same expected score conditional on their respective SES and using Korea's instruction style. This suggests that, although Korea's reliance on teacher-directed instruction methods likely improves their ability to perform well on the PISA, there is still a large 54-point portion of their performance which is attributable to factors other than instruction style and economic performance.

Assuming these estimates would be directionally consistent in more recent years, any model of a country's ability to perform well on PISA must account for the relationships between instruction methods and mathematical achievement. Most would agree that the relationship between SES and math scores is not spurious, but what about the relationship between SO instruction and math scores? We argue this is because SO instruction is not effective. Or, put another way, team work – along with other student-oriented instructional practices – does not appear to make the dream work.

⁸ Japanese students used group work even less often, with 72 percent reporting they never or hardly ever participated in group work in math classes.

6. Student level analysis

We saw above that SO teaching methods correlate with poorer national-level math performances on the PISA exam. We now move to a student-level analysis of the individual teaching methods which underlie the factors computed for the analysis above.

We present here a simple model of a student's test score. In the following analysis, we estimate PISA mathematics exam scores in the following way:

$$score_{i,c} = B_0 + \sum_{j=1}^9 B_j teaching_method_{i,j} + \sum_{k=4}^K B_k X_k + \epsilon,$$

where $score_{i,c}$ is the math score for a student i in OECD country c , $teaching_method_{i,j}$ is i 's response to the question related to teaching method j , the same responses used to compute the factors found in Section 3 above, and X_k is a set of control variables, including formative assessment responses, country dummies, and other variables plausibly related to academic achievement, described above in Section 3.

Our first set of estimates appear below in Table 6. Each row corresponds to a different teaching style: the first five are considered TD methods while the second four are considered SO methods. Column (1) includes all teaching styles while columns (2) through (10) show univariate estimates for each teaching method. Note that observation counts differ somewhat column to column as some students did not answer all nine instruction questions.

Point estimates of these relationships are difficult to interpret because the underlying variables are categorical. However, positive coefficients indicate that more (less) of the teaching method is associated with higher (lower) scores.⁹ From Column 1 we see that three of the five teacher-directed instruction methods are associated with higher math scores while all four of the student-oriented instruction methods are associated with lower math scores. Similar to the international regression analysis performed above, we can see that in the univariate cases, TD teaching styles are associated with worse scores in four of the five cases, but accounting for a student's exposure to SO teaching styles reverses this sign for three methods and significantly reduces the negative effect in the remaining cases.

Based on the results in Table 6, clearly defining and informing a student of learning goals and encouraging a student to think and reason on their own appear to be the most effective teaching methods while assigning complex projects, planning large classroom-wide activities, and relying on group work appear to be the most detrimental techniques.

⁹ A one unit increase in a teaching method's variable corresponds to a shift in the method being applied from in "no lessons" to in "some lessons," from "some lessons" to "most lessons," or in "most lessons" to "every lesson." The coefficient is thus the average increase in math scores associated with a one-step increase in these categorical changes, weighted by the number of students in each group.

Table 5. Actual and predicted scores for each country based on estimates from Table 4

Country	Actual Math	Instruction Factors			Predicted Scores		
		SO	TD	FA	Using SES	Using SES & Instruction Factors	Using SES & Korea Instruction Factors
Singapore	573	-0.1	0.0	-0.1	488	492	502
Hong Kong	561	-0.4	-0.5	0.3	472	504	498
Taiwan	560	-0.2	-0.2	0.2			
Korea	554	-0.3	-0.4	0.7	463	500	500
Japan	536	-0.3	-0.4	0.7	482	512	511
Liechtenstein	535	0.0	0.1	0.1	563	538	553
Switzerland	531	-0.1	-0.1	0.2	512	501	522
Netherlands	523	-0.2	-0.3	0.2	483	496	504
Estonia	521	-0.4	-0.2	0.2	457	506	487
Finland	519	-0.3	-0.3	0.3	481	512	504
Canada	518	-0.1	0.0	-0.1	485	492	501
Poland	518	-0.3	-0.3	0.2	453	489	484
Belgium	515	-0.4	-0.2	0.3	479	515	502
Germany	514	-0.2	-0.2	0.2	478	500	501
Vietnam	511	0.1	0.2	0.1	445	454	478
Austria	506	-0.4	-0.2	0.1	482	513	501
Australia	504	-0.2	-0.1	0.0	498	507	510
Ireland	501	-0.6	-0.2	0.2	482	541	503
Slovenia	501	-0.3	-0.1	0.1	461	500	489
Denmark	500	-0.2	-0.3	0.2	490	493	509
New Zealand	500	-0.2	-0.2	0.0	475	484	495
Czech Republic	499	-0.2	0.0	0.3	459	488	489
France	495	-0.4	-0.3	0.3	476	518	499
Great Britain	494	-0.2	0.0	-0.2	477	496	495
Iceland	493	0.0	-0.1	0.2	480	478	502
Latvia	491	0.0	0.1	0.1	454	469	483
Luxembourg	490	-0.3	-0.3	0.3	533	546	537
Norway	489	-0.2	-0.3	0.1	525	513	529
Portugal	487	0.1	0.1	-0.2	459	455	484
Italy	485	-0.3	-0.2	0.0	471	493	493
Spain	484	-0.3	-0.2	0.1	466	492	492
Russia	482	0.3	0.5	-0.3	455	445	478
Slovakia	482	-0.2	-0.2	0.0	457	477	484
United States	481	0.1	0.1	-0.1	485	469	500

Lithuania	479	-0.1	0.0	0.1	455	472	484
Sweden	478	0.1	-0.1	0.1	490	470	506
Hungary	477	-0.5	-0.2	0.1	453	510	484
Croatia	471	-0.4	-0.1	0.1	454	507	483
Israel	466	0.0	0.1	0.0	470	472	492
Greece	453	-0.2	0.0	0.2	461	494	489
Serbia	449	0.0	0.1	0.0	448	456	477
Turkey	448	0.1	0.1	-0.1	452	447	481
Romania	445	0.2	0.1	-0.2	450	434	477
Bulgaria	439	0.4	0.4	-0.6	449	412	471
U.A.E.	434	0.6	0.4	-0.4	479	414	492
Kazakhstan	432	0.7	0.7	-0.6	453	394	473
Thailand	427	0.7	0.4	-0.4	448	383	473
Chile	423	0.2	0.2	-0.1	455	448	482
Malaysia	421	0.4	0.1	-0.3	451	412	476
Mexico	413	0.3	0.2	0.0	452	427	481
Montenegro	410	0.0	0.1	0.0	448	463	478
Uruguay	409	0.0	-0.1	0.2	456	457	486
Costa Rica	407	0.1	0.0	0.1	451	444	483
Albania	394	0.7	0.7	-0.6	446	391	470
Brazil	389	0.2	0.1	-0.1	453	440	479
Argentina	388	0.2	0.1	0.1	453	440	483
Tunisia	388	0.3	0.1	0.0	446	419	477
Jordan	386	0.7	0.5	-0.5	446	377	471
Colombia	376	0.5	0.3	-0.3	449	402	475
Qatar	376	0.8	0.4	-0.5	522	413	519
Indonesia	375	0.4	0.3	-0.2	446	408	475
Peru	368	0.3	0.2	-0.2	448	418	476
Average	470.5	0.0	0.0	0.0	469.1	469.1	492.0
OECD Average	496.3	-0.2	-0.1	0.1	476.3	492.8	498.4

Source: 2012 PISA Exam & Student Questionnaire; Author's Calculations.

Table 6. Regression estimates of test scores on instruction styles at the individual student-level

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Sets Clear Goals	-4.041* (0.752)	-8.529* (0.690)								
Encourages Thinking and Reasoning	8.389* (0.745)		-2.886* (0.667)							
Checks Understanding	4.535* (0.745)			-2.582* (0.656)						
Summarizes Past Lessons	-6.209* (0.605)				-12.965* (0.573)					
Informs about Learning Goals	9.762* (0.701)					3.830* (0.676)				
Differentiates Between Students	-6.146* (0.581)						-16.263* (0.527)			
Assigns Complex Projects	-14.792* (0.965)							-24.793* (0.857)		
Has Students Work in Small Groups	-10.025* (0.937)								-19.254* (0.934)	
Plans Classroom Activities	-14.593* (0.885)									-25.290* (0.704)
Constant	367.099* (-3.530)	471.622* (1.972)	482.671* (2.222)	484.291* (1.964)	456.243* (2.144)	496.218* (1.768)	437.635* (1.937)	409.533* (3.221)	432.729* (3.497)	406.025* (2.562)
R-Squared	0.112	0.007	0.001	0.001	0.019	0.001	0.030	0.059	0.043	0.056
Observations	188108	192118	191951	191697	191859	191836	191806	191799	191865	191832

Source: 2012 PISA Exam & Student Questionnaire; Author's Calculations.

Note: Sample limited to students in OECD countries. Standard errors in parentheses.

* $p < .01$

To check the robustness of these results, we layer in additional controls and present these results in Table 7 below. The table is divided into four sections: TD instruction questions, SO instruction questions, formative assessment questions, and additional controls, in that order. The estimates found in Column 1 reflect the model specification with all teaching methods (including questions about formative assessment) but no additional controls. Column 2 adds in a student-level measure of SES. Column 3 layers in a measure of family structure, Column 4 adds an indicator for whether the student speaks the test language in their home, Column 5 adds immigration status, and Column 6 includes country dummies.

The coefficient on “Sets Clear Goals” becomes statistically insignificant in the final specification where country dummies are included, but, otherwise, coefficient estimates on TD and SO instruction styles prove to be fairly robust. Three of the five teacher-directed teaching methods are associated with higher PISA mathematics exam scores. The exception, summarizing previous lessons, is associated with lower scores in all specifications. It is unclear intuitively why reviewing prior lessons would correlate with lower scores, unless first, doing so reduced time available for other more productive instruction, or second, such reviews tended to be more

Table 7. Regression estimates of test scores on instruction styles at the individual student-level, including several controls

	(1)	(2)	(3)	(4)	(5)	(6)
Sets Clear Goals	-3.00*** (0.757)	-1.989** (0.667)	-2.529*** (0.694)	-2.574*** (0.700)	-2.553*** (0.727)	-0.420 (0.725)
Encourages Thinking and Reasoning	8.750*** (0.731)	7.743*** (0.680)	7.645*** (0.742)	7.568*** (0.754)	7.465*** (0.756)	8.146*** (0.753)
Checks Understanding	5.786*** (0.755)	6.752*** (0.751)	6.902*** (0.786)	6.712*** (0.786)	6.718*** (0.798)	8.263*** (0.745)
Summarizes Previous Lessons	-5.793*** (0.620)	-3.881*** (0.595)	-3.850*** (0.595)	-3.908*** (0.608)	-4.001*** (0.597)	-5.857*** (0.616)
Informs about Learning Goals	9.900*** (0.765)	7.120*** (0.706)	6.819*** (0.729)	6.759*** (0.738)	6.784*** (0.745)	4.562*** (0.738)
Differentiates Between Students When Giving Tasks	-4.811*** (0.620)	-3.240*** (0.606)	-3.108*** (0.615)	-3.024*** (0.616)	-2.890*** (0.592)	-6.970*** (0.594)
Assigns Complex Projects	-14.098*** (0.957)	-12.439*** (0.844)	-11.581*** (0.854)	-11.553*** (0.888)	-11.477*** (0.923)	-9.565*** (0.933)
Has Students Work in Small Groups	-9.136*** (0.923)	-9.113*** (0.715)	-9.061*** (0.783)	-9.014*** (0.774)	-8.776*** (0.765)	-3.070*** (0.767)
Plans Classroom Activities	-12.593*** (0.897)	-7.876*** (0.792)	-7.405*** (0.776)	-6.932*** (0.774)	-6.829*** (0.775)	-10.224*** (0.712)
Gives Feedback	-3.557*** (0.787)	-5.645*** (0.729)	-5.492*** (0.765)	-5.353*** (0.748)	-5.436*** (0.745)	-0.297 (0.673)
Gives Feedback on Strengths and Weaknesses	-3.065*** (0.883)	-3.932*** (0.825)	-3.706*** (0.824)	-3.611*** (0.839)	-3.565*** (0.838)	-3.044*** (0.842)
Informs About Expectations	6.473*** (0.818)	2.153** (0.775)	2.126** (0.818)	2.080** (0.835)	2.186** (0.853)	4.958*** (0.822)
Tells How to Get Better	-6.856*** (0.763)	-3.372*** (0.696)	-3.305*** (0.686)	-3.355*** (0.690)	-3.487*** (0.705)	-4.041*** (0.712)
SES		33.036*** (0.612)	31.903*** (0.645)	31.776*** (0.651)	31.814*** (0.662)	29.125*** (0.622)
Family Structure			12.528*** (1.364)	12.965*** (1.368)	12.823*** (1.392)	9.494*** (1.312)
Test Language at Home				10.732*** (3.075)	8.176** (3.709)	6.060* (3.618)
Immigration Status					-2.590 (2.200)	-0.730 (2.112)
Constant	367.706*** (3.570)	390.368*** (3.342)	375.779*** (4.484)	367.636*** (5.619)	374.791*** (7.641)	401.591*** (7.245)
Country Dummies	No	No	No	No	No	Yes
R-Squared	0.120	0.252	0.243	0.245	0.244	0.308
Observations	186601	185510	169333	163644	161734	161734

Source: 2012 PISA Exam & Student Questionnaire; Author's Calculations.

Note: Sample limited to students in OECD countries. Not all students provided responses to all survey questions, hence the observation counts decrease as we add in controls. Standard errors in parentheses.

* $p < 0.1$, ** $p < 0.05$, *** $p < .01$

common in classrooms whose students are lower-performing for reasons other than those that can be accounted for using our controls.

On the other hand, all four student-oriented teaching styles are correlated with worse performances on the math portion of the PISA exam even when controlling for a student’s family structure, SES, test language comfort, and immigration status.

We also report coefficients on our control variables of expected signs. For example, higher SES and speaking at home the language in which the test is written are consistently associated with better scores across all relevant specifications, though the latter effect appears to be moderated by immigration status. Interestingly, households with two parents outperform households with one or zero parents even after controlling for household resources (SES), as shown in Columns 2 through 5. This may be because two parents have additional time to devote to their children’s education, even after controlling for the material resources available to them.

As a final analysis, we estimate a similar regression model which includes each of our instruction styles factors rather than the individual questions themselves. Our estimates are presented in Table 8. Using the estimates presented in Column 6, a one standard deviation increase in the use of student-oriented mathematics instruction correlates with a decline in PISA exams scores of 0.27 standard deviations, while a one standard deviation increase in teacher-directed instruction corresponds with a 0.19 standard deviation increase in math scores. For context, a one standard deviation increase in SES predicts an increase in score of 33 points, or 0.33 standard deviations; shifting from a one-parent household to a two-parent household corresponds with an increase of about 10 points, or about 0.1 standard deviations; and shifting from a student not speaking the test language at home to speaking it at home corresponds with an exam score increase of 6.4 points or 0.07 standard deviations. These results imply that mathematics instructional methods result in differences in mathematics proficiency that are not only statistically significant but meaningful in size.

7. Limitations

In this paper we report a statistically significant and robust negative relationship between student-oriented instruction methods and student performance on the math portion of the PISA exam, at both the international- and student-level. This being said, the data and methods used here have several limitations, which we describe below.

The evidence presented here is not causal. That is, while we include several covariates to try to isolate the relationships of interest, we cannot claim to have demonstrated causal evidence of this relationship. Crucially, instruction techniques may plausibly be guided by student ability, as noted by Echazarra et al. (2016), potentially in ways that are not accounted for by the background variables we include. More refined research requires causal (i.e., randomized assignment of students to instructors) or pseudo-causal (i.e., a policy which as-if

Table 8. Regression estimates of test scores on instruction styles at the individual student-level, using instruction style factors and including several controls

	(1)	(2)	(3)	(4)	(5)	(6)
SO Factor	-46.129*** (1.233)	-37.764*** (1.227)	-36.040*** (1.289)	-35.422*** (1.299)	-34.959*** (1.337)	-33.024*** (1.358)
TD Factor	24.539*** (0.918)	22.345*** (0.944)	21.205*** (1.033)	20.674*** (1.025)	20.511*** (1.037)	21.548*** (1.052)
FA Factor	-8.298*** (0.892)	-10.280*** (0.83)	-9.841*** (0.898)	-9.635*** (0.883)	-9.697*** (0.886)	-5.477*** (0.894)
SES		33.570*** (0.614)	32.390*** (0.649)	32.244*** (0.658)	32.300*** (0.666)	29.883*** (0.633)
Family Structure			12.866*** (1.35)	13.320*** (1.35)	13.211*** (1.382)	9.816*** (1.302)
Test Language at Home				10.992*** (3.109)	8.400** (3.724)	6.365* (3.638)
Immigration Status					-2.517 (2.269)	-0.521 (2.226)
Constant	487.596*** (1.095)	492.696*** (0.938)	472.985*** (2.788)	463.005*** (4.347)	468.925*** (6.395)	476.634*** (6.230)
Country Dummies	No	No	No	No	No	Yes
R-Squared	0.103	0.244	0.234	0.236	0.235	0.295
Observations	186601	185510	169333	163644	161734	161734

Source: 2012 PISA Exam & Student Questionnaire; Author's Calculations.

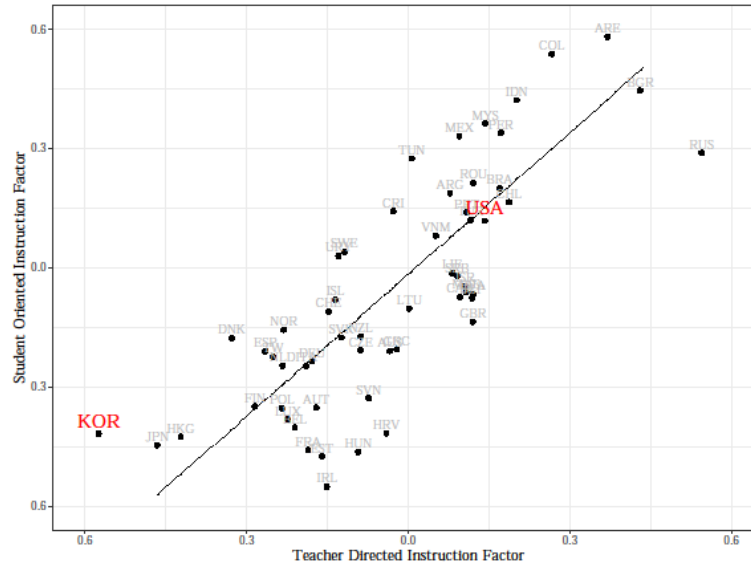
Note: Sample limited to students in OECD countries. Not all students provided responses to all survey questions, hence the observation counts decrease as we add in controls. Standard errors in parentheses.

* $p < 0.1$, ** $p < 0.05$, *** $p < .01$

randomly assigns students to instructors) methodologies. We believe the results presented in this paper support the pursuit of such research.

For several analyses, we use PCA to compute several instruction style indexes using student survey responses. PCA is a dimensionality-reducing statistical method which identifies and estimates a latent variable which explains variation in a larger set of variables. In this case, we use it to identify latent teaching styles, namely student-oriented and teacher-directed styles of instruction, using a series of survey questions about instruction style. While this process identifies latent variables consistent with our expectations, it predicts values which are highly positively correlated, as shown below in Figure 4.

This is the exact opposite of the relationship we would expect to see between these two variables if teaching instruction was best modeled as a continuum between these two styles. That is, under the continuum assumption, less SO instruction predicts more TD instruction since it is the only other way to teach, but, empirically, we predict less TD instruction. This

Figure 4. International teaching styles, PISA 2012

Source: 2012 PISA Exam & Student Questionnaire; Author's Calculations.

implies there is some other, poorly-captured mode of instruction which is not captured in our analysis, nor in the underlying data seeing as this correlation exists in the OECD measures of teaching style, as well.

8. Conclusions

The knowledge and skills acquired during primary and secondary education have long-lasting impacts on an individual's ability to succeed both socially and economically. In this paper, we use data from the 2012 PISA exam to analyze the ways in which teachers assist students in that process. We conclude that specific mathematical teaching methods are consequential to that student's learning, specifically presenting evidence that student-oriented instruction methods lead to lower exam performances for students compared to the teacher-directed instruction methods. We find this to be true both when comparing average performance by country and when comparing students within countries.

At the international level, we find a robust negative relationship between student-oriented instruction and math performance. Employment of student-oriented instruction has considerable explanatory power, accounting for 55 percent of the variation in math scores across OECD countries. Inquiries into the nature and causes of nations' educational performances must account for the trends displayed here. No doubt such theories should include socioeconomic factors such as GDP per capita, but here we argue the teaching styles commonly adopted in a country should be included, as well. We also exploit the highly-granular, student-level data published by the OECD to perform a student-level analysis which leads to similar conclusions. Instruction choices matter.

We conclude that the OECD's nuanced attitude to mathematics instruction, in which both student-oriented and teacher-oriented instruction are held to have a place, may be too nuanced. To the extent that instructional leaders must devote class time and resources to one or the other of the approaches, teacher-directed instruction appears more likely to result in students exhibiting proficiency on the PISA or similar mathematics exams.

These results point to the utility of future research that explores choices in mathematics instructional styles in greater detail, for example through gathering additional data on teaching styles and seeking out natural experiment settings where questions about a teacher's instruction style can be reliably measured and isolated from other factors. This research may use PISA data or similar data, but we also believe alternative data sources should be used which are better able to quantify teaching styles.

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