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A Scoping Review of the Relationship Between Students' ICT and Performance in Mathematics and Science in the PISA Data

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Abstract

This scoping literature review examines the relationship between ICT and performance scores in mathematics and science for students around the world included in the PISA assessment. In this review we examined 25 publications and showed that the relationship between ICT and academic achievement is not consistent. The different types of ICT revealed different relationships with performance, depending on the subject and country of the students being examined. Although there is a lack of overall consensus, it seems that moderate use, rather than high or no use of ICT, can positively predict academic scores. Although autonomy, interest, and use of ICT as a topic in conversations have been less scrutinized by researchers, they seem to positively predict both mathematics and science scores in 15-year-old students. Implications, limitations, and recommendations are discussed.

Keywords: ICT, mathematics, science, PISA, technology, review

1. Introduction

In developed countries, it is difficult to find a classroom that does not incorporate digital devices and other forms of technology into student learning in one way or another. Information and Communication Technology (ICT) is a category of technology that focuses on the goal of sharing information and enabling communication between users (OECD, 2005). This includes software, hardware, and networks that connect users to information and to each other. In the digital 21st century, ICT has become synonymous with modern classrooms (Lewis, Burks, Thompson, and Austin, 2019). This relationship is due, in part, to the necessity of equipping individuals with ICT skills upon entering the workforce (Bresnahan and Yin, 2017).

The OECD is a global organization that strives to study educational standards and economics in many countries and proposes policies that implement world-wide equitable education (OECD, 2020). This organization implemented PISA, an assessment tool that measures students' academic achievement and whether students' education is preparing them for life after school. Beginning in 2000, the survey is delivered every three years to participating countries to test 15-year-old students in mathematics, science, and reading, as well as in other areas, such as familiarity with ICT. After 2000, more specific questions were added to parse out the ways in which students were interacting with ICT (Ray and Margaret, 2003; OECD, 2005, 2009, 2014a, 2017). Initially, the questions were part of the student questionnaire and referred to as Information Technology questions until there were enough questions for the *ICT Familiarity Questionnaire* in PISA 2003. Over the years, the surveys went from pencil and paper based to computer based.

In this scoping literature review, the ICT interactions are split into nine different contexts laid out by the Program for International Student Assessment's (PISA) *ICT Familiarity Questionnaire* in PISA 2015 (OECD, 2014b, 2017). This *ICT Familiarity Questionnaire* was used as a supplementary set of optional questions to collect data as part of the Organization for Cooperation and Development's (OECD) PISA survey from the iteration in 2000 to 2015 (OECD, 2002, 2005, 2009, 2014a, 2017). The nine contexts of ICT that the survey focuses on are the following: ICT use at home for entertainment, ICT use at home for school work, ICT use at school, ICT availability at home, ICT availability at school, interest in ICT, perceived competence in ICT, perceived autonomy in ICT, and ICT use as a topic in social interactions.

Despite the quick adoption of ICT into classrooms, research is still divided on the benefits of ICT on students' learning (Reboot Foundation, 2019). As mentioned in the Reboot Foundation report, context makes an important contribution to understanding the relationship between ICT and student scores. For instance, when examining different countries from the perspective of their students' interactions with ICT, distinctions can be made between a country's wealth, education quality, available technology, and technology culture. It was found that the number of computers available to students varies greatly from under five students per computer in some countries to over 40 students per computer in other countries in the early 2000s (Law, Pelgrum, and Plomp, 2008). In the context of technological innovations and advancements, countries can be split into two categories, *digital challengers* and *digital frontrunners* (Novak et al., 2018). Digital challengers generally have less advanced technology standards than the average country, which means that they display a higher growth potential. According to Novak et al. (2018), Bulgaria, Croatia, the Czech Republic, Hungary, Latvia, Lithuania, Poland, Romania, Slovakia, and Slovenia are examples of digital challengers. On the other end of the scale, more technologically advanced countries that display a high digitization rate would be considered digital frontrunners. These are countries like Belgium, Denmark, Estonia, Finland, Ireland, Luxembourg, the Netherlands, Norway, and Sweden. Novak et al. (2018) discuss an important connection between STEM learners and a country's status as Frontrunner or Challenger. The authors discuss the need for STEM learners to transform a country from a digital challenger to a digital frontrunner. This supports our research that investigates the important connection between mathematics and science education and ICT within the context of different countries. The results from this research can inform practice in classrooms across the globe. If the proper ICT interactions that promote mathematics and science education can be parsed out, then schools could improve the use of ICT to support learning. As a result, this transformation could turn a digital challenger country into a digital frontrunner. According to Novak et al. (2018), this would increase a country's GDP, lower unemployment, and shorten work weeks.

In this review, we set out to answer the following research question: Do students' interactions with ICT measured by PISA have a positive, negative, or no effect on 15-year-old student mathematics and science scores?

The rest of the manuscript is organized as follows. First, we discuss the theoretical framework and methodology that underlie this work. Then, we present our results. We conclude with a discussion of our results, their implications, limitations, and directions for future work.

2. Theoretical Framework

This research draws on several theoretical frameworks to conceptualize the relationship between ICT and the academic scores of students from different countries. First, it draws on the Arksey and O'Malley (2005) approach to conduct a scoping literature review. As well, it draws on self-determination theory to link the non-cognitive factors underpinning students' interactions with ICT to the cognitive measures of their performance in mathematics and science.

2.1. Scoping Review

A scoping review represents an exploratory method that maps systematically the literature on a topic, identifying key concepts, theories, and sources of evidence, and addressing broader research topics where many different study designs might be applicable. Rather than exhaustively researching a topic, this type of review explores "the extent, range, and nature of research activity in a topic area" (Pham, Rajić, Greig, Sargeant, Papadopoulos, and McEwen, 2014, p. 371). A five-stage searching and selecting method was employed to conduct this review

(Arksey and O'Malley, 2005) that includes: 1) identifying the research questions; 2) identifying relevant studies; 3) selecting studies; 4) charting the data; and 5) collating, summarizing, and reporting the results. The Method section provides more details on our procedure.

2.2. Self-Determination Theory

Self-Determination Theory (SDT) posits that an individual's learning is driven by self-motivation and determination. SDT underlies some of the measurements around students' ICT interactions. Specifically, the learner exerts effort to obtain a positive outcome (Ryan and Deci, 2000). There are three basic psychological needs that are tied to SDT: competence, autonomy, and relatedness. These are reflected closely in the *ICT Familiarity Questionnaire* (OECD, 2014b) from PISA 2015, where there are questions that assess a student's perceived competence, autonomy, and use as a social topic. Competence reflects a student's level of mastery and control over outcomes when using ICT. Autonomy constitutes the student's desire to make their own choices when using ICT. Relatedness is the drive to connect and communicate with others. In the PISA 2015 *ICT Familiarity Questionnaire* (OECD, 2014b), competence is measured by the COMPICT (IC014) subscale. Students' self-reported autonomy around the use of ICT is measured by the AUTICT (IC015) subscale. Relatedness is measured by the SOIAICT (IC016). The subscales in the *ICT Familiarity Questionnaire* are detailed in PISA's reports (OECD, 2017). When these needs are fulfilled, they increase an individual's self-motivation. According to SDT, people view their actions as self-determined and, when they perform well, this enhances their feelings of autonomy. Positive social interactions, competence, and autonomy are conducive to increasing intrinsic motivations. With high intrinsic motivation, students will be self-driven to challenge themselves with using technology, which creates the conditions in which learning is more likely to occur (Hamari, Shernoff, Rowe, Coller, Asbell-Clarke, and Edwards, 2016; Hung, Sun, and Yu, 2015). SDT also explains that a person's motivation and achievement is influenced by their environment. Optimal development and mastering skills can only occur if the individual is in a nurturing environment that supports growth (Ryan and Deci, 2000). This can be tied to digital frontrunners and challengers because students who master technology may also learn better when using technology, given that they were raised in an environment where ICT is abundant and easily integrated into their lives. Conversely, in a digital challenger country, fewer interactions with ICT during development may lead to suboptimal performance with ICT when attempting to learn using ICT later in life.

3. Method

Exploratory scoping review methods were used to conduct this scoping literature review according to the Arksey and O'Malley's (2005) framework. This allowed us to compare and contrast theoretical frameworks, methods, analyses, and results. The purpose of this review is not an extensive and comprehensive representation of all research on the topic. Rather, it is to gain an understanding of the variety of results found when examining the relationship between ICT interactions and academic achievement using PISA data. Our main research question was the following: *Do students' interactions with ICT as measured by PISA have a positive, negative, or no effect on 15-year-old student mathematics and science scores?*

To locate studies for this review, our search began in Google Scholar, PsycINFO, and Education Resources Information Center (ERIC). Key search terms included: (*ICT OR "information and communication technolog*"), AND (mathematics achievement OR science achievement), AND (PISA OR "program for international student assessment"), AND (ICT use OR ICT availability OR ICT interest OR ICT competence OR ICT autonomy OR ICT social interactions OR ICT social relatedness OR ICT attitudes)*. The asterisk in "*Technolog**" allows for the search engine to auto complete the word with any possible endings. This enables us to shorten the syntax of the search while getting hits for technology, technologies, technological, and more. Publication alerts were set up with similar keywords to retrieve new studies relative to these topics. A snowball approach was used to probe journals for other useful studies and citations. Our inclusion criteria narrowed the search to secondary research that was conducted with PISA data from any iteration between 2000 and 2015. The studies had to use items or subscales from the *ICT Familiarity Questionnaire* as predictor variables and either plausible mathematics or science values, or both, as outcome variables. Studies that did not conduct quantitative statistics on numerical data provided by PISA were not included.

The query in ERIC returned 30 articles, of which 6 were used. This search in PsycINFO provided 3 useful articles after removing duplicates. The remainder of the articles were found in Google Scholar and through the snowball method. Google Scholar returned 612 results which were reduced to 586 when the date was limited to 2000, the year when the PISA assessment commenced. Table 1 shows all 25 articles that were included in the scoping literature review. Table 2 is split into positive, negative, and null results to help visualize the spread of the results found.

[Insert Table 1 here]

Despite the fact that we refer to all OECD participating groups as countries, we acknowledge that some identify as separate economies or states. We would also like to acknowledge that, although we discuss about some lower performing and lower ranking countries on the PISA scale, PISA is a specific measure and countries cannot be reduced to their PISA rank.

[Insert Table 2 here]

4. Results

4.1. Methods Exploring the Relation Between ICT and Performance Scores

Researchers have employed a wide range of methods and angles to examine the relation between ICT and students' achievement. For instance, Petko, Cantieni, and Prasse (2017) used multiple linear regression to examine the relationship between ICT and mathematics and science scores for 39 of the participating countries in the 2012 PISA database. Hu, Gong, Lai, and Leung (2018) uncovered details about ICT interactions with mathematics and science scores at an average OECD level with 44 countries using hierarchical linear modelling (HLM) in PISA 2015. Meng, Qiu, and Boyd-Wilson (2018) analyzed Chinese and German ICT data from PISA 2015 with multi-group structural equation modelling (SEM). Meggiolaro (2018) used PISA 2012 data to explore the intersection of ICT and mathematics in Italian students using multilevel models, while Gamazo, Martínez-Abad, Olmos-Migueláñez, and Rodríguez-Conde (2018) used the same method and logistic regression to analyze the PISA 2015 data for Spanish students. Using exploratory factor analysis and HLM on the PISA 2006 data, Luu and Freeman (2011) compared science scores and ICT interactions of Canadian and Australian students. Using SEM, Bulut and Cutumisu (2018) examined use and availability of ICT for Turkish and Finnish students in the PISA 2012 data. Skryabin, Zhang, Liu, and Zhang (2015) reviewed data from 39 countries in PISA 2012 as well as other large international databases using HLM to explore the links between ICT and mathematics and science scores. Tan and Hew (2018) studied the impact of ICT interactions on mathematics scores for students in seven Confucian heritage cultures (CHC) who participated in PISA 2012 using HLM. The groups identified as CHCs are Hong Kong, Japan, Korea, Macau, Shanghai, Singapore, and Taipei. Using the first iteration of PISA in 2000, Papanastasiou, Zembylas, and Vrasidas (2003) implemented regression models to examine the relationship between computer use and availability in students from the United States of America. Koğar (2019) reported findings linking mathematics and science scores with ICT interactions using the Chi-squared automatic interaction detection method on 35 OECD countries from PISA 2015. Zhang and Liu (2016) examined PISA data at the OECD level from 2000 to 2012 and reported the connections between ICT interactions and academic achievement using HLM. The Reboot Foundation used more broad measures of general computer use and computers per student from PISA 2003 to 2015 using correlational methods. Other researchers used data mining techniques to uncover patterns in large standardized assessment data (Martínez-Abad, Gamazo, and Rodríguez-Conde, 2018). Juhaňák, Zounek, Záleská, Bárta, and Vlčková (2018) employed multilevel modelling and included gender as a control variable later in their analysis to examine ICT interactions with mathematics and science scores of students in the PISA 2015 database from the Czech Republic. As part of a large-scale study, Rodrigues and Biagi (2017) examined the relationship between low, medium, and high intensity use of ICT and mathematics and science for 25 European countries in PISA 2015 using multiple linear regression. Agasisti, Gil-Izquierdo, and Han (2017) examined the effects of ICT use at home for schoolwork on 12 European countries from PISA 2012 using propensity score matching and instrumental variables. Özberk, Kabasakal, and Öztürk (2017) examined Turkish students from PISA 2012 using two-level hierarchical linear modelling. Delen and Bulut (2011) examined the PISA 2009 science and mathematics scores with ICT availability of Turkish students using hierarchical linear modelling. Using multiple models of Spanish students' ICT data from PISA 2009, Fuentes and Gutiérrez (2012) inspected the effects on their mathematics and science scores. Su (2017) used PISA 2015 data to explore the effects of ICT on mathematics performance for Chinese and Korean students. The researcher used a variety of methods, such as the International Association for the Evaluation of Educational Achievement (IEA) international database analyzer, t-tests, and path analysis models to answer their research questions. Kubiatko and Vlckova (2010) investigated the relationship between ICT and science scores of Czech students in the PISA 2006 data using analyses of variance with post-hoc pairwise comparisons. Srijamdee and Pholphirul (2020) used SEM to examine how ICT use, availability, and comfort effect mathematics and science performance in Thai students from PISA 2015. Kunina-Habenicht and Goldhammer (2020) employed SEM to both German and Swiss samples from PISA 2015 to study the relationship between academic scores and ICT use and confidence. Hatos (2020) investigated the science scores of 47 countries from PISA 2015 and their relation to ICT.

4.2. ICT Use at School (USESCH)

4.2.1. Mathematics

4.2.1.1. Positive Relations. Meggiolaro (2018) found that Italian students' mathematics scores were positively correlated with several ICT use factors regardless of whether they take place in their home or school in the PISA 2012 data. The strongest correlation occurred with moderate rather than extreme use of ICT. Examples of ICT-use factors at school that were positively associated with higher mathematics scores were gaming, problem solving, knowledge creating, and retrieving, organizing, and managing information. Similarly, the Reboot Foundation (2019) reported that moderate ICT users in classes achieved higher scores than their peers who use technology at the extremes in the PISA 2015 data. Interestingly, students with the highest reported ICT use at school, although outperformed by students reporting moderate ICT use, achieved higher scores than students who did not use ICT at all. Koğar (2019) uncovered a positive relationship between use of ICT devices while at school and mathematics scores in the

PISA 2015 data. Conversely, Rodrigues and Biagi (2017) found that low-intensity users of ICT at school in European countries in PISA 2015 had higher scores than other levels of users.

4.2.1.2. Negative Relations. Not all types of ICT use yielded mathematics benefits for Italian students. For instance, intensity of computer use at school in mathematics lessons and some related mathematics activities were negatively associated with mathematics scores for Italian students in the PISA 2012 data (Meggiolaro, 2018). In 2009 and 2015, Spanish students performed worse in academics when they used more ICT in school (Fuentes and Gutiérrez, 2012; Gamazo et al., 2018; Martínez-Abad et al., 2018). Hu et al. 2018 analyzed 44 OECD countries from PISA 2015 and found that, on average, students would drop nearly ten points in mathematics with an increase of one standard deviation of ICT use at school. Petko, Cantieni, and Prasse (2017) found the same results using 39 countries from PISA 2012. Skryabin et al. (2015) replicate these results with the same PISA 2012 data. Bulut and Cutumisu (2018) examined Finnish and Turkish students from PISA 2012 also found a negative relationship between ICT use at school and mathematics scores. Juhaňák et al. (2018) found that Czech students who accessed the Internet for more than one hour per day at school showed lower academic achievement in PISA 2015. On average, for European countries, mid-ICT and high-ICT users held a negative relationship between ICT use at school and mathematics scores in PISA 2015 (Rodrigues and Biagi, 2017). German and Swiss students from PISA 2015 showed negative relationships to ICT use at school and mathematics (Kunina-Habenicht and Goldhammer, 2020). Su (2017) found that both Chinese and Korean students from PISA 2015 had a negative relationship between mathematics scores and ICT use at school. However, the students' ICT Use at School score measured by the USESCH variable positively predicted their self-perceived competence.

4.2.1.3. No Relations. Although the literature revealed some associations between ICT and mathematics, there were also instances in which no associations were found. For instance, Tan and Hew (2018) found no significant relationship between the use of ICT devices at school and mathematics scores in the PISA 2012 data. In PISA 2015, researchers found that the use of ICT by Czech students in school (USESCH) is uncorrelated with their mathematics performance (Juhaňák et al., 2018). However, when the interaction with school type is considered, the relationship with mathematics scores becomes significant and is stronger. Here school type refers to schools including state funded, church funded, or private (Juhaňák et al., 2018).

<u>*4.2.2. Science*</u>

4.2.2.1 Positive Relations. The aspect of using computers in Australian schools was positively associated with science scores in the PISA 2006 data (Luu and Freeman, 2011). For Canadians, browsing the Internet at school or at home was also positively linked to higher science scores. European students who use low levels of ICT in schools also tend to perform better in science in PISA 2015 (Rodrigues and Biagi, 2017).

4.2.2.2. Negative Relations. Hu et al. (2018), Petko, Cantieni, and Prasse (2017), Bulut and Cutumisu (2018), and Skryabin et al. (2015) found a negative relationship between ICT use at school and science scores using PISA 2012 and 2015 data. Luu and Freeman (2011) examined the link between ICT and science performance for Canada and Australia using the PISA 2006 data. Most other facets of ICT use, other than browsing the Internet, were negatively associated with science scores. Gamazo et al. (2018) also reported a negative relationship for Spanish students in 2015. Very high frequencies of ICT use were associated with worse science scores than medium use for both Canadian and Australian students (Luu and Freeman, 2011). The academic scores of students who are plugged into the Internet for more than one hour a day at school suffer (Juhaňák et al., 2018). Similar to the mathematics results, European students in PISA 2015 performed worse in science when they used ICT from medium to high levels (Rodrigues and Biagi, 2017). Hatos (2020) found a general negative influence of ICT use at school on science scores from PISA 2015. German and Swiss students from PISA 2015 showed negative relationships to ICT use at school and science (Kunina-Habenicht and Goldhammer, 2020). Spanish students in PISA 2009 and 2015 with more ICT use performed worse than their peers on mathematics (Fuentes and Gutiérrez, 2012; Martínez-Abad et al., 2018).

4.2.2.3. No Relations. Luu and Freeman (2011) discussed several mixed results, but specific ICT use at school was not associated with science scores for Canadian students in the PISA 2006 data. In PISA 2015, researchers found that the use of ICT by Czech students in school is not correlated with their science performance (Juhaňák et al., 2018). However, as in the case of mathematics, when the interaction of school type is included, the relationship becomes significant.

4.3. ICT Use at Home for Schoolwork (HOMESCH)

4.3.1. Mathematics

4.3.1.1. Positive Relations. As with the ICT use at school, Meggiolaro (2018) found a positive relationship between mathematics scores and ICT when ICT is used at home for academic purposes in PISA 2012. Opposite to their previous findings, Petko, Cantieni, and Prasse (2017) found a positive relationship between ICT use at home for schoolwork and mathematics scores. Tan and Hew (2018) also uncovered a positive relationship between ICT use at home for schoolwork and mathematics scores in PISA 2012. Rodrigues and Biagi (2017) also reported a positive relationship between mathematics and ICT use at home for schoolwork but only for European students who used relatively low ICT in PISA 2015.

4.3.1.2. Negative Relations. Skryabin et al. (2015) found a significant negative relationship between students who use ICT at home for school related purposes and lower mathematics scores in the PISA 2012 data. Medium and high users of ICT in Europe also had lower mathematics scores in PISA 2015 (Rodrigues and Biagi, 2017). Agasisti, Gil-Izquierdo, and Han (2017) also found a relationship for European students. In fact, this relationship was slightly stronger for students with higher socio-economic status (SES). German and Swiss students from PISA 2015 showed negative relationships to ICT use at home for schoolwork and mathematics (Kunina-Habenicht and Goldhammer, 2020). Spanish students in PISA 2015 also show a negative relationship between mathematics and ICT Use at Home for Schoolwork measured by the HOMESCH variable (Martínez-Abad, Gamazo, and Rodríguez-Conde, 2018). When examining Chinese and Korean students' mathematics scores from PISA 2015, Su (2017) reported that HOMESCH acted as a negative predictor for China but was not significant for Korea. Also, HOMESCH acted as a positive predictor for a students' self-perceived competence towards ICT is China, but once again, was not significant in Korea.

4.3.1.3. No Relations. Hu et al. (2018) found no significant relationship between mathematics and ICT use at home in PISA 2015. Other researchers found no significant relationship between ICT use at home for academics and mathematics scores for Finnish and Turkish students in PISA 2012 (Bulut and Cutumisu, 2018) and for Czech students in PISA 2015 (Juhaňák et al., 2018).

4.3.2. Science

4.3.2.1. Positive Relations. Petko, Cantieni, and Prasse (2017) observed a positive relationship only for the top-performing countries in the PISA 2012 data. Same as for mathematics, European students who use low amounts of ICT achieved higher science scores in PISA 2015 (Rodrigues and Biagi, 2017).

4.3.2.2. Negative Relations. All countries that were not top performing exhibited a negative relationship for ICT use at home for schoolwork and science scores in the PISA 2012 data (Petko, Cantieni, and Prasse, 2017). Hu et al. (2018) as well as Skryabin et al. (2015) established a negative relationship between ICT use at home for schoolwork and science achievement at the OECD level in the PISA 2015 and PISA 2012 data, respectively. This lack of relationship was also found in Australia in 2012 and the Czech Republic in 2015 (Luu and Freeman, 2011; Juhaňák et al., 2018) also found this relationship, but only for Australia, in the PISA 2012 data. German and Swiss students from PISA 2015 showed negative relationships to ICT use at home for schoolwork and science (Kunina-Habenicht and Goldhammer, 2020). In Europe, medium and high users of ICT performed worse on science assessments than low users of ICT (Rodrigues and Biagi, 2017). Agasisti, Gil-Izquierdo, and Han (2017) also found this relationship with European students. The effect was slightly stronger for students with higher SES. Spanish students in 2015 also had a negative relationship between science scores and HOMESCH (Martínez-Abad, Gamazo, and Rodríguez-Conde, 2018).

4.3.2.3. No Relations. The results for science and academic ICT use at home were not significant for Canadian students in 2006 as well as for Finnish and Turkish students in 2012, respectively (Bulut and Cutumisu, 2018; Luu and Freeman, 2011).

4.4. ICT Use at Home for Entertainment (ENTUSE)

4.4.1. Mathematics

4.4.1.1. Positive Relations. When ICT devices are used at home for entertainment rather than for schoolwork, some researchers report different relationships with academic scores.

Students from both Italy and Turkey were found to perform better in mathematics with more ICT use at home for entertainment in the PISA 2012 data (Bulut and Cutumisu, 2018; Meggiolaro, 2018). Italian students who used ICT for gaming also had high mathematics scores in the PISA 2012 data. Srijamdee and Pholphirul (2020) found that Thai students who play video games for entertainment scored higher in PISA 2015 mathematics than students who did not take part in video games. For Turkish students, ICT use at home for entertainment was connected to higher mathematics scores in the PISA 2012 data (Bulut and Cutumisu, 2018; Özberk, Kabasakal, and Öztürk, 2017). Petko, Cantieni, and Prasse (2017) discovered that students in countries with high mathematics scores reported lower levels of overall ICT use at home for entertainment in the PISA 2012 data. Low European users of ICT for entertainment showed higher mathematics scores compared to other users (Rodrigues and Biagi, 2017). Thai students who report higher Internet usage outperformed students who did not use the Internet at all, however students who upload content to the Internet and participate in online chats daily have decreased academic scores (Srijamdee and Pholphirul, 2020).

4.4.1.2. Negative Relations. In contrast to Turkish students, Finnish students' mathematics scores seemed to suffer with higher ICT use at home for entertainment in the PISA 2012 data (Bulut and Cutumisu, 2018). These results are reflected by Petko, Cantieni, and Prasse (2017) and Skryabin et al. (2015) who noticed that high levels of ICT use at home for entertainment were detrimental for countries with higher mathematics scores. Students who use the Internet for fewer than 30 minutes or use the Internet more than 6 hours per day at home perform worse than students who access the Internet between 31 minutes and 6 hours per day (Juhaňák et al., 2018). European students who are high users of ICT showed a negative relationship with mathematics (Rodrigues and Biagi, 2017). In PISA 2009 and 2015, Spanish students with higher measures of ICT Use at Home for Entertainment (ENTUSE) performed worse on the mathematics assessment (Fuentes and Gutiérrez, 2012; Martínez-Abad et al., 2018). German and Swiss students from PISA 2015 showed negative relationships to ICT use for entertainment and mathematics (Kunina-Habenicht and Goldhammer, 2020). Like for the USESCH variable, Su (2017) reported ENTUSE as a positive predictor for mathematics scores for Chinese and Korean students from PISA 2015. ENTUSE also acted as a positive predictor for a students' sense of self-competence around ICT.

4.4.1.3. No Relations. At the OECD level, Hu et al. (2018) again found no significant relationship for mathematics scores and ICT use outside of school, even for entertainment. Similarly, Juhaňák et al. (2018) reported no relationship between the mathematics scores of Czech students and use of ICT for entertainment. Finally, European students with mid-frequency ICT use did not have a significant relationship with mathematics (Rodrigues and Biagi, 2017).

4.4.2. Science

4.4.2.1. Positive Relations. Bulut and Cutumisu (2018) found a positive relationship for Turkey in the PISA 2012 data for both science and mathematics. Unlike finding a null relationship for mathematics in the PISA 2015 data, Hu et al. (2018) discovered a positive relationship between science scores and ICT entertainment use outside of school. Like in mathematics, Thai students who play video games for entertainment scored higher in PISA 2015 science than students who did not take part in video games (Srijamdee and Pholphirul, 2020). In general, Hato (2020) found a positive trend in science scores and ICT use for entertainment in all included countries of PISA 2015. Again, low-intensity users of ICT showed higher science scores than their peers, but extreme users did worse (Rodrigues and Biagi, 2017; Srijamdee and Pholphirul, 2020).

4.4.2.2. Negative Relations. Bulut and Cutumisu (2018) found a negative relationship between ICT use at home for entertainment and science scores for Finnish students. Petko, Cantieni, and Prasse (2017) revealed a significant negative relationship for science scores and ICT use at home for entertainment at the OECD level. Using earlier data from 2006, Luu and Freeman (2011) discovered that frequent ICT use for entertainment or schoolwork was negatively associated with students' science scores in Canada, apart from browsing the Internet. German and Swiss students from PISA 2015 showed negative relationships to ICT use for entertainment and mathematics (Kunina-Habenicht and Goldhammer, 2020). Czech students who use the Internet for fewer than 30 minutes or more than 6 hours per day at home achieved lower science scores than students who use the Internet between 31 minutes and 6 hours a day (Juhaňák et al., 2018). Similar to before, in Europe, high-intensity users of ICT performed worse on science assessments in PISA 2015 (Rodrigues and Biagi, 2017). In PISA 2009 and 2015, Spanish students with higher measures of ENTUSE performed worse on the science assessment (Fuentes and Gutiérrez, 2012; Martínez-Abad et al., 2018).

4.4.2.3. No Relations. Skryabin et al. (2015) found no significant relationship between students' science scores and their use of ICT for entertainment outside of school in the PISA 2012 data. Juhaňák et al. (2018) replicated these results when examining the Czech Republic in the same database. Medium users of ICT in Europe did not have a significant relationship with science scores (Rodrigues and Biagi, 2017).

4.5. ICT Availability at School (ICTSCH)

4.5.1. Mathematics

4.5.1.1. Positive Relations. Research revealed that availability of different ICT devices at school was associated with higher mathematics scores for Turkish students in PISA 2012 and Spanish students in PISA 2009 (Bulut and Cutumisu, 2018; Fuentes and Gutiérrez, 2012).

4.5.1.2. Negative Relations. In contrast to the result found for Turkey, availability of ICT at school was associated with lower scores in Finland in PISA 2012 (Bulut and Cutumisu, 2018). Koğar (2019) reported a negative relationship between ICT use at school and mathematics scores at the OECD level in the PISA 2015 data. The author highlighted eBook reading devices as the strongest negative predictor of scores. Overall, the Reboot Foundation (2019) found negative associations between students with more access to technology in the classroom and their PISA mathematics scores. Unlike the findings of Fuentes and Gutiérrez (2012) in 2009, Martínez-Abad et al. (2018) found negative results for the number of ICT devices at home and mathematics scores.

4.5.1.3. No Relations. Hu et al. (2018) uncovered no significant relationships between availability at school and mathematics scores at the average OECD level in PISA 2015. Tan and Hew (2018) also found no relationship between ICT devices available at school and mathematics scores in PISA 2012. The math scores of Czech students in 2015 are not significantly correlated with ICT availability at school (Juhaňák et al., 2018). A higher ratio of computers to students does not have a significant effect on mathematics scores (Reboot Foundation, 2019).

4.5.2. Science

4.5.2.1. Positive Relations. Analogous to results for mathematics, Turkish students from PISA 2012 and Spanish students from PISA 2009 also achieved increased science scores with more ICT availability at school (Bulut and Cutumisu, 2018; Fuentes and Gutiérrez, 2012).

4.5.2.2. Negative Relations. Koğar (2019) reports a negative relationship between available ICT devices and science scores in PISA 2015. As in the case of mathematics, eBook readers were associated with lowest science scores. Matching the results for math, the Reboot Foundation (2019) found a small negative correlation between the availability of computers in schools and science scores. Spanish students' science scores were lower when they had more ICT devices available to them at school (Martínez-Abad et al., 2018). Of all countries in PISA 2015, Hato (2020) found an overall negative relationship with science scores and availability of ICT in schools.

4.5.2.3. No Relations. Analyses of the data from Czech, Finnish, and American students revealed a non-significant relationship between science scores and ICT availability at school in PISA 2015, 2012, and 2000, respectively (Bulut and Cutumisu, 2018; Juhaňák et al., 2018; Papanastasiou et al., 2003). Similarly, the relation between the science score and ICT availability at school was, on average, non-significant for 44 countries who participated in PISA 2015 (Hu et al., 2018). The specific ratio of students to computers did not significantly predict science scores (Reboot Foundation, 2019)

4.6. ICT Availability at Home (ICTHOME)

4.6.1. Mathematics

4.6.1.1. Positive Relations. Bulut and Cutumisu (2018) found the same results for ICT availability at home as they did for availability at school for both mathematics and science achievement in PISA 2012. Specifically, a positive relation between mathematics and ICT availability at home was found for Turkish students in PISA 2012. Also using Turkish data, but from PISA 2009, Delen and Bulut (2011) found a positive correlation between ICT availability at home and mathematics scores. Similarly, Fuentes and Gutiérrez (2012) also found a positive relationship while analyzing Spanish students from PISA 2009. In Thailand, Srijamdee and Pholphirul (2020) found overall positive influences on mathematics scores from ICT availability at home, however access to Wi-Fi was the most positive predictor from PISA 2015.

4.6.1.2. Negative Relations. Hu et al. (2018) reported a negative relationship between students' ICT availability at home and both mathematics and science scores at the OECD level in PISA 2015. Tan and Hew (2018) also found a negative relationship in a sample of students from Asian countries with Confucian heritage cultures in PISA 2012. At a single country level, Spanish students held negative relationships for higher ICT availability at home and mathematics scores from PISA 2015 (Martínez-Abad et al., 2018).

4.6.1.3. No Relation. Research revealed a null relationship between mathematics and ICT availability for Finnish and Czech students in PISA 2012 and 2015, respectively (Bulut and Cutumisu, 2018; Juhaňák et al., 2018).

4.6.2. Science

4.6.2.1. Positive Relations. An increase in ICT availability at home was associated with an increase in science scores for Turkish students in PISA 2009 and 2012 (Delen and Bulut, 2011; Bulut and Cutumisu, 2018). Papanastasiou et al. (2003) found a positive relationship between the number of ICT devices at home and science scores for American students in PISA 2000. Fuentes and Gutiérrez (2012) also found a positive relationship while analyzing Spanish students from PISA 2009. As in Mathematics, Srijamdee and Pholphirul (2020) found positive links between science scores and ICT availability at home for Thai students.

4.6.2.2. Negative Relations. As before, Hu et al. (2018) found a negative link between ICT availability at home and academic scores in PISA 2015. Juhaňák et al. 2018 also found a negative relationship for ICT availability at home and science scores. In PISA 2015, Spanish students held negative relationships for higher ICT availability at home and mathematics scores (Martínez-Abad et al., 2018). Parallel to ICTSCH, Hato (2020) found a negative relationship between science scores and ICT availability at home for all participating countries in PISA 2015.

4.6.2.3. No Relations. No association was found between Finnish students' science scores and ICT availability at home in PISA 2012 (Bulut and Cutumisu, 2018).

4.7. ICT Interest (INTICT)

4.7.1. Mathematics

4.7.1.1. Positive Relations. Meng et al. (2018) used ICT interest among other personal ICT perceptions in Chinese and German students who participated in PISA 2015. They found that student interest in ICT was a positive predictor of mathematics and science scores for Chinese students. Hu et al. (2018) reported an overall positive relationship between ICT interest and mathematics and science scores. An interest in the Internet as a tool was positively associated with mathematics scores at the OECD level in PISA 2015 (Koğar, 2019). Kunina-Habenicht and Goldhammer (2020) reported positive associations between ICT interest and mathematics achievement for German and Swiss students in PISA 2015. Finally, positive relations between ICT interest and mathematics were found for Spanish students in PISA 2015 (Martínez-Abad, Gamazo, and Rodríguez-Conde, 2018).

4.7.1.2. Negative Relations. Research revealed a negative relationship between mathematics scores and interest in ICT for German students in PISA 2015 (Meng et al., 2018).

4.7.1.3. No Relations. Although initially ICT interest was not a significant factor for mathematics in a PISA 2015 study sampling Czech students, researchers found that, in some cases, gender significantly moderated the relation between ICT interest and mathematics (Juhaňák et al., 2018). Boys who showed higher interest in ICT had higher scores while girls who showed high interest in ICT had lower scores. This effect is, however, stronger for boys than it is for girls.

4.7.2. Science

4.7.2.1. Positive Relations. Hu et al. (2018) found an overall positive link between interest in ICT and science scores for 44 countries in PISA 2015. Meng et al. (2018) replicated this relationship for China within the same dataset. Kunina-Habenicht and Goldhammer (2020) reported positive associations between ICT interest and science achievement for German and Swiss students in PISA 2015. Finally, positive relations between interest in ICT and science were found for Spanish students in PISA 2015 (Martínez-Abad, Gamazo, and Rodríguez-Conde, 2018).

4.7.2.2. Negative Relations. German students who participated in PISA 2015 showed lower science scores as interest in ICT increased (Meng et al., 2018).

4.7.2.3. No Relations. Juhaňák et al. (2018) reported no relationship while examining the science scores and interest in ICT from the Czech Republic in 2015. The interaction of interest and gender for science scores was not significant among Czech students.

4.8. ICT Competence (COMPICT)

4.8.1. Mathematics

4.8.1.1. Positive Relations. Comparable to the results for ICT interest, a student's perceived self-competence was found to be a positive predictor of mathematics scores in PISA 2015 (Hu et al., 2018). Zhang and Liu (2016) reported that confidence in Internet tasks was generally a positive predictor of higher mathematics and science scores from 2003 to 2009. Higher math scores were also associated with more confidence in high-level ICT tasks in 2006 and 2009, but not in 2003. Comfort using unfamiliar ICT devices was a positive predictor of high mathematics scores in PISA 2015 (Koğar, 2019). Finally, positive relations between ICT competence and mathematics were found for Spanish students in PISA 2015 (Martínez-Abad, Gamazo, and Rodríguez-Conde, 2018). Using data from PISA 2009, Fuentes and Gutiérrez (2012) found a positive relationship between mathematics scores and both attitudes towards ICT and ICT skills for Spanish students. For Thai students in PISA 2015, Srijamdee and Pholphirul (2020) discuss the positive relationship between students who have used ICT since a young age and mathematics scores. Kunina-Habenicht and Goldhammer (2020) reported positive associations between ICT competence and mathematics achievement for German and Swiss students in PISA 2015.

4.8.1.2. Negative Relations. Meng et al. (2018) found a negative relationship between competence and mathematics scores for Chinese students in PISA 2015.

4.8.1.3. No Relations. A null relationship was uncovered for German students' mathematics scores and ICT Competence in PISA 2015 (Meng et al., 2018). There was no relation between ICT competence and academic achievement in a PISA 2015 study with Czech students (Juhaňák et al., 2018).

<u>4.8.2. Science</u>

4.8.2.1. Positive Relations. Confidence in high-level ICT tasks was associated with higher science scores in PISA 2009 (Zhang and Liu, 2016). According to Luu and Freeman (2011), more confidence in basic ICT skills and in presentation software was correlated with higher science scores in Canada and Australia in PISA 2012. Papanastasiou et al. (2003) found higher science scores in American students who were comfortable using word processing software to write papers in PISA 2000. Positive relations between COMPICT and science were found for Spanish students in PISA 2015 (Martínez-Abad, Gamazo, and Rodríguez-Conde, 2018). Fuentes and Gutiérrez (2012) found a positive relationship between mathematics scores and both attitudes towards ICT and ICT skills for Spanish students from PISA 2009. Again, Srijamdee and Pholphirul (2020) discuss the positive relationship between students who have used ICT since a young age and science scores for Thai students in PISA 2015. Kunina-Habenicht and Goldhammer (2020) reported positive associations between ICT competence and science achievement for German and Swiss students in PISA 2015.

4.8.2.2. Negative Relations. Meng et al. (2018) again found a negative relationship between competence and science scores for Chinese students in PISA 2015.

4.8.2.3. No Relations. For German students, ICT competence did not predict science scores in PISA 2015 (Meng et al., 2018). In American students who participated in PISA 2000, comfort with general computer use and taking tests on the computer was not associated with science scores (Papanastasiou et al., 2003). As it was for mathematics, the science score for Czech students in 2015, a non-significant relationship is present even with the inclusion of the gender interaction (Juhaňák et al., 2018).

4.9. ICT Autonomy (AUTICT)

4.9.1. Mathematics

4.9.1.1. Positive Relations. Both Hu et al. (2018) and Meng et al. (2018) found positive associations between a student's perceived self-autonomy involving ICT and their mathematics scores in PISA 2015. Another study found a significantly positive relationship in PISA 2015 between student performance and perceived autonomy in ICT use for Czech students (Juhaňák et al., 2018). Spanish students held the same relationship in PISA 2015 (Gamazo et al., 2018; Martínez-Abad, Gamazo, and Rodríguez-Conde 2018). Kunina-Habenicht and Goldhammer

(2020) reported positive associations between ICT autonomy and mathematics achievement for German and Swiss students in PISA 2015.

4.9.1.2. Negative or No Relations. The literature search did not yield any studies with negative or no relations between AUTICT and mathematics.

4.9.2. Science

4.9.2.1. Positive Relations. A positive relation was also found between science scores and level of ICT autonomy by Hu et al. (2018), Meng et al. (2018), and Juhaňák et al. (2018) for Czech students in PISA 2015. The same relationship was also found for Spanish students in PISA 2015 (Gamazo et al., 2018; Martínez-Abad, Gamazo, and Rodríguez-Conde 2018).

Kunina-Habenicht and Goldhammer (2020) reported positive associations between ICT competence and science achievement for German and Swiss students in PISA 2015.

4.9.2.2. Negative or No Relations. The literature search did not yield any studies with negative or no relations between AUTICT and science.

4.10. ICT Inclusion in Social Interaction (SOIAICT)

4.10.1. Mathematics

4.10.1.1. Positive Relations. Martínez-Abad, Gamazo, and Rodríguez-Conde (2018) found a positive association between students' ICT inclusion in social interaction and mathematics performance in PISA 2015 for Spanish students.

4.10.1.2. Negative Relations. Student enjoyment of social interactions involving ICT was negatively connected to student mathematics scores in PISA 2015 (Hu et al., 2018). In PISA 2015, a negative correlation exists between mathematics scores and social relatedness of using ICT for Spanish Czech and Chinese and German students, respectively (Gamazo et al., 2018; Juhaňák et al., 2018; Meng et al. 2018).

4.10.1.3. No Relations. The literature search did not yield any studies with no relations between students' ICT inclusion in social interaction and mathematics.

<u>*4.10.2. Science*</u>

4.10.2.1. Positive Relations. Martínez-Abad, Gamazo, and Rodríguez-Conde (2018) found a positive association between students' ICT inclusion in social interaction and science performance in PISA 2015 for Spanish students.

4.10.2.2. Negative Relations. Student enjoyment of social interactions involving ICT was negatively connected to student science scores in PISA 2015 (Hu et al., 2018). Meng et al. (2018) reported a negative correlation between Chinese and German students' science scores and their social relatedness of using ICT in PISA 2015. Similarly, Juhaňák et al. (2018) and Gamazo et al. (2018) found negative relationships between science scores and students' ICT inclusion in social interaction for Czech and Spanish students, respectively.

4.10.2.3. No Relations. The literature search did not yield any studies with negative or no relations between students' ICT inclusion in social interaction and science.

5. Discussion

In this review, we summarized the literature exploring the relationships among students' mathematics and science scores with the ICT variables used by PISA. We found mixed research results. This is likely due to the very particular nature of ICT interactions influencing students' scores. There are many facets of ICT that intersect with students' daily lives and each facet can be associated with a different academic outcome. The variation in results may also be attributed to the different measures countries included and timeframes used. Even studies that use PISA data can differ due to the changes in the *ICT Familiarity Questionnaire* (OECD, 2014b) since its inception, as pointed out by Zhang and Liu (2016). This scoping literature review reflects some of the variety in previous findings.

Do students' interactions with ICT measured by PISA have a positive, negative, or no effect on 15-year-old student mathematics and science scores? The answer is not a clear "positive" or "negative" because as we have seen, the different types of ICT interactions have different effects on mathematics and science performance for students from different countries. Researchers found positive, negative, and null relationships when looking into different aspects of ICT interactions and their interaction with academic achievement. Some researchers included several countries, while others focused on pairs or a single country, as shown in Table 3. The complexity of the types of relations between ICT and performance led to researchers using the methods shown in Table 3, such as multiple linear regression, HLM, SEM, exploratory factor analysis, logistic regression, propensity score matching, instrumental variables, and chi-squared automatic interaction detection. The data examined in the reviewed publications consisted of PISA iterations from 2000 to 2015. Seven of the studies used HLM for their analysis, five studies used MLR, and two studies used SEM. The mixed results between ICT and academic performance yielded by the scoping literature review suggests that more research needs to be done using rigorous statistical methods to examine and compare all available countries for a more in-depth comparison and understanding.

[Insert Table 3 here]

Given the plethora of literature on the topic of ICT and learning, we focused the scope on studies that used PISA ICT data from 2000 to 2015. Research which examined specific countries, or all participating countries were included to compare results and methods. The range of PISA iterations used in the reviewed studies is displayed in Table 4. Individually or in pairs, 14 countries were examined in 16 articles. These countries include Australia, Canada, China, the Czech Republic, Finland, Germany, Italy, Turkey, and the United States of America. Otherwise, nine studies included a large group of participating countries. One study employed data from the first version of PISA in 2000, two used PISA 2006, two use PISA 2009, six used PISA 2012, eleven used PISA 2015, one study used data from PISA 2000 to PISA 2012 and one study used data from PISA 2003 to PISA 2015. From the publications reviewed, Hu et al. (2018), Areepattamannil and Santos (2019), and Koğar (2019) used the most up-to-date version of PISA (i.e., 2015) and analyzed data from all participating countries. However, Koğar (2019) did not use the same variables in question as the other studies. This highlights the need for large-scale multigroup analysis of the current PISA data. Hu et al. (2018) used HLM in their methods, however a more robust approach such as SEM may better explain the complex relationships using latent variables and other incorporated methods, as demonstrated by Areepattamannil and Santos (2019).

[Insert Table 4 here]

Results from the studies reviewed varied but some trends were observed. First, Finland seemed to have more null results for ICT use and availability when compared to Turkey (Bulut and Cutumisu, 2017). Perhaps there is less variation in the ICT scores for Finland, or it is possible that ICT affects academic scores in fewer ways. Not many articles were found that discussed the impact of ICT autonomy or use of ICT as a social topic. However, the two that did (Hu et al., 2018; Meng et al., 2018) agreed that autonomy of ICT use was positively associated with mathematics and science scores, while using ICT as a topic in social interactions was associated negatively with mathematics and science scores. Although Meng et al. (2018) found a negative relationship between ICT competence and mathematics and science for China, most other studies reported a positive relationship (Koğar, 2019; Hu et al., 2018; Zhang and Liu, 2016 Luu and Freeman, 2011; Papanastasiou et al., 2003; Kunina-Habenicht and Goldhammer, 2020) and some reported a null relationship (Kubiatko and Vlckova, 2010; Meng et al., 2018; Papanastasiou, 2003) dependent on country. Interest in ICT was more frequently found to be positively associated with academic scores (Hu et al., 2018; Koğar, 2019; Meng et al., 2018; Kunina-Habenicht and Goldhammer, 2020) except for in Germany (Meng et al., 2018). No study found null results for this relationship. ICT availability at home and school held a positive relationship with Turkey and a null relationship for Finland for both mathematics and science (Bulut and Cutumisu, 2017). Hu et al. (2018) reported negative relationships for ICT availability at home and null relationships for availability at school. A negative relationship between ICT use at school and academic scores was found by Petko et al. (2017), Hu et al. (2018), Luu and Freeman (2011), Bulut and Cutumisu (2017), Hato (2020), Kunina-Habenicht and Goldhammer (2020), as well as Skryabin et al. (2015). ICT use at school related to math was found to be negative by Skryabin et al. (2015). Petko et al. (2017), Hu et al. (2018), Luu and Freeman (2011) for Australia, Bulut and Cutumisu (2017) and Skryabin et al. (2015) found this negative relationship with science scores as well. However, Meggiolaro (2018), Koğar (2019), and Srijamdee and Pholphirul (2020) found positive relationships between ICT use at school and mathematics scores. Skryabin et al. (2015) and Kunina-Habenicht and Goldhammer (2020) reported a negative relationship between ICT use at home for schoolwork and mathematics scores. ICT use as entertainment had also null effects for math but positive for science (Hu et al., 2018). The results from the Reboot Foundation (2019) report shows that mild usage of technology that is available to the students is the best predictor for higher mathematics and science scores even after controlling for demographic and economic data.

Rather than examining science scores, Areepattamannil and Santos (2019) investigated how students' perceived competence and autonomy towards ICT related to their thoughts and feelings towards science in general. The authors found a positive relationship between higher ICT competence and autonomy and positive views towards science. These included an interest, enjoyment, self-efficacy, and conceptions about science. Therefore, promoting ICT competence and autonomy in school can make a more receptive environment to learning science material in the classroom. Students' perceived self-competence of ICT was examined as a more influential factor, with results indicating that an increased use of ICT at school, at home for school work, and for entertainment was related to an increase in ICT competence in Chinese and Korean students from PISA 2015 (Su, 2017). As seen in other studies (Fuentes and Gutiérrez, 2012; Hu et al., 2018; Koğar, 2019; Luu and Freeman, 2011; Martínez-Abad et al., 2018; Papanastasiou et al., 2003; Zhang and Liu, 2016; Kunina-Habenicht and Goldhammer, 2020), self-perceived competence is a positive predictor for higher mathematics and science scores. This indicates that the relationship between ICT predictors is as complicated as the relationship with academic outcomes.

Another trend in results that should be discussed is the frequency of ICT use. Juhaňák et al. (2018) reported that Czech students that use the Internet between 30 minutes and six hours a day perform better academically than students who spend over six hours or under 30 minutes on the Internet. More specifically, students perform worse when they use the Internet more at school. They perform best when they use two to four hours of Internet at home. Luu and Freeman (2011) reported that moderate, very high, and very low ICT usage levels negatively affected Canadian and Australian academic scores in PISA 2006. Srijamdee and Pholphirul (2020) found that, for Thai students in PISA 2015, students with higher internet usage outperformed students who did not use the internet at all. In contrast, students who upload internet content daily and chat online often have decreased academic scores. As mentioned in the report from the Reboot Foundation (2019) students from PISA 2003 to 2015 performed worse if they used either no ICT or high ICT. Students with moderate ICT use performed the best on academic assessments. As seen in these studies, moderate ICT usage promotes the best academic performance when compared to little or no use or excessive use.

Rodrigues and Biagi (2017) studied the connection between frequency of use and socio-economic status (SES) in PISA 2015. Socio-economic background is a factor that can influence both academic scores and ICT interactions in schools (Hatos, 2020). Students from a low socio-economic background have less opportunities to succeed than their peers. Students who use low levels of ICT from mid to low SES tend to benefit from an increase in use at home. Conversely, students with mid to high SES who are low frequency users of ICT benefit the most from an increase of ICT use at school. Type of school that the student attends is also a factor that plays a role in understanding academic achievement and ICT interactions (Juhaňák et al., 2018). The type of school has been found to mediate this relationship. In the Czech Republic, 6-year and 8-year gymnasiums (i.e., a type of secondary school) have a stronger negative relationship for USEICT than other school types. Rodrigues and Biagi (2017) reported that the positive relationship for HOMESCH and science scores is stronger for students with low SES in private schools with a greater number of computers available.

Clearly there is a gap in the literature that needs to be addressed. There has been a large focus on ICT use measures in many studies to date. As a result, variables like competence, interest, and autonomy are more often disregarded. This is unfortunate because understanding the factors that would make students more comfortable with ICT and what attributes promote meaningful ICT use among students should come before deciding how much a country should spend on their educational ICT budget. In this review, the most frequently studied variables were HOMESCH, USESCH, and ENTUSE. The least frequently used variables were INTICT, AUTICT, and SOIAICT. This review found positive, negative, and null results for all variables except AUTICT and SOIAICT. Specifically, AUTICT did not show any negative and null relationships, while SOIAICT did not show any null relationships. This could be due to these variables having a strong significant relationship as predictors with academic achievement. Alternatively, there has not been enough investigation to find the situations in which negative and null relationships are found. Either way, more research needs to be conducted to examine the softer measures of the *ICT Familiarity Questionnaire* (OECD, 2014b). All avenues of ICT must be understood to effectively promote or limit the correct types of interactions that improve education world-wide.

5.1. Limitations

This scoping literature review constitutes a first step in elucidating the role of various aspects of ICT in students' mathematics and science academic achievement. Thus, it presents several limitations, many of which are shared by the reviewed studies. We distinguish two types of limitations: practical and methodological.

From a practical perspective, this scoping literature review is not as comprehensive as a systematic literature review and, therefore, it may not contain all the relevant literature at the time of this publication. Also, we were constrained by the number of published articles on this topic, especially as the PISA assessment is only administered every three years. However, we believe that the current results serve to provide examples of where the relations among the ICT variables and achievement work and how they can be moderated to enhance student achievement.

From a methodological perspective, we have identified several limitations of this review. All studies reviewed are correlational and cross-sectional, due to the nature of the PISA data. Therefore, no cause-and-effect relationships can be drawn from these results. Even studies that use multiple iterations of PISA cannot be used as longitudinal to find causation because the methods and measures change over the iterations. Using PISA data, the authors are unable to discern specific causes for the differences in positive, negative, or null relationships among ICT interactions. Speculation based on the country economics and ICT environment is the only way without conducting more rigorous research methods or in-depth qualitative research. The details available about the context of ICT use provided by the *ICT Familiarity Questionnaire* (OECD, 2014b) are limited, as they do not indicate the quality of the devices or the meaningfulness of the use. As a consequence, we can only reflect on the more general interactions with ICT that students have. Quality of ICT use is an important predictor for academic achievement and is needed for students to have a positive relationship between ICT and quality of learning (Lei, 2010; Lei and Zhao, 2007). The ICT measures are also limited as they do not indicate more specific contexts of ICT interactions in school. For example, it cannot be deduced what ICT devices are used for mathematics classes or science classes. Unfortunately, the numbers of teachers or parents who are skilled in ICT are not included in the *Student Questionnaire*. This would be a valuable covariate to include in analysis (Giacquinta, Bauer, and Levin, 1993; Goldhaber and Brewer, 2000).

All authors are limited by the number of covariates they can include. It would be impossible to identify, measure, and control all the possible covariates that can affect academic achievement. It is also ill advised to include any and all covariates that might be related to your outcome variable (Achen, 2005). Like statements above, researchers cannot be certain whether or not the ICT interactions are the true reason for different levels in academic scores. As mentioned by Meng et al. (2018), measurement invariance that has been established in some countries cannot be easily transferred to other countries. As a result, measurement invariance would need to be established in all countries which would be a laborious task. When it comes to choosing a country, theoretical reasons must be explained for the choice. For example, economic state, ICT environment, and whether the country will be representative of others should be part of the decision. The *ICT Familiarity Questionnaire* in PISA consists of self-reported data; therefore, the ICT measures may not perfectly reflect true scores. Another limitation is the sample used in these studies. Specifically, several countries do not take part in the PISA surveys, and even more do not implement the optional *ICT Familiarity Questionnaire*. Furthermore, as the participants are all 15-year-old students, the results are only generalizable to 15-year-olds who are in school.

In addition, the PISA survey is far from a perfect measure. The data collection is not always completely representative of the country's indigenous schools or special-needs students (C.D. Howe Institute, 2018; LeRoy, Samuel, Deluca, and Evans, 2018). The results provided by PISA must be viewed with a level of uncertainty as they are only able to present ranges of results and imperfect methods of analysis (Murphy, 2010; Ercikan, Roth, and Asil 2015; OECD, 2020).

5.2. Recommendations

In the near future, the outcomes from this scoping literature review can provide a base of knowledge for researchers to guide their future research questions. In an attempt to mitigate the limitations mentioned above, research can, in future studies, take the steps to ensure quality results. Researchers should use theoretical reasoning and other correlational research to pinpoint the ideal covariates and psychological factors available in PISA to act as control variables. This is how researchers can find more accurate results without over-controlling in their models. Similar methods as past studies can be replicated using the same countries in new iterations of PISA to see if the relationships change over time. If there are any changes, the authors can attempt to explain it by examining any shifts in the educational system. As pointed out by Tan and Hew (2018), it would be beneficial to see more mixed methodologies when investigating ICT interactions to achieve a more in-depth understanding.

Given the mixed results revealed by this scoping literature review, it is clear that student achievement is related to ICT interactions differently depending on the country of the students and the subject that is targeted. A model needs to be constructed to attempt to explain these relationships for different countries and subjects, while also including appropriate confounding variables. Soon, policy will need to be crafted on the basis of recent findings. Results from studies covered here can contribute to inform practice in schools involving ICT. As context is an important aspect of ICT interactions in relation to academic achievement, and because the various contexts have different relations with mathematics and science scores, policy and practice will need to promote the positive interactions, while trying to limit the negative ones. We would also recommend that curricula should not teach to the goal of increasing a country's rankings on the PISA list, as these measures are very specific and do not provide a holistic view of a country's level of achievement or ICT interactions (Rieckmann, 2017; Dall, 2011). Moreover, rankings are meaningless to a country's performance because the smallest shifts can cause large jumps in placing (Gorur, 2014). Furthermore, placings are often used for shaming and blaming countries who cannot top the charts (Grey and Morris, 2018). If a country does adopt curricula that match only the needs of PISA, they risk lowering their students' inquiry-based learning skills, concomitantly increasing their anxiety (Davie, 2017; Sjøberg, 2017).

6. Conclusions

This scoping literature review has explored the relations between ICT variables and academic achievement in mathematics and science for 15-year-old students who took the *ICT Familiarity Questionnaire* administered as part of the PISA assessment. This study makes the following contributions: 1) it synthesizes the relevant literature on ICT and performance in mathematics and science in a large international assessment, PISA; 2) it highlights the gaps in the literature that explores the relation between ICT and performance in mathematics and science, including in the types of statistical methods used to analyze these relations, the countries in focus, and the variables examined; 3) it revealed the need to conduct more research, as it found mixed results for most of the variables examined; and 4) it shed light onto the importance of students' autonomy in enhancing their academic outcomes.

The answer to the research question "Do students' interactions with ICT measured by PISA have a positive, negative, or no effect on 15-year-old student mathematics and science scores?" yielded mixed results of ICT with performance in mathematics and science. Of all the ICT variables, students' self-reported autonomy around the use of ICT yielded only positive performance outcomes in this scoping literature review. Other variables were a mix of negative, positive, or null results depending on the country. Future work will explore these same relations in multiple countries. This research will be continued by including all available countries who completed the *ICT Familiarity Questionnaire* in PISA 2015 into a multigroup model using SEM. The alignment method by Asparouhov and Muthén (2014) should be explored as statistical analysis that can simply incorporate many groups into a SEM.

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Tables

Table 1

The articles included in the current scoping literature review.

Reference	APA Reference of Reviewed Articles
[1]	Petko, D., Cantieni, A., & Prasse, D. (2017). Perceived quality of educational technology matters: A secondary analysis of students' ICT use, ICT-related attitudes, and PISA 2012 test scores. *Journal of Educational Computing Research, 54*(8), 1070-1091.
[2]	Hu, X., Gong, Y., Lai, C., & Leung, F. K. (2018). The relationship between ICT and student literacy in mathematics, reading, and science across 44 countries: A multilevel analysis. *Computers & Education, 125*, 1-13.
[3]	Meng, L., Qiu, C., & Boyd-Wilson, B. (2018). Measurement invariance of the ICT engagement construct and its association with students' performance in China and Germany: Evidence from PISA 2015 data. *British Journal of Educational Technology*. 1-19. doi:10.1111/bjet.12729.
[4]	Meggiolaro, S. (2018). Information and communication technologies use, gender and mathematics achievement: evidence from Italy. *Social Psychology of Education, 21*(2), 497-516.
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[6]	Bulut, O., & Cutumisu, M. (2017, June). When technology does not add up: ICT use negatively predicts Mathematics and Science achievement for finnish and Turkish students in PISA 2012. In EdMedia+ Innovate Learning (pp. 935-945). *Association for the Advancement of Computing in Education (AACE)*.
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[10]	Tan, C. Y., & Hew, K. F. (2018). The impact of digital divides on student

	mathematics achievement in Confucian heritage cultures: A critical examination using PISA 2012 data. *International Journal of Science and Mathematics Education, 17*: 1213. https://doi.org/10.1007/s10763-018-9917-8
[11]	Papanastasiou, E. C., Zembylas, M., & Vrasidas, C. (2003). Can computer use hurt science achievement? The USA results from PISA. *Journal of science education and technology, 12*(3), 325-332.
[12]	Koğar, E. Y. (2019). The Investigation of the Relationship Between Mathematics and Science Literacy and Information and Communication Technology Variables. *International Electronic Journal of Elementary Education, 11*(3), 257-271.
[13]	Reboot Foundation (2019). *Does Educational Technology Help Students Learn? An analysis of the connection between digital devices and learning*. Retrieved from https://reboot-foundation /does-educational-technology-help-students-learn.
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[15]	Gamazo, A., Martínez-Abad, F., Olmos-Migueláñez, S., & Rodríguez-Conde, M. J. (2018). Evaluación de factores relacionados con la eficacia escolar en PISA 2015. Un análisis multinivel 1 Assessment of factors related to school effectiveness in PISA 2015. A multilevel analysis. *Revista de educación, 379*, 56-84.
[16]	Su, M. (2017). The Influence of Information and Communication Technology (ICT) on Chinese and Korean Students' Math Achievement in PISA 2015. Doctoral dissertation. State University of New York at Buffalo.
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[19]	Agasisti, T., Gil-Izquierdo, M., & Han, S. W. (2017). *ICT use at home for school-related tasks: what is the effect on a student's achievement? Empirical evidence from OECD PISA data.* Retrieved from https://mpra.ub.uni-muenchen.de/81343/1/MPRA_paper_81343.pdf.
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[21]	Delen, E., & Bulut, O. (2011). The relationship between students' exposure to technology and their achievement in science and math. *The Turkish Online Journal of Educational Technology (TOJET), 10*(3), 311-317.
[22]	Fuentes, M. D. C., and Gutiérrez, J. J. T. (2012). Does ICT improve Spanish students' academic performance?. In *Investigaciones de economía de la educación, 7*. 955-975. Asociación de Economía de la Educación.
[23]	Srijamdee, K., & Pholphirul, P. (2020). Does ICT familiarity always help promote educational outcomes? Empirical evidence from PISA-Thailand. Education and Information Technologies, 1-38.
[24]	Kunina-Habenicht, O., & Goldhammer, F. (2020). ICT Engagement: a new construct and its assessment in PISA 2015. Large-scale Assessments in Education, 8, 1-21.
[25]	Hatos, A. (2020). Is using ICT at home good or bad for learning? A cross-country comparison of the impact of home use of ICT for entertainment and learning on PISA 2015 Science test results.

Table 2

Relationship Between ICT interactions and Scores in Mathematics and Science for the articles included in this scoping literature review.

ICT	**Math**			**Science**		
	Positive	**Negative**	**Null**	**Positive**	**Negative**	**Null**
HOMSCH (use of ICT at home for schoolwork)	[1] ([4] ITA) ([10] CHC) ([17 EUR-low use) [23]	[9] ([16] QCN) ([17 EUR-mid,high use) ([18] ESP) ([19 EUR) [24]	[2] ([6] FIN, TUR) ([14] CZE) ([16] KOR)	([1] high score countries) ([7] Czech mid use)([17 EUR-low use) [23]	[2][1] ([5] AUS)[9] ([14] CZE) ([17 EUR-mid,high use) ([18] ESP) ([19 EUR) [24]	([5] CAN) ([6] FIN, TUR)
USESCH (use of ICT at school)	([4]ITA) [12] ([17 EUR-low use) [23]	[1] [2] ([6] FIN, TUR) [9] ([15] ESP) ([16] QCN, KOR)	([10] CHC) ([14] CZE)	([5] CAN, browse Internet) ([17 EUR-low use) [23]	[2][1] ([5] CAN, frequent use, AUS) ([6] FIN,	([5] CAN) ([14] CZE

		([17 EUR-mid, high use) ([18] ESP) ([22] ESP) [24]			TUR) [9] ([15] ESP) ([17 EUR-mid, high use) ([18] ESP) ([22] ESP) [24] [25]	)
ENTUSE (use of ICT for entertainment)	([4] ITA) ([1] low score countries) ([6] TUR)([17 EUR-low use) ([20] TUR) [23]	([1] high score countries) ([6] FIN) [9] ([16] QCN, KOR) ([17 EUR-high use) ([18] ESP) ([22] ESP) [24]	[2] ([14] CZE) ([17 EUR-mid use)	[2] ([5] CAN, AUS, browse Internet) ([6] TUR) ([17 EUR-low use) [23] [25]	[1] ([5] CAN, frequent use, AUS most use) ([6] FIN) ([17 EUR-high use) ([18] ESP) ([22] ESP) [24]	[9] ([14] CZE) ([17 EUR-mid use)
ICTHOME (ICT availability at home)	([6] TUR) ([21] Tur) ([22] ESP) [23]	[2] ([10] CHC) ([18] ESP)	([6] FIN) ([14] CZE)	([6] TUR) ([11] USA) ([21] Tur)([22] ESP) [23]	[2] ([14] CZE) ([18] ESP) [25]	([6] FIN)
ICTSCH (ICT availability at school)	([6] TUR)([22] ESP)	([12] eBook readers) [13] ([18] ESP)	[2] ([6] FIN) ([10] CHC) ([14] CZE)	([6] TUR)([22] ESP)	([12] eBook readers) [13] ([18] ESP) [25]	[2] ([6] FIN) [11] USA) ([14] CZE)
INTICT (interest in ICT)	[2] ([3] QNC) ([12] Internet) ([18] ESP) [24]	([3] DEU) ([14] CZE mod by gender)	([14] CZE)	[2] ([3] QNC) ([18] ESP) [24]	([3] DEU)	([14] CZE)
COMPICT (competence in ICT use)	[2] [8] ([12] unfamiliar device)	([3] QNC)	([3] DEU) ([14] CZE)	[2] ([5] CAN, AUS, basic skills, presentation	([3] QNC)	([3] DEU) [7] ([11]

	([18] ESP) ([22] ESP, attitudes and skill) [24]			software) ([8] 2009) [11] USA, writing papers) ([18] ESP) ([22] ESP, attitudes and skill) [24]		USA, general use, test taking) ([14] CZE)
AUTICT (autonomy of ICT use)	[2] ([3] QNC, DEU) ([15] ESP) ([14] CZE) ([18] ESP) [24]	-	-	[2] ([3] QNC, DEU) ([15] ESP) ([14] CZE) ([18] ESP) [24]	-	-
SOIAICT (ICT inclusion in social interactions)	([18] ESP) [24]	[2] ([3] QNC, DEU) ([14] CZE) ([15] ESP) [23]	-	([18] ESP) [24]	[2] ([3] QNC, DEU) ([14] CZE) ([15] ESP) [23]	-

AUS - Australia; CAN - Canada; QCN - China; CZE - Czech Republic; EUR - European; FIN - Finland; DEU - Germany; ITA - Italy; KOR - Korea; ESP - Spain; TUR - Turkey; CHC - Confucian Heritage Culture (Hong Kong, Japan, Korea, Macau, Shanghai, Singapore, and Taipei).

Table 3

Analysis methods used for the studies reviewed. Number of countries sampled by each reference is included in parentheses following the reference.

Statistical Method/ Country	HLM	SEM	MLR	Logistic regression	EFA	Linear regression	CHAID	Path analysis	IEA international database analyzer	Data Mining	Propensity score matching	Instrumental variable analysis	ANOVA

Australia	[5]				[5]								
Canada	[5]				[5]								
China		[3]						[16]	[16]				
CHC*	[10]												
Czech Republic	[14]												[7]
Finland		[6]											
Germany		[3] [24]											
Italy			[4]										
Korea								[16]	[16]				
Spain			[15]	[15]		[22]				[18]			
Turkey	[21]	[6]	[20]										
United States of America						[11]							
Switzerland		[24]											
Thailand		[23]											
Europe			([17] 25)								([19] 12)	([19] 12)	
PISA 2000 all	[8]												
PISA 2003 all	[8]												
PISA 2006 all	[8]												

PISA 2009 all	[8]												
PISA 2012 all	[8] ([9] 39)		([1] 39)										
PISA 2015 all	([2] 44)					([13] 30)	([12] 35) [25]						

*CHC is comprised of Hong Kong, Japan, Korea, Macau, Shanghai, Singapore, and Taipei.

Table 4

PISA iterations used in the reviewed studies.

PISA Year/ Iteration	2000	2003	2006	2009	2012	2015
Single iteration used	[11]		[5] [7]	[21] [22]	[1] [4] [6] [9] [19] [20]	[2] [3] [12] [14] [15] [16] [17] [18] [23] [24] [25]
Multiple iterations used	[8]	[8] [13]	[8] [13]	[8] [13]	[8] [13]	[13]

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