1 Mathematics and Science Learning in Primary and Secondary School EMI Classrooms

Evidence from PISA and TIMSS

Sibel Kaya

Mathematics Learning in EMI Classrooms

Traditionally, mathematics is believed to be a subject that does not require strong language skills. However, researchers highlight the importance of a good command of language to be successful in mathematical reasoning and problem-solving (Bernardo, 2005). Especially, word problems in mathematics require students to read and understand the problem to solve them. In English Medium Instruction (EMI) classrooms, if students have not yet mastered English, they might struggle to understand and solve word problems even though they do not have mathematical difficulties.

In some countries such as the Philippines, EMI in mathematics used to start as early as prekindergarten. In a quasi-experimental study, Ricablanca (2014) compared the mathematics achievement of first-grade students in EMI and mother tongue instruction classrooms. The participants were sixty-three first-grade students (thirty-one mother tongue, thirty-two EMI) from the same school in the Philippines. During this period, the students were taught the same lessons by the same teacher and exposed to the same activities and homework in two different media of instruction. Students took the same achievement test as the pretest, posttest, and retention test, but the mother tongue classroom took the test in their mother tongue whereas the EMI classroom took it in English. Paired samples *t*-test and analysis of covariance (ANCOVA) were used to analyze the data. Students in the mother tongue classroom received significantly higher scores on the mathematics achievement test compared to their peers in the EMI classroom both in the posttest and in the retention test. The researcher recommends that the school systems should consider using the mother tongue for mathematics instruction in the early years since important mathematical concepts are easier to grasp in the mother tongue. When students try to learn a subject such as mathematics in a language they have not yet mastered, they take on a cognitive load alongside learning the concepts, which affects their academic performance negatively. In 2013, the Philippines government institutionalized the use of the mother tongue in all subjects from preschool to third grade as part of a new educational law. This decision has not been welcomed by parents and students due to the perceived high value of English in society (Tupas, 2015). However, recent studies point out the academic advantage of mother tongue instruction in the Philippines (Perez & Alieto, 2018).

Hong Kong is another country where EMI in mathematics and science teaching has been debated. In a meta-analysis, Lo and Lo (2014) systematically analyzed twenty-four studies on EMI education in Hong Kong. Most of the studies were cross-sectional and correlational, so the authors cautioned against making strong claims. Effect size estimation and *z*-statistics were used to determine the statistical significance of the results. Effect sizes between 0.2 and 0.5 were considered to be low, between 0.5 and 0.8 were moderate, and 0.8 and above were considered high. According to the findings, EMI schools were better in terms of English proficiency, but they fell behind Chinese-medium instruction (CMI) schools in science. There was not a sizable difference in mathematics. The authors highlighted the significance of the type of outcome measure such that EMI students scored better than their CMI peers when standardized tests were used; however, they scored worse when self-designed tests were used. In terms of affective learning outcomes, EMI students showed higher levels of self-concept, interest, and motivation toward learning in mathematics but not in science. They had lower self-concept and less interest in learning science compared to CMI students.

Some researchers recommend the use of learners' mother tongue as a supplement to EMI when teaching mathematics. For example, in a pretest–posttest experimental design, Launio (2015) compared the mathematics achievement between EMI only and EMI supplemented with the Hiligaynon language in a Filipino high school. The author conducted independent samples *t*-test analyses in the Statistical Package for Social Sciences (SPSS) to examine differences in mathematics achievement between the two groups. Results showed that there was no significant difference in the pretest but in the posttest the bilingual group scored significantly higher than the English-only group at a 0.05 significance level. The author recommends that teachers should be able to explain concepts in learners' mother tongue in EMI mathematics classrooms when difficulties in understanding arise.

Recent research in EMI mathematics learning recommends the use of translanguaging in classrooms. The primary objective of translanguaging is content learning. During translanguaging, students are allowed and encouraged to use both their first and second languages to make sense of scientific content and to facilitate their understanding (Karlsson et al., 2019). Since students are allowed to use their full linguistic potential, a more equitable learning environment can be provided for all students regardless of their English language proficiency. During translanguaging, teachers can act as a learner rather than as the sole provider of knowledge. Through colearning opportunities, teachers and students learn from each other and coconstruct knowledge. Through comfortable dialogues, teachers can increase student motivation and self-confidence, create enjoyable classroom contexts, and conform to the EMI policy. Therefore, translanguaging in EMI classrooms can help achieve a range of pedagogical objectives for promoting student learning (Tai & Wei, 2021a). Translanguaging may also help EMI teachers who are not confident in their English usage in classrooms since it allows the colearning of linguistic aspects such as pronunciation and the meaning of vocabulary.

Tai and Wei (2021b) introduced playful talk as a form of translanguaging in a middle school mathematics classroom. The playful talk involves the use of rhyming words, drawings, mnemonics, switching intonations, and personal experiences to promote meaningful communication between the teacher and students. In typical EMI mathematics classrooms, students have limited opportunities to interact with the teacher. However, playful talk in EMI classrooms creates a dynamic environment and facilitates students' participation. The authors suggest that the longitudinal implementation of translanguaging through playful talk could provide further evidence of the effectiveness of this method for content acquisition in EMI classrooms.

Science Learning in EMI Classrooms

Language plays an important role in gaining scientific literacy (Gee, 2000; Yore et al., 2003). Norris and Phillips (2003) emphasize that scientific literacy involves reading, writing, and oral communication in science. These practices improve scientific reasoning and understanding. According to the definition of the Organisation for Economic Co-operation and Development (OECD), scientific literacy is the ability to engage with science-related issues and the ideas of science as a reflective citizen. This ability includes explaining natural and technological phenomena scientifically, designing scientific investigations, interpreting data, and drawing conclusions (OECD, 2017). El Masri et al. (2016) highlight that even though the OECD's description of scientific literacy does not mention language or linguistic proficiency, one can only assume that high language proficiency is needed to acquire the set of abilities stated there. According to Cummins (2008), two sets of skills are needed for language learning. One of them is used for everyday communication and described as "basic interpersonal communicative skills." The other one is called "cognitive academic language proficiency." Learning a scientific language requires a second set of skills that can be complex and demanding (van Laere et al., 2014). Cummins (2000) points out that all learners need to develop academic language proficiency to engage with the more abstract ways of thinking and communicating required for academic learning. The requisite academic language proficiency takes much longer to develop compared to communicative proficiency. Therefore, students might appear to be orally proficient in English yet not perform well academically in EMI classrooms.

Yip et al. (2003) compared the science achievement of secondary students in EMI and CMI schools in Hong Kong through an achievement test made up of multiple-choice and open-ended questions. They used a multilevel regression model to explain the variance in students' science achievement. They used aptitude, socioeconomic status, and gender at the student level and school-mean aptitude, school-mean socioeconomic status, and medium of instruction at the school level. Findings showed that EMI students performed worse than their peers in CMI. They performed especially poorly on items in which mastery of scientific terminology, abstract concepts, and application of scientific knowledge to real-life problems were tested. EMI students scored better only on multiple-choice items with low cognitive demand. These findings indicate that when students learn science in a language without mastering it, they are at a clear disadvantage compared to those who learn it in their mother tongue.

Another important concept in science learning is science process skills, which are the skills that scientists use to solve problems and construct knowledge. Science process skills include basic skills such as observing, inferring, predicting, measuring, classifying, and communicating; higher-level skills include defining operationally, hypothesizing, controlling variables, experimenting, and interpreting data. Students need these skills to carry out scientific investigations and to make sense of natural phenomena (Carin et al., 2005; Harlen, 1999). Science process skills incite creativity, reflective thinking, and problem-solving in students, which are critical for the scientific and technological development of nations (Olufunminiyi & Afolabi, 2010). Therefore, science teachers in EMI classrooms should emphasize these skills in their teaching methodology (Tilakaratne & Ekanayake, 2017).

In a large-scale correlational study, Tilakaratne and Ekanayake (2017) examined the science process skills of more than 6,000 secondary school students in Sri Lanka in terms of some variables, including the medium of instruction. Schools that participated in the study used three different languages as the medium of instruction: Sinhala (the primarily spoken language in Sri Lanka), Tamil, and English. Students took a science process skills test that measured their ability to observe, measure, classify, identify variables, infer, hypothesize, and experiment. Data were analyzed in SPSS through one-way analysis of variance (ANOVA), with the medium of instruction as the factor and the level of understanding of students' science process skills as the dependent variable. The researchers used the Tukey post hoc test to compare pairwise means of the three groups, Sinhala, Tamil, and English. Results showed that students who studied science in Sinhala medium performed better in their understanding of science process skills compared to the students in Tamil and English medium. The general perception about the medium of instruction in Sri Lanka is that students who attend EMI schools perform better than students who attend Sinhala or Tamil medium of instruction schools. However, the findings of this study showed that in terms of science process skills, EMI students performed worse than students in the other two mediums.

In addition to cognitive learning outcomes, EMI may also negatively influence students' affective learning outcomes in science. Yip and Tsang (2007) investigated the self-concept of around 16,000 students attending Hong Kong's EMI and CMI schools in Chinese, English, mathematics, and science subjects. Student achievement was measured through a written test near the end of the school year, and self-concept was measured by a student questionnaire given at the same time as the written tests. Student scores were compared through ANOVA in SPSS. In Chinese, English, and mathematics, EMI students showed a higher self-concept compared to CMI students. However, they showed a lower self-concept in science. Researchers claim that due to the reliance on abstract thinking and language proficiency, EMI students might experience learning difficulties in science classrooms, and therefore caution against the negative effects of EMI on science learning. This finding is especially concerning since EMI schools in Hong Kong recruit the top-performing students in terms of academic achievement (Yip & Tsang, 2007).

Science teachers often resort to mother tongue instruction in EMI classrooms to help their students understand complex science topics. Pun and Macaro (2019) examined the types of teacher questions asked in the mother tongue and English in Hong Kong's EMI high schools during science lessons. A total of thirty-three science lessons were observed, and observations were coded. Interrater coding reliability of Cohen's kappa was found to be greater than 0.8, which indicates a reliable coding process. The teacher questions were classified as "lower order" and "higher order." Questions that ask for factual recall information were coded as lower order, and questions that require students to explain a phenomenon, analyze, evaluate, and synthesize were coded as higher order. Findings showed that when teachers used English in EMI classrooms, they asked more lower-order questions, whereas when they switched to Cantonese, they asked more higher-order questions and the lesson was more interactive. Researchers emphasize that mother tongue use in EMI classrooms may promote higher-order thinking and meaningful science learning but it may also inhibit the acquisition of academic English. Pedagogical support programs for content subject teachers are recommended to improve their skills in integrating content and language. During these programs, case studies of the effective implementation of EMI in science classrooms can be provided.

Science teachers in EMI classrooms consider EMI as a tool for transmitting knowledge, not for learning a second language (Block & Moncada-Comas, 2022; Pun & Tai, 2021; Pun et al., 2022). Even though most science teachers desire a flexible EMI policy where they can use their mother tongue for different purposes, excessive and incautious use of the mother tongue can be detrimental to the quality of EMI (Pun et al., 2022). According to Williams (2002), in translanguaging, the alternation between languages should not be spontaneous but rather strategic to help students understand the content and scaffold their language learning. Recent studies showcase how translanguaging can be used in EMI classrooms to create an interactive and enjoyable science learning environment (Lin, 2019; Pun & Tai, 2021). In their study, Pun and Tai (2021) observed grade 10 biology and chemistry laboratory sessions in Hong Kong and analyzed how science teachers and students utilize translanguaging practices. They observed that even though teachers delivered instructions in English, students chose to communicate in Cantonese (their mother tongue) among themselves. They also used a wide range of modalities such as speaking, text, diagrams, and hands-on experiments. Researchers emphasized that not restraining students with English allowed them to engage in active scientific inquiry and argumentation. Translanguaging, especially, gives voice to those students with limited English proficiency, who are generally passive learners in monolingual EMI classrooms. As in EMI mathematics classrooms (Tai & Wei, 2021a, 2021b), translanguaging in EMI science classrooms reduces hierarchical relationships between the teacher and students and creates a safe space for colearning.

Evidence from PISA and TIMSS

Periodically conducted every three and four years, the Programme for International Student Assessment (PISA) and Trends in International Mathematics and Science Study (TIMSS) measure students' performance in mathematics and science at the international level. PISA collects data from fifteen-year-old students across countries and partner economies every three years (OECD, 2019), while TIMSS monitors trends in mathematics and science achievement in the fourth and eighth grades every four years (Mullis & Martin, 2017). Based on the results of these comparative assessments, important policy decisions are taken in several countries regarding education systems (Anderson et al., 2007). For example, due to the declining trend in mathematics and science performance in TIMSS, the Malaysian government changed the medium of instruction from English to Malay, the official language of the country spoken by the majority of the population, in 2012 (Thien & Ong, 2015).

Besides measuring student performance, these assessments collect rich contextual information at the student, classroom, school, and national levels, and both datasets are publicly available on their related websites. Researchers can conduct secondary data analysis on the released datasets regarding their research interests. For instance, factors affecting cognitive and noncognitive outcomes within and across nations can be investigated.

PISA and TIMSS have similarities as well as differences. Both assessments collect rich contextual information through school, teacher, student, and home questionnaires. They do not use exact student achievement scores because students take only a portion of the test due to time constraints. Therefore, PISA and TIMSS offer plausible values as the measure of student achievement, each plausible value describing a random value of a student's scores. The final scale is reported with an average of 500 and a standard deviation of 100 in all countries (Martin et al., 2016; OECD, 2020). Both assessments use a probability proportional to size sampling procedure where the probability of selecting a sample depends on its size. However, in PISA, only a number of fifteen-year-old students are assessed from the selected schools, whereas in TIMSS, intact classrooms within the sampled schools participate in the assessment. Therefore, TIMSS contains classroom-level information since teachers who teach in these classrooms complete a questionnaire, but PISA does not have this information. Although a Teacher Questionnaire was implemented for the first time in PISA 2015, student-level data are usually aggregated into school-level variables. Another distinct difference between the two assessments is their testing objectives. PISA assesses the degree to which students apply their knowledge and skills to real-world problems (OECD, 2017), while TIMSS measures the mathematics and science achievement of fourth and eighth graders aligned with the national curricula (Mullis et al., 2005).

In terms of the test language, the OECD advises that it should be consistent with the participating countries' medium of instruction. Since several countries use more than one language of instruction in their education systems, the instruments have been translated into multiple languages. Tables 1.1 and 1.2 show the countries that used other test languages in addition to English. Countries use more than one medium of instruction for different reasons. For example, in Canada, the geographic region determines the educational language, and students' home language is usually the same as the educational language. On the other hand, in Hong Kong, even though an overwhelming majority of students speak Cantonese at home, it is the government's policy to implement EMI in schools. EMI schools in a country are usually tested in English in PISA and TIMSS. However, the final approval of the test language is up to the decision-makers in the countries (Ho, 2007). In some countries with high levels of linguistic diversity, such as South Africa, the majority of students do not use either of the test languages (English and Afrikaans) at home (Prinsloo & Harvey, 2020).

Table 1.1 *PISA languages used for the assessment*

Country		
Canada	English	French
Cyprus	English	Greek
Hong Kong (China)	English	Chinese
Ireland	English	Irish
Lebanon	English	French
Luxemburg	English	German
Macao (China)	English	Chinese
Malaysia	English	Malay
Malta	English	Maltese
Panama	English	Spanish
Qatar	English	Arabic
Sweden	English	Swedish
United Arab Emirates	English	Arabic
Wales (UK)	English	Welsh

Source: OECD (2020).

Table 1.2 *TIMSS languages used for the assessment*

Country			
Bahrain	English	Arabic	
Canada	English	French	
Cyprus	English	Greek	
Egypt	English	Arabic	
Hong Kong SAR	English	Chinese	
Georgia	English	Georgian	
Ireland	English	Irish	
Jordan	English	Arabic	
Kuwait	English	Arabic	
Lebanon	English	French	
Malaysia	English	Malay	
Malta	English	Maltese	
Oman	English	Arabic	
Pakistan	English	Urdu	Sindhi
Qatar	English	Arabic	
Saudi Arabia	English	Arabic	
South Africa	English	Afrikaans	
United Arab Emirates	English	Arabic	

Source: Martin et al. (2020).

Hong Kong

Hong Kong is a country where schools with EMI are considered to be more prestigious compared to schools with CMI (Ho & Man, 2007; Tsiu, 2008). To examine the differences in student performance in Chinese and English, the PISA 2000 study conducted the test in both languages in Hong Kong. In their report, Ho and Man (2007) focused on twenty-eight EMI schools tested in both Chinese and English. They compared the average scores for reading, science, and mathematics. Findings showed that reading and science scores were significantly higher with the Chinese version of the test compared to the English version of the test in EMI schools. The differences in mathematics were relatively smaller, with only five schools where students who took the test in Chinese scoring better. The authors emphasize that students in EMI schools have a better command of their mother tongue, which is Chinese in the case of Hong Kong, in terms of understanding and interpreting information in PISA. In another report, Ho (2007) compared the scientific literacy scores of students who took the PISA 2006 test in Chinese versus English from thirty-four EMI schools from grade 7 to grade 10. Students who were given the scientific literacy test in Chinese scored significantly higher than their peers who took the same tests in English, at all four grade levels.

Studies conducted with Hong Kong samples showed that EMI benefits only high-ability students. For the majority of students in EMI classrooms, using English is difficult; therefore, teachers often allow the use of students' mother tongue. Despite the evidence that instruction in the native language is superior in terms of overall student achievement, parents prefer EMI schools due to their advantages in career prospects (Tsiu, 2008). However, Ho and Man (2007) point out that unlike in Singapore and Malaysia where English is commonly used by different cultural groups, in Hong Kong, English-speaking and Chinese-speaking communities have distinct characteristics. Therefore, EMI and CMI schools can sometimes have wide economic and cultural disparities.

Malaysia

Malaysia has been indecisive regarding the medium of instruction issue. In 2002, as part of the country's efforts to prepare its human capital for the globalized world, the government changed the medium of instruction for mathematics and science from Malay to English. However, there was a decline in both the mathematics and science performance of Malaysian students in TIMSS assessments after 2002. As a result, the government reverted to using Malay as the medium of instruction for mathematics and science in 2012 (Thien & Ong, 2015).

Ismail and Awang (2012) investigated the relationship between student background variables and TIMSS 2007 mathematics achievement in Malaysia through multiple regression analysis. They found that students who did not speak the language of the test, which was Malay, at home scored significantly higher than those who did. They also conducted ANOVA where the frequency of speaking the test language at home was the factor. Findings suggested that students who speak the test language at home most frequently had lower mathematics achievement than other groups. These findings were consistent with the results of TIMSS 1999 and 2003. However, the medium of instruction was Malay in both 1999 and 2003, while it was English in 2007. The authors concluded that the medium of instruction did not significantly affect Malaysian students' mathematics performance.

Singapore

The medium of instruction in Singapore has been English since the 1970s. Singapore has always been very successful in TIMSS and PISA assessments and has been among the High-Performing Education Systems alongside Hong Kong, South Korea, and Finland. Although Singapore's success in using English as a medium of instruction is impressive, other political decisions have also contributed to its success, such as promoting English as an official language, emphasizing math and science education, and establishing high standards, academic merit, and high-stakes exams in education (Deng & Gopinathan, 2016).

Thien and Ong (2015) examined the influence of the affective characteristics of Singaporean and Malaysian students on their PISA 2012 mathematics achievement. They conducted two-level (student and school) hierarchical linear modeling (HLM) analyses for both countries. They reported that in both countries mathematics-related self-efficacy and anxiety have significant effects on mathematics performance at the student level. However, Malaysian students showed high levels of anxiety and low levels of self-efficacy compared to Singaporean students. The authors have not used language-related variables but they speculated that the high levels of mathematics anxiety in Malaysia could be due to the use of English as a medium of instruction in mathematics classrooms. The declining trend in TIMSS assessments after switching to EMI in mathematics classrooms could also be due to increased levels of anxiety among Malaysian students.

South Africa

In South Africa, despite the recent reformation toward multilingual education through constitutional changes and government policies, EMI is still considered to be superior among the public (Cummins 2015; Prinsloo & Harvey, 2020). Prinsloo and Harvey (2020) investigated the effect of non-equivalence between home language and instructional language on science and mathematics achievement by using South African grade 9 TIMSS 2015 country data. They used three-stage modeling of multiple regression analysis with student-level variables in the first model, school-level variables in the second model, and teacher/classroom-level variables in the third model. They included variables related to language in modeling at the learner, teacher, and school levels. At the student level, nearly 80 percent of students' home and school (test) languages were not equivalent. The influence of language equivalence was higher for science than mathematics. Students whose home and test languages were not the same scored fifty-one points lower in science compared to thirty-four points in mathematics. Researchers indicate that the inability to understand scientific language creates a barrier to science learning. They also speculate that language nonequivalence limits the attainment of a range of skills taught in science lessons such as critical thinking and problem-solving. These skills are not only critical for science learning but also necessary for the socioeconomic development of nations. According to Prinsloo and Harvey (2020), African home language learners are immersed in EMI too early in schooling, which causes poor development of both home language and instructional language. Igboanusi (2008) states that the sudden and early transition from mother tongue instruction to EMI interrupts students' cognitive development and causes poor academic achievement in science. Identically, African students exposed to a language of instruction that is not their mother tongue have relatively low academic achievement, especially students who have had rare exposure to English (Graham, 2010).

Wales

The status of EMI in Wales is somewhat different compared to the countries mentioned earlier. Welsh-medium instruction (WMI) schools are considered to be better due to their high level of achievement and positive reputation compared to EMI schools; therefore, they attract affluent families from middle- and upper-class backgrounds (Jones, 2017; Van den Brande et al., 2019). However, average PISA scores are lower among students attending WMI schools than among students attending EMI schools over time (Jerrim et al., 2022). Using five rounds of PISA data and an instrumental variable (language spoken at home) approach, Jerrim et al. (2022) conducted ordinary least squares and two-stage least squares regression analyses. They found that students who took the test in Welsh performed 26 points lower in mathematics and 33 points lower in science, compared with their peers who took the test in English. According to OECD (2019) 25–30 points in the PISA scale is equivalent to one year of schooling. The researchers state that this may be due to translation issues and the disparity between spoken and literary Welsh. They argue that unless an optimum solution is offered, such as providing students with test questions in both English and Welsh, the academic performance of teenagers in Wales will be underestimated in PISA.

Conclusion

In general, the findings of the studies reviewed in this chapter favored the instruction in the mother tongue for both cognitive and affective variables in mathematics and science at the primary and secondary school levels. EMI instruction seems to benefit only students with high English proficiency. Despite evidence that native-language instruction is superior in terms of overall student achievement, parents prefer EMI schools due to their advantages in the global economy, except in the case of Welsh education. Some of the challenges of EMI in terms of mathematics and science learning include inadequate English proficiency of teachers, low self-esteem of students, lower-order teacher questions, and less interaction in the classroom. Switching to EMI after attaining certain levels of English proficiency and providing language support for students who are already in EMI systems are recommended. Researchers also propose the use of translanguaging during content teaching in EMI classrooms, where students can use a wide range of modalities. As global economies are becoming more mathematics- and science-oriented, it is important to determine factors that benefit students' content learning in EMI classrooms. Longitudinal studies investigating how to maximize the efficiency of EMI mathematics and science teaching and how government policies regarding EMI influence students' performance in international assessments are recommended. It is important to take into account sociocultural, political, and linguistic contexts when examining TIMSS and PISA achievement, as they greatly influence the status of EMI within countries.

In recent years, researchers have increasingly utilized PISA and TIMSS datasets in various fields of education. It was reported that about two-thirds of the studies that used PISA and TIMSS datasets adopted basic and intermediate statistical analysis techniques, such as descriptives, independent samples *t*-test, ANOVA, and multiple regression, while one-third of the studies utilized advanced statistical techniques such as structural equation modeling, HLM, factor analysis, and item response theory (Liou & Hung, 2015). As advanced statistics become more accessible to researchers, the number of studies using them is likely to increase in the coming years. Specific to EMI research, the studies in this review relied mainly on comparative *t*-test and ANOVA to compare instructional language-related differences, as well as regression to determine the effect of language-related variables on achievement. Among the advanced methods, HLM can be useful in investigating EMI alongside other contextual and background variables at the student level and classroom/school level. Item response theory might shed light on question discrimination and difficulty in different mediums of instruction and might reveal issues such as translation. As TIMSS and PISA contain complex datasets, using advanced statistics is recommended to gain a deeper understanding of student achievement and to render robust findings.

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