

CHAPTER 3

TIMSS Advanced 2015 Context Questionnaire Framework

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Because the global community's prosperity and welfare depend on technological development and scientific discovery, it is crucial that the world's educational systems provide students with advanced skills in science, technology, engineering, and mathematics (STEM). Future leaders in science and technology need to be fully prepared to produce innovative ideas that can spark economic and human development. Recognizing this, countries across the world invest tremendous resources in specialized programs to ensure that at least some students study STEM subjects at the high level through the final years of upper secondary school and have the skills to excel in STEM fields at the tertiary level. The degree of selectivity and intensity of these programs varies across countries, as does the advanced nature of the content.

Given the importance that countries place on these specialized programs, TIMSS Advanced collects detailed data on student achievement in advanced mathematics and physics, particularly in relation to system structure, school organization, curricula, teacher education, and classroom practices. These data can inform educational policy makers of key predictors of student learning and point them toward effective strategies for improving the educational system in scientific and technological areas.

The TIMSS Advanced 2015 Context Questionnaire Framework establishes the foundation for the background information that will be collected by TIMSS Advanced. The context questionnaires are administered to the students participating in TIMSS Advanced, as well as to their teachers and school principals, and provide a wide array of policy relevant information about the home and school contexts for teaching and learning advanced mathematics and

physics. The student questionnaires also ask about attitudes toward learning advanced mathematics and physics. In addition, countries participating in TIMSS Advanced 2015 each contribute information about their provision for advanced mathematics and physics education in their country's chapter of the *TIMSS 2015 Encyclopedia*.

Contexts for student learning in the final year of secondary school typically include community, school, classroom, and home environments. Reflecting this situation, the TIMSS Advanced 2015 Context Questionnaire Framework encompasses four broad areas:

- National and community contexts;
- School contexts;
- Classroom contexts; and
- Student characteristics and attitudes toward learning.

National and Community Contexts

At the national and community level, key policy decisions about how to nurture students into STEM careers are made in the context of the cultural, social, political, and economic situation of the country. The success a country has in providing effective advanced mathematics and physics instruction often depends on a number of interrelated national characteristics and decisions:

- Economic resources;
- Organization and structure of the educational system;
- Admission or recruitment into specialized STEM programs;
- Intended advanced mathematics and physics curricula;
- Teachers and teacher education; and
- Administration of high-stakes summative examinations.

Economic Resources

Adequate economic resources are crucial for implementing a rigorous STEM curriculum and providing better educational facilities for teaching STEM subjects, technological resources to aid students in their learning, and well-trained mathematics and physics teachers. Financial resources also provide

the opportunity to invest in programs that promote mathematics and physics education and incentivize students to enter these fields, such as special science schools with cutting edge technological equipment or partnerships with researchers in high-tech industries.

Organization and Structure of the Educational System

Some countries have highly centralized educational systems in which most policy-related decisions are made at the national or regional level. In these systems, there is typically a high-level of educational uniformity across the system, in terms of curriculum, textbooks, and general policies. National policy makers can ensure that the curriculum reflects what the national government deems to be essential for the formation of young scientists and mathematicians. In addition, a centralized system allows countries to structure the educational system so that the quantity of students in the STEM pipeline matches the expectations and projected needs of the national economy.

Other countries have more decentralized systems in which many important decisions are delegated to local governments and schools. A decentralized structure can result in greater variation in the curriculum, how schools operate, and how students are taught. Likewise, schools and school districts may have more autonomy to decide the number of students admitted to advanced mathematics and physics programs, or the students themselves may have more curricular choices.

TIMSS Advanced 2008 showed that differences exist across countries in the number of students in the STEM pipeline. In many countries, there is concern that not enough students are choosing to enter STEM programs (Ainley, Kos, & Nicholas, 2008; European Commission, 2004; National Research Council, 2011; Organisation for Economic Co-operation and Development (OECD), 2008), and there also is concern that women and minority groups are underrepresented in STEM fields (National Research Council, 2010; National Research Council, 2011; OECD, 2008). In this context, some countries have national strategies to promote educational opportunities in these fields. National initiatives include the installation of STEM centers to improve STEM teaching and develop STEM culture, and competitions and campaigns to make science more appealing across society (Kearney, 2011).

Admission or Recruitment into Specialized STEM Programs

TIMSS Advanced examines the educational achievement of the relatively small proportion of a student cohort that participates in specialized programs of study in advanced mathematics and physics. In this context, it is important to understand how students are selected to participate in these STEM programs. In some countries, the number of students studying advanced mathematics and physics is linked to system-level tracking that assigns students to academic or vocational pathways. In the context of TIMSS Advanced 2015, understanding the timing and extent of the selection process is important to interpreting the results. Some countries track students with aptitude in mathematics and physics into elite secondary institutions. In other countries, the top mathematics and physics students attend schools with other students who are on a more general track.

Intended Advanced Mathematics and Physics Curricula

At the senior secondary level, compared to earlier grades, there is considerable differentiation between countries regarding the curricular goals for advanced mathematics and physics, both in how subject mastery is defined and how the curricula specify that mastery should be achieved.

For advanced mathematics, countries vary in how much they emphasize advanced content, such as calculus, as well as high-level algebra, geometry, and trigonometry. There are differences between countries on how much weight is placed on expressing mathematics theories, results, and problems in numerical, analytical, and graphical form. There also is variation between countries in the relative emphasis that is placed on communicating and reasoning mathematically, developing mathematical models to describe real situations, and the degree to which various digital computing devices are used and relied on in the problem solving process.

For physics, countries emphasize to varying degrees the TIMSS Advanced content domains of mechanics and thermodynamics, electricity and magnetism, and wave phenomena and atomic/nuclear physics. Some countries stress the practice of physics more than other countries. The use of inquiry in physics teaching also varies across curricula. Other teaching strategies that are implemented to varying degrees include student involvement in planning and carrying out investigations, student involvement in developing and using mental models, and the extent to which students analyze and interpret data.

The relative emphasis on communicating scientific theory, constructing explanations, and engaging in arguments from evidence varies across countries, as does the use of technology to support student work.

Teachers and Teacher Education

Considering the complexity of the advanced mathematics and physics subject matter, many educational systems struggle to develop and retain a sufficient number of advanced mathematics and physics teachers to fill the needs of secondary schools (American Association for Employment in Education, 2010; National Committee for the Mathematical Sciences of the Australian Academy of Science, 2006; Schleicher, 2012). The pathway to becoming a STEM teacher differs between countries, but generally the pathway includes advanced coursework in mathematics and/or physics in lower and upper secondary school as well as a university qualification in mathematics and/or physics.

Administration of High-stakes Summative Examinations

Because TIMSS Advanced 2015 assesses students at the end of their secondary school careers, a country or educational systems' employment of summative assessments can be an important educational factor to take into account when interpreting TIMSS Advanced results. These high-stakes assessments, which can be used to determine student graduation and honors as well as placement in post-secondary institutions, may be the focal point for students at this stage in their academic career.

School Contexts

A school's environment and organization can influence the ease and effectiveness of fostering the education of students in STEM fields. Accepting that an effective school is not simply a collection of discrete attributes, but rather a well-managed integrated system where each action or policy directly affects all other parts, TIMSS Advanced focuses on a set of well-researched school quality indicators:

- School composition by student socioeconomic background;
- Instruction affected by resource shortages;
- Teacher career satisfaction and teacher retention;
- Principal leadership; and
- School climate.

School Composition by Student Socioeconomic Background

The collective socioeconomic status of the students in the school can be a strong predictor of the achievement of individual students (Martin, Foy, Mullis, & O'Dwyer, 2013; Rumberger & Palardy, 2005; Sirin, 2005). Attending a school with many students from advantaged backgrounds can have a beneficial effect over and above the effects of a student's own home background. Furthermore, the relationship between advantaged schools and achievement may be influenced by other school factors. For example, in some countries, schools with many students of lower socioeconomic status have difficulties recruiting highly qualified teachers (Akiba, LeTendre, & Scribner, 2007; Clotfelter, Ladd, & Vigdor, 2010; Schleicher, 2012).

Instruction Affected by Resource Shortages

As a means of promoting STEM subjects and attracting students to enter and remain in the pipeline, many countries heavily invest to ensure that STEM schools and subjects are well-resourced. Research has shown that the extent and quality of school resources are critical for quality instruction (Greenwald, Hedges, & Laine, 1996; Lee & Barro, 2001; Lee & Zuze, 2011). These may include resources as basic as well-trained teachers, or adequate classroom space and school facilities (Schneider, 2002). Results from TIMSS 2011 at the fourth and eighth grades indicate that students in schools that are sufficiently resourced generally have higher achievement than those at schools where resource shortages affect the capacity to implement the curriculum. Subject-specific resources for advanced mathematics and physics may include availability of a variety of computing devices (e.g., tablets and graphing calculators), software for educational games and simulations, and laboratory equipment for physics experiments.

Teacher Career Satisfaction and Teacher Retention

TIMSS Advanced 2008 results revealed that, in some countries, a high percentage of teachers were nearing retirement age and that there were concerns about having enough teachers qualified in these advanced subject areas to replace them. From a school leadership perspective, it is important to encourage qualified teachers in advanced mathematics and physics to stay in the profession by providing good working conditions and fostering teacher career satisfaction.

The transition from university to a school teaching position can be difficult for teachers. Consequently, in many countries a large percentage of new teachers leave the profession after only a few years of teaching (Australian Primary Principals' Association, 2007; Guarino, Santibañez, & Daley, 2006; Hancock & Scherff, 2010). The extent to which schools take an active role in the acculturation and transition of new teachers may be important for maintaining a stable teaching force. Mentoring programs, modeling of good teacher practice by peers, and induction programs designed by experienced teachers within the school may be important aids to the beginning teacher (Moskowitz & Stephens, 1997; Tillmann, 2005). Nevertheless, because there may be only one physics teacher in a small or medium-sized school, the implementation of subject-specific physics mentoring programs, as well as other subject-specific collaboration programs, may not be possible in many schools (Tsfaye & White, 2012).

Providing good working conditions for STEM teachers also is essential to teacher retention. A manageable workload, adequate facilities, and the availability of instructional materials are important ingredients to fostering productive working conditions and promoting teacher satisfaction (Johnson, 2006; Johnson, Kraft, & Papay, 2012). Important social factors in a school that can affect teacher career satisfaction include a positive school culture, collaboration among teaching staff, and the leadership of the principal (Johnson et al., 2012). Teacher collaboration, in particular, has been found to be associated with increased student learning (Goddard, Goddard, & Tschannen-Moran, 2007; Wheelan & Kesselring, 2005).

Principal Leadership

A characteristic of a successful principal is being able to articulate the mission of the school (Witziers, Bosker, & Krüger, 2003). As such, a principal makes important decisions about the relative emphasis that is placed on STEM education within the school. Principals can foster a culture that emphasizes STEM education by hiring well-qualified teachers in advanced mathematics and physics, promoting their professional development, offering an advanced curricula in technological areas, and organizing activities such as contests and exchanges that promote student interest in studying STEM subjects.

In addition, successful principals often are involved in guiding the teaching process as instructional leaders and ensuring that teachers receive the necessary training and development to produce high achievement among the students

(Robinson, Lloyd, & Rowe, 2008). Within the constraints of the educational system, it is often the principal's responsibility to ensure that instructional time, and in particular the time devoted to advanced mathematics and physics, is sufficient for the purposes of curriculum implementation.

School Climate

One of the principal's central duties is maintaining a safe, orderly, and disciplined school. Results from TIMSS Advanced 2008 showed that there was not much concern about discipline or safety problems at schools for students in these specialized programs. Respect among individual students and teachers as well as constructive interactions among administrators, teachers, parents, and students, all contribute to this positive school climate and lead to higher student achievement (Cohen, McCabe, Michelli, & Pickeral, 2009; Konishi, Hymel, Zumbo, & Li, 2010). A socially welcoming school environment and friendships with classmates also can foster a sense of belonging (Goodenow & Grady, 1993; Hamm & Faircloth, 2005; Juvonen, 2007). Teachers can promote a sense of belonging for students by fostering supportive teacher-student relationships (Cornelius-White, 2007; Marzano, Marzano, & Pickering, 2003).

Classroom Contexts

Because most of the teaching and learning in school takes place in the classroom, STEM learning is influenced by the classroom environment and instructional activities. TIMSS Advanced 2015 focuses on the following factors that impact teaching and learning:

- Teacher preparation and experience;
- TIMSS Advanced 2015 mathematics and physics topics taught;
- Classroom instructional resources and technology;
- Instructional time; and
- Instructional engagement.

This section benefitted especially from John Hattie's (2009) book, *Visible Learning: A Synthesis of Over 800 Meta-analyses Relating to Achievement*.

Teacher Preparation and Experience

The preparation and competence of teachers is critical (Darling-Hammond, 2000; Hill, Rowan, & Ball, 2005), especially given the advanced content knowledge and pedagogical training required to teach advanced mathematics or physics. Prospective teachers need coursework to gain advanced content knowledge in these subjects, to understand about how students learn, and to develop and implement pedagogy for engaging students in the learning process. With appropriate coursework, teachers can gain the competence necessary to teach these subject areas confidently and spark student interest in them (OECD, 2006).

Content-focused professional development is especially important for fostering student achievement in advanced mathematics and physics. Professional development through seminars, workshops, conferences, and professional journals can help teachers increase their effectiveness and broaden their knowledge (Blank & de las Alas, 2009; Yoon, Duncan, Lee, Scarloss, & Shapley, 2007), as well as expose teachers to recent developments within the STEM fields (OECD, 2008).

In addition to preservice education and training, teaching experience is essential, and the first years of teaching experience are especially important for teacher professional development (Harris & Sass, 2011; Leigh, 2010). However, research also has found that teachers continue to develop after five years of experience, and that this development can positively affect student achievement (Harris & Sass, 2011).

With education, training, and experience, teachers should feel prepared and confident to teach advanced mathematics and physics topics. Research has shown teachers' confidence in their teaching skills to be associated with increased student motivation and student learning (Bandura, 1997; Caprara, Barbaranelli, Steca, & Malone, 2006; Henson, 2002; OECD, 2006).

TIMSS Advanced 2015 Mathematics and Physics Topics Taught

A major focus of the implemented curriculum is the extent to which the advanced mathematics and physics topics in the TIMSS Advanced 2015 frameworks are covered in the classroom. TIMSS Advanced addresses this question by asking advanced mathematics and physics teachers of the

participating students to indicate whether each of the topics tested has been covered in class in current or previous years.

Classroom Instructional Resources and Technology

Improvements in the functionality and availability of a wide range of computing devices (e.g., tablets, calculators, and smartphones) have increased the potential for incorporating technology within advanced mathematics and physics instruction. Teachers' decisions to use technology in the classroom can result from their beliefs, attitudes, and comfort levels, as well as access to training and materials (Mueller, Wood, Willoughby, Ross, & Specht, 2008; Russell, Bebell, O'Dwyer, & O'Connor, 2003).

How best to incorporate technology into the classroom and what role technology should have in advanced mathematics and physics instruction continue to be questions of importance to advanced mathematics and physics curricula specialists and teachers. For example, in TIMSS Advanced 2008, calculator use in advanced mathematics and physics instruction varied widely among, and even within, countries, as did the type of calculators that were used. Research on graphing calculators has concluded that these devices aid students in gaining conceptual understanding of the content, and the gains from using a graphing calculator are maximized when calculators are employed both in instruction and testing (Ellington, 2006). However, with the increasing functionality and accessibility of digital devices such as computers, tablets, and smart phones, the use of handheld graphing calculators may be decreasing as students increasingly use applications to perform the calculations once done only on a calculator.

Computers, including tablets such as iPads, and the Internet provide students tools to explore physics and advanced mathematics concepts in depth. Computers are used in a variety of ways, including tutorials, simulations, and educational games. Applications for modeling and visualization can aid students in grasping the abstract concepts of advanced mathematics and physics. Computer applications also can aid students in conducting simulations. For these various technologies to be integrated effectively into instruction, teachers must feel comfortable using them and receive adequate technical and pedagogical support. Nonetheless, research has confirmed the positive effects of computer technology use in the classroom on student learning (Li & Ma, 2010; Liao & Chen, 2007; Tamim, Bernard, Borokhovski, Abrami, & Schmid, 2011).

Instructional Time

At the school level, the relative emphasis and amount of time specified for advanced mathematics and physics can affect students' opportunities to learn. Results from TIMSS Advanced 2008 show that there is variation between countries in the intended instructional time prescribed by the curriculum and the actual time of implementation in the classroom. In some countries, the advanced mathematics or physics programs of study are highly specialized, and students receive almost exclusive instruction in these subjects and related fields. In other countries, students take advanced mathematics and/or physics in addition to a general course load that includes instruction in the arts, humanities (national language(s), foreign language(s)) and social sciences (government, social studies), among other subjects.

Instructional Engagement

In order to learn the complex concepts in subjects like advanced mathematics and physics, students need to actively engage with the content. According to McLaughlin et al. (2005), student content engagement focuses the student's "in-the-moment" cognitive interaction with the content. "Learning occurs through the cognitive engagement of the learner with the appropriate subject matter knowledge" (McLaughlin et al., 2005, p.5). Engagement can take place when students listen to the teacher, conduct lab experiments, or solve a mathematics problem. Engagement has been conceptualized as the idea that a student's "in-the-moment" mindset is torn between meaningful involvement with instruction and distractions that are unrelated to the topics in the class (Yair, 2000). The challenge for the teacher is to use effective methods of instruction to maintain student engagement in the content, activating the students cognitively (Klieme, Pauli, & Reusser, 2009; Lipowsky et al., 2009).

Although lectures can be an integral part of advanced mathematics and physics instruction, effective teachers also ensure that students are actively involved in their own learning process. Active involvement can occur when students are working individually or with their peers (Shernoff, Csikszentmihalyi, Schneider, & Shernoff, 2003; Yair, 2000). Peer-tutoring, small-group work, and peer mentoring are effective strategies that promote student engagement and are linked to achievement (Hattie, 2009; Springer, Stanne, & Donovan, 1999).

In order for advanced mathematics and physics students to grasp difficult content, it is important that teachers link the new material and concepts to the students' prior knowledge and understanding (Kleime et al., 2009; McLaughlin et al., 2005). Students also are more engaged when they are challenged and face greater cognitive demands (Shernoff et al., 2003; Yair, 2000). However, with the complexity of the content covered in these advanced subjects, it is important that the teacher conveys to the students that the challenges of the tasks are attainable. In this respect, effective teaching is setting challenging yet attainable goals for each student and supporting the students in reaching the goals (Hattie 2009; Klein, Wesson, Hollenbeck, & Alge, 1999). In setting goals, it is important that students understand the process of achievement, what outcome is expected, and why the goal is important for the learning process (Hattie, 2009; Martin, 2006).

STEM teachers have an important role, not only to foster student learning in the classroom, but also to act as ambassadors for these career paths (OECD, 2006, 2008). Many countries face the problem that students decide to leave STEM fields to study other subjects during their upper secondary or undergraduate education. An inspiring teacher who can model enthusiasm for STEM fields of study can convey the idea that STEM careers can offer interesting and fruitful career options.

Student Characteristics and Attitudes Toward Learning

In order to better understand the factors that support and motivate students studying advanced mathematics and physics, it is important to collect information about the students' background characteristics and their attitudes toward mathematics and physics. TIMSS Advanced focuses on the following indicators of student achievement:

- Educational and career intentions;
- Student motivation to learn advanced mathematics and physics;
- Expectations for educational attainment;
- Home resources for learning;
- Home use of language(s) of instruction;
- Student gender; and
- Tutoring.

Educational and Career Intentions

The TIMSS Advanced questionnaire data provide important information about whether students intend on continuing along the STEM path in their postsecondary education as well as whether students are interested in entering STEM careers upon completion of their postsecondary education. Policy makers can use these data to inform projections about the future workforce in these fields. Longitudinal research has confirmed that early student career plans are an important predictor of student likelihood to obtain a university degree in a STEM field (Maltese & Tai, 2011; Tai, Liu, Maltese, & Fan, 2006).

Student Motivation to Learn Advanced Mathematics and Physics

TIMSS Advanced 2008 results showed a positive relationship between student affect towards advanced mathematics and physics and student achievement in these subjects. Students participating in these specialized programs tend to have a high level of motivation to excel in school, although their intent to continue on toward careers in STEM fields varies considerably. The source of academic motivation and how it can be facilitated within the school, classroom, and home have been recurrent areas of research (Bandura, 1997; Csikszentmihalyi, 1990; Deci & Ryan, 1985). Intrinsic motivation is an “energizer of behavior” (Deci & Ryan, 1985, p.32), and as such tends to be strongly related to student achievement and career choice. Students who are intrinsically motivated to learn mathematics or physics find the subject to be interesting and enjoyable (Deci & Ryan, 1985).

Nevertheless, not all students have a penchant for studying advanced mathematics or physics. A common strategy to recruit students into these fields is to instill motivation into students by advising them of the career options available for engineers, scientists, and mathematicians. Extrinsic motivation refers to the drive that comes from external rewards like praise, career success, money, and other incentives. However, while extrinsic rewards can entice students to study and even excel in STEM fields, research shows that intrinsic motivation is more closely related to achievement than extrinsic motivation (Becker, McElvany, & Kortenbruck, 2010; Vansteenkiste, Timmermans, Lens, Soenens, & Van den Broeck, 2008).

Expectations for Educational Attainment

Students who excel in highly quantitative subjects, such as advanced mathematics and physics, generally have high expectations for their educational attainment, and these expectations drive them to persist through the rigors posed by challenging mathematical and scientific content. Research on educational expectations has found socioeconomic status to be highly related to a student's educational expectations, as is the selectivity and composition of the school that the student attends (Sikora & Saha, 2007). Research has found that students may reevaluate their educational expectations over time as they receive more information on their abilities and the opportunities that may be presented, although there is contention about the extent of this reevaluation process (Andrew & Hauser, 2011; Morgan, 2005).

Home Resources for Learning

In educational research, the most influential predictors of student achievement tend to be those that measure socioeconomic status of the parents or caregivers (Bradley & Corwyn, 2002; Dahl & Lochner, 2012; Davis-Kean, 2005; Martin, Foy, Mullis, & O'Dwyer, 2013; Sirin, 2005; Willms, 2006), often indicated through proxy variables such as parental level of education, income, occupational class, and, more generally, home resources such as access to technology, the Internet, and books. In addition to being predictors of student achievement, socioeconomic characteristics provide important insight into the factors influencing students entering the STEM pipeline, and to issues of access to STEM programs generally within countries. Because these students are in a specialized educational program, identifying their home background characteristics can facilitate countries in identifying underrepresented sub-populations in the STEM pipeline as well as achievement gaps among students taking these advanced courses.

Home Use of Language(s) of Instruction

Language fluency can be an obstacle to participation in STEM pipeline programs (Airey & Linder, 2006; Gasbarra & Johnson, 2008). TIMSS and other studies have shown that a learning gap can be associated with students not speaking the language of instruction in the home (Entorf & Minoui, 2005; Schnepf, 2007; Trong, 2009). If students are not fluent in the language of instruction, this can be an additional barrier to participation in the advanced coursework necessary for STEM programs.

Student Gender

The underrepresentation of women in advanced mathematics and physics careers is a concern in many countries (OECD, 2008). While TIMSS results have demonstrated increasing similarities in mathematics and science achievement between the genders at the fourth and eighth grades, TIMSS Advanced 2008 results showed that in most participating countries more male students were taking the advanced mathematics and physics courses than female students, and in many countries male students performed better than female students in advanced mathematics and physics. The pattern agrees with research on STEM career paths (OECD, 2006, 2008).

Tutoring

In some countries, students in advanced courses enroll in shadow education programs, private tutoring, or classes outside of formal schooling to supplement the academic instruction received at school. The reason advanced students enroll in this supplemental schooling varies. Some students enroll in these programs to keep pace with the class, and they find the support provided to be critical for understanding the complex material covered in these courses (Baker, Akiba, LeTendre, & Wiseman, 2001). Students also enroll in shadow education programs with the goal of mastering the curriculum in order to excel in school or to do well on a high-stakes examination (Bray, 2007; Buchman, Condrón, & Roscigno, 2010), especially in circumstances where students compete for limited opportunities in select educational programs (Baker & LeTendre, 2005).