

When Technology Does Not Add Up: ICT Use Negatively Predicts Mathematics and Science Achievement for Finnish and Turkish Students in PISA 2012

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Abstract: This study examines data of students from Finland ($n = 8,829$) and Turkey ($n = 4,848$) who participated in the 2012 Programme for International Student Assessment (PISA). The purpose of this study is to discern whether the use of information and communication technologies (ICT) at home and at school has a differential predictive effect for academic achievement in mathematics and science. Structural equation modeling analyses revealed that the *use* of ICT at home for schoolwork and at school for mathematics lessons was negatively associated with mathematics and science achievement in both countries, while merely the *availability* of ICT at home and at school was positively associated with achievement in Turkey but not in Finland. The use of ICT for *entertainment* was associated positively with achievement in Turkey but negatively in Finland. These results have implications for the adoption of ICT in formal and informal learning environments.

Keywords

mathematics; science; academic achievement; information and communication technology (ICT); Finland; Turkey; PISA

Introduction

Recent research regarding large-scale international assessments (e.g., PISA, TIMSS or PIRLS) has yielded mixed results pertaining to the associations between student achievement and the frequency of information and communication technology use in schools and at home. For instance, test scores tend to be associated positively with computer use at home but negatively with computer use in school (Petko, Cantieni, & Prasse, 2017). Given the importance and advent of technology in education, this study explores the relationship between ICT-related variables and students' academic achievement in mathematics and science. It employs data originating from both the 2012 *Programme for International Student Assessment* (PISA) and the *Information and Communication Technology Familiarity Questionnaire* (OECD, 2013a) for students from Finland and Turkey (PISA, 2013), two countries with different access to ICT in an attempt to shed more light onto the potential "digital divide" or the differences in access to ICT and use of ICT between these countries.

Information and Communication Technology (ICT) Use

The PISA *ICT Familiarity Questionnaire* was designed to gather data about students' access, use, and attitudes towards ICT. This questionnaire was administered after the international student questionnaire and took approximately five minutes to complete. It includes several survey items about the use of technical devices, such as computers, as well as tools employed for information and communication. ICT survey items include questions about the use of devices, at school and at home, for activities such as downloading media, gaming, Internet surfing, and time spent on various ICT-related activities.

Mathematics, Science, and ICT

Mathematics is a subject that relies increasingly on computers and technology. For example, students use games and simulations (Chang, Wu, Weng, & Sung, 2012; Van Eck & Dempsey, 2002) to learn many complex aspects of mathematics. Science also uses ICT intensively, especially to model phenomena difficult to observe in

nature (Osborne & Dillon, 2010; Wals, Brody, Dillon, & Stevenson, 2014). There is also a wide disparity in terms of ICT among the *Organisation for Economic Co-operation and Development* (OECD) and partner countries. These discrepancies in ICT availability and use may have an impact on academic achievement. For example, Finland, a country with an advanced economy and homogeneous access to ICT (Niemi, Kynäslahti, & Vahtivuori-Hänninen, 2013; Wilska & Pedrozo, 2007), achieved above-OECD average scores in mathematics (519) and science (545) in PISA 2012, respectively. At the same time, Turkey, a country with an emerging and developing economy and heterogeneous access to ICT (Uluyol, 2013; Yildirim, 2007), achieved below-OECD average scores in mathematics and science (448 and 463, respectively) in PISA 2012 (OECD, 2013a). Therefore, we aim to investigate the extent to which students' ICT use affects their achievement in mathematics and science in two European countries with different access to ICT. Specifically, the main objective of this study is to discern whether the ICT use at home and at school has a differential predictive effect for academic achievement in mathematics and science. We pose the following research questions:

- a) *Does ICT use at home and at school predict academic achievement in mathematics and science?*
- b) *Are the results similar for students in Finland and Turkey?*

The following sections include a review of the relevant literature, a description of the PISA assessments, the methodology employed to analyze the data, a discussion of the findings, and future research directions.

Literature Review

Research examining the ICT use at home and at school yielded widely different and somewhat inconsistent results. In this section, we briefly outline the research results we found in the literature for ICT use at home and at school, respectively.

ICT Use at Home

Researchers investigated the relationship between the different purposes of ICT use (i.e., low-level tasks, such as browsing the Internet for entertainment, high-level tasks, such as programming or using advanced software, and confidence in their ICT use for these purposes, respectively) and achievement in mathematics for the PISA 2006 data (Güzeller & Ayça, 2014). They found that the ICT variables explained only a small amount of variance in mathematics achievement. Specifically, ICT use (both low and high level) is a significant negative predictor of mathematics, whereas confidence in performing these activities is a significant positive predictor of mathematics. Other researchers found a strong association between the frequent use of ICT at home and higher levels of ICT self-efficacy (Tømte & Hatlevik, 2011).

In an earlier study surveying over five hundred Finnish students ranging from 11 to 18-year old, researchers found that students' ICT use at home influenced their overall ICT use the most, even in schools with intensive ICT use (Hakkarainen et al., 2000). These results emphasize the importance of the ICT activities unfolding at home.

ICT Use at School

Researchers found that, even though students from Germany and the USA reported a higher frequency of ICT use at school for software and programming in the PISA 2000 data, they performed below the OECD average in both mathematics and science (Papanastasiou, Zembylas, & Vrasidas, 2005; Papanastasiou & Ferdig, 2006). At the same time, in Finland, findings show that even schools that reported an intensive ICT use were not successful in integrating ICT in students' schoolwork, although students' ICT use at school was a factor that influenced their overall ICT use (Hakkarainen et al., 2000).

Programme for International Student Assessment (PISA)

PISA is an international assessment of competencies that has been administered every three years since 2000 to 15-year-old students from the OECD member countries and other partner countries (OECD, 2017). It is a

two-hour paper-based test that evaluates students' mathematics, science, and reading competencies. Additionally, PISA collects self-reported data on students' backgrounds, schools, and learning experiences via a questionnaire that takes approximately 30 minutes to complete. The tests combine open-ended and multiple-choice questions grouped under a real-life scenario. Every three years, PISA focuses on a specific subject. In 2012, PISA focused on mathematics and it was administered to nearly 510,000 students between the ages of 15 years 3 months and 16 years 2 months in 65 countries representing 80% of the world's economy (PISA, 2013). In 2012, some students were asked to complete 40-minute computer-based assessments of mathematics, reading, and problem solving. In this study, we focus on the impact of ICT on students' achievement in both mathematics and science.

Mathematics and Science Academic Skills

The relation between students' ICT use and academic achievement in mathematics and science was extensively explored. We distinguish three types of results in the literature: positive associations, negative associations, and no association.

Positive Associations. Delen and Bulut (2011) analyzed the PISA 2009 data employing hierarchical linear modeling and found that ICT use explained the achievement gap in mathematics and science between individuals and schools for Turkish students. Specifically, they found that students' out-of-school ICT time had a larger impact on their mathematics and science achievement than their in-school ICT time, which was found to be a weak predictor of mathematics and science achievement. Furthermore, the PISA 2006 data revealed that Czech students who integrated ICT into their learning process achieved higher science scores than students who did not use ICT (Kubiak & Vlckova, 2010). Similarly, Korean students with long-term ICT experience achieved higher scores in mathematics, science, and reading (Kim, Seo, & Park, 2008). Additionally, the PISA 2006 data revealed that Turkish students' achievement in mathematics was positively associated with self-reliance in performing ICT Internet tasks and negatively associated with self-reliance in performing ICT high-level tasks, such as programming or using advanced software (Ziya, Doğan, & Kelecioğlu, 2010).

Negative Associations. Researchers examined the role of arts-related ICT use in students' mathematics and science academic achievement (Liem, Martin, Anderson, Gibson, & Sudmalis, 2014). They used structural equation modeling to explore the 2003 PISA data, including the ICT survey data. Results showed that the quality of students' arts-related ICT use was positively associated with mathematics and science achievement, while the quantity of students' arts-related ICT use was negatively associated with science and mathematics achievement.

No Associations. At the same time, no significant differences were found in the PISA 2006 data between students' achievement in mathematics and their ICT use, including their ICT use for entertainment and Internet activities (Aypay, 2010). As well, no association was found between computer access or frequency of computer use at home and mathematics achievement of students from Germany who participated in PISA 2003 (Wittwer & Senkbeil, 2008). Similarly, in PISA 2003, there was no association between ICT use in school and mathematics, reading and science test scores (Shewbridge, Ikeda, & Schleicher, 2006). Additionally, in PISA 2000, no association was found between computer use at home or at school and student academic achievement (Bielefeldt, 2005).

These mixed results between students' ICT use and their mathematics and science scores warrant a closer examination to clarify the differential contribution of ICT at school and at home to academic achievement.

ICT Familiarity Questionnaire

The *ICT Familiarity Questionnaire* is an optional instrument employed in addition to the assessment of reading, mathematics, and science competencies. This instrument aims to assess the availability and use of ICT both at school and outside school, as well as students' general computer use and attitudes towards computers. In PISA 2012, eight scaled indices were computed based on the information obtained from the ICT self-report questionnaire using item response theory models. The detailed descriptions of these indices and statistical procedures used for creating them can be found in the PISA 2012 Technical Report (PISA, 2014).

In this study, we included six of the ICT-related indices as predictors of mathematics and science achievement, as illustrated in Table 1. Each index typically ranges from -4 to 4 on a logarithmic scale. Higher and positive values indicate higher levels of the latent trait being measured by each of those indices.

Table 1. ICT-related indices included in the analyses

Index	Index Definition
ICTHOME	ICT availability at home
ICTSCH	ICT availability at school
ENTUSE	ICT use for entertainment outside of school
HOMESCH	ICT use at home for school-related tasks
USESCH	Use of ICT at school
USEMATH	Use of ICT in mathematics lessons at school

Methods

Participants and Procedure

We analyzed the publicly-available PISA 2012 data restricted to two countries, Finland and Turkey. A subset of the PISA countries also participated in the ICT survey. In this study, we focus on a sample of students illustrated in Table 2. The PISA 2012 assessment consisted of a stratified random sample with 8,829 Finnish students randomly selected from 311 middle schools in Finland and 4,848 Turkish students randomly selected from 170 middle schools in Turkey (OECD, 2013b). The proportions of male and female students in both countries were very similar, as shown in Table 2.

Table 2. PISA 2012 participants from Finland and Turkey

Country	Number of Students		
	Total	Female	Male
Finland	8,829	4,370 (49.5%)	4,459 (50.5%)
Turkey	4,848	2,370 (48.9%)	2,478 (51.1%)

Measures

We built a series of structural equation models. Each model included several independent variables and a latent variable that was based on five observed variables. The variables are described in detail in the following section.

ICT

The independent variables in this study represent the ICT use at school and at home, and they are further refined based on the type of the ICT activity. As described earlier, all of the ICT-related variables were derived from the ICT Familiarity Questionnaire.

ICT at School

The variables relevant to ICT at school that we included in the study were: *Availability of ICT at school* (ICTSCH), *Use of ICT at school* (USESCH), and *Use of ICT in Mathematics Lessons* (USEMATH).

ICT at Home

The questions relevant to ICT at home that we included in the study were: *Availability of ICT at home* (ICTHOME), *ICT Use at Home for School-related Tasks* (HOMESCH), and *Use of ICT for Entertainment Purposes* (ENTUSE).

Achievement in Mathematics and Science

The dependent variables that we included in the study are *Math* and *Science*. For each of these two variables, we employed the corresponding five plausible values of students' PISA 2012 scores. Using the plausible values, a single latent variable that represents the achievement in either mathematics or science was created for each model. The independent variables representing *ICT at home* and *ICT at school* were used to predict the latent variables of mathematics and science achievement using the structural equation modeling approach.

Table 3 provides a descriptive summary of the variables used in this study across Finland and Turkey. This table indicates that the students from Finland performed significantly better than the students in Turkey in both *Math* and *Science*. Furthermore, both values of the ICT availability at home (*ICTHOME*) and at school (*ICTSCH*) in Finland exceed the corresponding values in Turkey. An interesting finding is that, despite higher ICT availability in Finland, both the use of ICT in mathematics lessons (*USEMATH*) and the use of ICT at home for school-related tasks (*HOMESCH*) seem to be higher in Turkey. Finally, students from Finland report a significantly higher use of ICT at school (*USESCH*) and for entertainment (*ENTUSE*) than students from Turkey.

Table 3. Descriptive statistics of the variables by country

Variable	Finland		Turkey	
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>
ICTHOME	-0.009	0.721	-1.194	1.237
ICTSCH	0.307	0.784	-0.415	1.145
ENTUSE	0.176	0.741	-0.421	1.396
HOMESCH	-0.644	0.875	0.059	1.040
USESCH	0.159	0.692	-0.327	1.092
USEMATH	-0.253	0.814	0.267	1.102
Math	507.326	86.829	449.371	90.057
Science	527.664	95.694	464.066	73.349

Analyses

Data analyses were conducted using structural equation modeling (SEM), a general statistical technique to model complex relationships between observed and latent variables using multivariate procedures (Hox & Bechger, 1998). In PISA, instead of a single test score in reading, mathematics, and science, five plausible values are generated for each student from the posterior distribution given the information available about that student. In this study, two latent variables, *Math* and *Science* scores, were created as averages of the five plausible values provided for each of these subject areas in the PISA 2012 database. Then, these latent variables were predicted by the observed variables related to ICT use at school and ICT use at home.

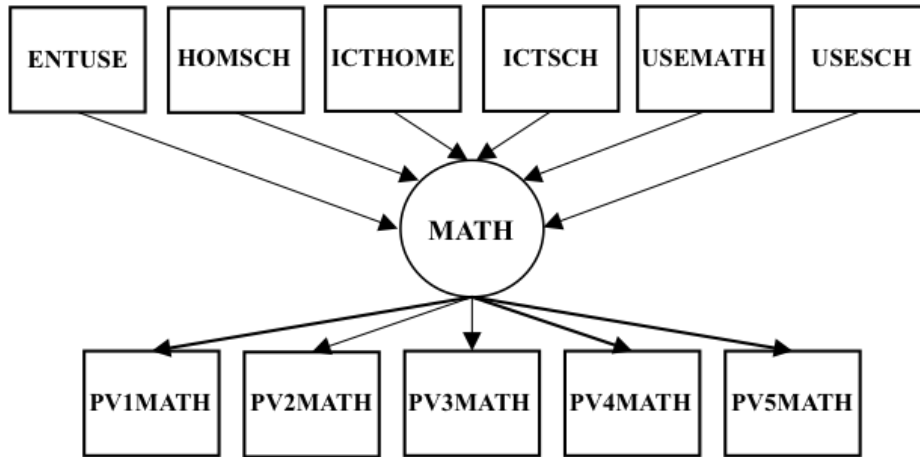


Figure 1. The relation between ICT use and Math scores

We created two SEM models per country, one model to explore the relation between ICT and achievement in mathematics (see Figure 1) and another to explore the relation between ICT and science (see Figure 2). All of the six ICT-related predictors described above were used in the analysis to predict mathematics scores and the same ICT-related predictors, except for *Use of ICT in Mathematic Lessons* (USEMATH), were used to predict science scores. The SEM models were estimated for each grade band using maximum likelihood estimation with robust standard errors (MLR) in Mplus 7 (Muthén & Muthén, 1998-2017). We examined the model-data fit, as well as the statistical significance of the relationships between mathematics and science scores and the ICT-related variables at the .05 significance level.

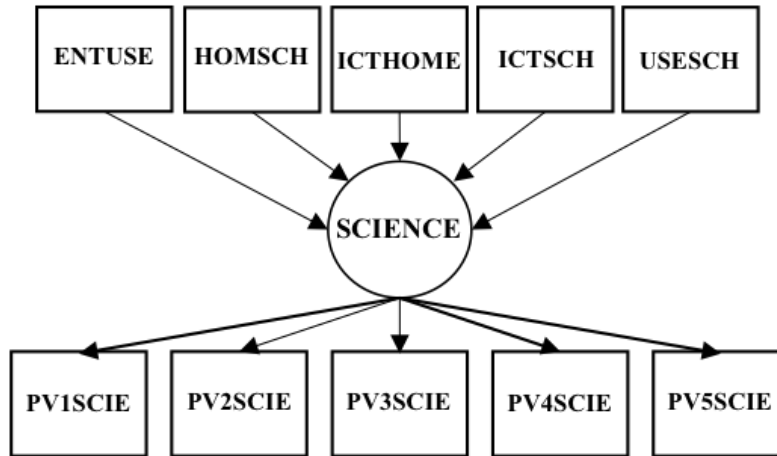


Figure 2. The relation between ICT use and Science scores

Results

The fit of the SEM models was evaluated based on factor loadings of the variables and various model-fit indices, such as the comparative fit index (CFI), Tucker-Lewis index (TLI), and root-mean-square error of approximation (RMSEA). CFI and TLI values greater than 0.90 are typically considered acceptable, while values greater than 0.95 are considered a good fit (Hu & Bentler, 1999). RMSEA values smaller than 0.05 are usually considered a close fit, while values equal to or greater than 0.10 are considered a poor fit (Browne, Cudeck, Bollen, & Long, 1993). Based on these criteria, we found that each of the SEM models indicated a good model-data fit, as shown by the model fit information presented in Table 4.

Table 4. Summary of model fit from the SEM models

Country	Subject	χ^2	df	CFI	TLI	RMSEA
Finland	Math	22.510	29	1	1	.001
Finland	Science	27.460	29	1	1	.001
Turkey	Math	23.676	29	1	1	.001
Turkey	Science	31.139	29	1	1	.004

Note: CFI: Comparative fix index; TLI: Tucker-Lewis index; RMSEA: root-mean-square error of approximation.

ICT for Schoolwork

Table 5 provides a summary of the standardized factor loadings resulting from the SEM analyses. We found that the use of ICT at school (USESCH) was negatively associated with achievement in mathematics and science in both Finland and Turkey. As the schools in Finland and Turkey used ICT in instructional activities more frequently, student achievement in mathematics and science decreased significantly in both countries. Similarly, the use of ICT for mathematics lessons in school (USEMATH) was negatively associated with achievement in mathematics and science in both Finland and Turkey. Unlike these two ICT-related predictors, ICT use at home for school-related tasks (HOMESCH) was not statistically related to mathematics and science achievement in Finland and Turkey.

ICT Availability

Additionally, we found that ICT availability at home (ICTHOME) and ICT availability at school (ICTSCH) were positively associated with mathematics and science achievement in Turkey, whereas these predictors did not have any significant impact on mathematics and science achievement in Finland.

ICT for Entertainment

Finally, we found that the use of ICT for entertainment (ENTUSE) was positively associated with achievement in Turkey, whereas it was negatively associated with achievement in Finland, as shown in Table 5. The association between the use of ICT for entertainment and test scores in Math and Science was very similar within each country.

Table 5. Summary of standardized factor loadings

Country	Subject	ENT	HS	ICTH	ICTS	USES	USEM
Finland	Math	-.070*	.019	.001	.001	-.101*	-.133*
Finland	Science	-.055*	-.011	-.009	.009	-.107*	
Turkey	Math	.068*	-.018	.231*	.088*	-.107*	-.250*
Turkey	Science	.069*	-.019	.209*	.094*	-.120*	

Note: * p -value < .05; ENT: ENTUSE (entertainment at home), HS: HOMESCH (at home for schoolwork), ICTH: ICTHOME (availability at home), ICTS: ICTSCH (availability at school), USES: USESCH (at school), USEM: USEMATH (math lessons at school).

Discussion, Limitations, and Future Work

ICT for Schoolwork

Findings of this study suggest that ICT use at home for schoolwork and ICT use at school for mathematics lessons were negatively associated with achievement in mathematics and science in both countries. These results indicate that high levels of ICT use for schoolwork may help students become more digitally literate or more versed in using advanced software, but it may detract from understanding basic concepts in mathematics and science on a deeper level. Similar results were found in the PISA 2006 data that also included questions about programming and use of advanced software for homework in the ICT questionnaire: students' advanced ICT use was a significant negative predictor of mathematics (Güzeller & Ayça, 2014). These results are consistent with other findings in the literature regarding the PISA 2012 assessment that found a negative relation between ICT use at school and student academic achievement (Skryabin, Zhang, Liu, & Zhang, 2015). Some of the implications of this finding include a reconsideration of the ICT use for academic purposes both in school and at home, as well as further inquiry into other potential factors that affect student achievement in mathematics and science.

ICT Availability

We found that both the ICT availability at home and the ICT availability at school were positively associated with mathematics and science achievement in Turkey. These results are consistent with other findings in the literature regarding the PISA 2012 assessment that found a positive relation between ICT activities at home and student test scores (Skryabin, Zhang, Liu, & Zhang, 2015). However, no association was found in Finland, perhaps because this country is more homogeneous than Turkey in terms of availability of technology. Finland is one of the most advanced countries with respect to information technology and it ranks second, with a value of 6.0 and a high-income OECD economy, on the 2016 Networked Readiness Index (NRI) list. At the same time, Turkey ranks 48th, with a value of 4.4 as an upper-middle-income economy (Baller, Dutta, & Lanvin, 2016). NRI assesses several aspects that help countries employ ICT to increase the competitiveness and wellbeing of their citizens. In summary, ICT availability does not seem to affect Finnish students either positively or negatively, but it affects Turkish students, more dramatically at home than at school.

Some of the implications of this finding include economic considerations when decisions regarding ICT availability are made in schools and in students' homes. More ICT availability at school may make a difference for students who do not have access to ICT at home. Conversely, more ICT availability at home may help students who do not have a chance to use ICT at school acquire digital literacy skills (e.g., browsing the Internet for help with their homework etc.) that may improve their academic skills, even if they do not have access to a high student-teacher ratio at school. For example, in 2013, the average class size for lower secondary education (i.e., gymnasium or ages 12-15) in Finland was 20 students, while in Turkey it was 28 (OECD, 2011). In Finland, the average class size is among the smallest of the OECD and partner countries. Moreover, within the country, the difference between the smallest 10% and the largest 10% of classes is also small (i.e., 10 students or fewer). In contrast, the difference between the smallest 10% and largest 10% of classes can be at least double in Turkey (OECD, 2011).

ICT for Entertainment

This study showed that, for students in Turkey, the use of ICT for entertainment outside of school was beneficial for mathematics and science achievement, but the opposite was true in Finland. Other researchers found that mathematics achievement of Turkish students in PISA 2006 was positively associated with self-reliance in performing ICT Internet tasks (Ziya, Doğan, & Kelecioğlu, 2010). This may point to motivational and economic factors and, hence, it requires more in-depth analyses. This finding has implications for restructuring ICT activities in a way that encourages students to employ technology for entertainment outside of school to reap the benefits of ICT for academic achievement. Such a result can be interpreted in connection with the availability of ICT at home as a result of higher family income in Turkey. Students who possess technological devices for entertainment use, such as computers or video game consoles, tend to belong to higher-income families and, thus, they often have access to a better quality of education. For example, there is a moderate correlation ($r = .287$) between the use of ICT for entertainment (ENTUSE) and the index of economic, social and cultural status (ESCS, in the PISA 2012 database) in Turkey, whereas the correlation between the same variables is quite weak ($r = .027$) in Finland.

Limitations and Future Work

One of the limitations of this study is the self-reported nature of the ICT questionnaire data that does not necessarily provide an accurate approximation of students' ICT use. Future work will examine other data sets that may provide a more accurate view of students' ICT use. Another limitation stems from the selection of the two countries. Further evidence is required to determine how representative these two countries are on the spectrum of ICT use. For example, other countries included in PISA 2012 will be considered in future analyses to explore the generality of the results reported in this work. Additionally, other data sources will be considered. Lastly, this study used the items included in the PISA ICT questionnaire, but there may be other indicators more predictive of ICT that we could explore, including social attitudes towards teachers, teachers' attitudes towards technology, their salaries, the value placed on education in society, and students' mindset.

Conclusions

The study examined data from the PISA 2012 multinational assessment and revealed that, although students in Finland scored significantly higher in both mathematics and science than students in Turkey, overall, the use of ICT for schoolwork proved detrimental for students in both countries. ICT availability, although more so at home, was positively associated with achievement in mathematics and science for students in Turkey, where ICT availability is scarcer, but it had no effect for students in Finland, where ICT availability is prevalent. The use of ICT for entertainment outside of school was associated with better achievement in mathematics and science for Turkish students, but it detracted from Finnish students' academic achievement in these subjects. ICT use at home for schoolwork had no effect on academic achievement in mathematics and science for neither country. The results have major implications in how mathematics and science subjects are taught. Specifically, this research has educational implications for work aiming to introduce or further develop ICT use in formal (e.g., schools etc.) and informal (e.g., homes, museums, etc.) learning environments with the goal of enhancing students' academic outcomes, as well as for designing effective classroom environments.

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