

# Chapter 6

## Introduction: A Glass Half Full?



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**Abstract** The three chapters in this section each exemplify authentic practical problems addressed in learning situations. In so doing they point to the implied questions of scaling up problems so that a wider range of learners and teachers might engage with practical STEM. How can the work of inspirational and creative teachers with high levels of mathematical understanding be extended for wider participation? This part of the book draws out these issues by considering the slippiness of STEM in a generalised, selective and examination-focused curriculum. In so doing, technology-afforded practice highlights specific areas for teacher development and curriculum liberation. In this section the authors of the chapters are grappling with some difficult issues. The work is all to a greater or lesser extent empirically driven. The studies to which the chapters refer are smaller scale, and although one (Mayes) draws on a project with 20 schools, the other two are set in the context of a single group of students working on a single project.

### 6.1 Glass Half Full?

Each chapter has a focus on authentic practical problems. LópezLeiva, Pattichis & Celedón-Pattichis present an out-of-school project aimed at Latinx students, in which middle-school students learn to programme digital videos. The other two chapters (Mayes and Sokolowski) both present in-school situations, designed to provoke problem solving that cuts across the Science, Technology, Engineering and Mathematics (STEM) disciplines, and generates different forms of thinking. Sokolowski focuses on developing student mathematical predictions in a teacher stimulated laboratory-based activity, rolling a basketball. Mayes is curriculum-based, and draws on work in the Real STEM Project that identified characteristics of interdisciplinary STEM scenarios to stimulate student-led problem solving. All the authors have written ‘glass half full’ chapters, enthusiastically reporting on activities that have generated learner engagement, with Sokolowski and Mayes writing about what is possible in school,

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and LópezLeiva et al. demonstrating that out of school learning has a part to play in reaching the entire range of learners. Each chapter identifies opportunities for teachers to develop mathematical reasoning with students, although each also notes that students' inclination to mathematical reasoning is infrequent and, or, low level.

The overall challenge for educators, from the chapters in this section, is that interdisciplinary STEM is context dependent and so resists definition. Challenges for schools in providing authentic interdisciplinary curriculum activities in STEM include the high degree of specificity of genuine problems and their connection to specific occupational areas: medicine, engineering and so on. As Hoyles, Noss, Kent, and Bakker (2010) have previously shown, the nature of mathematical thinking at work, is, firstly, technology-related and technology afforded, and second, undertaken in specific ways afforded by the technology and the context. This means that, for example, airline pilots and bankers will engage in mathematical thinking about similar structural problems in entirely different ways. Mathematical reasoning is indeed a process cutting across STEM, but it is undertaken differently in different circumstances.

One way of tackling the difficulty of identifying cross-cutting skills and concepts, is to imagine what professional scientists, engineers, and mathematicians do, and then emulate their activities. This approach leads to exemplar simulations, because what does 'interdisciplinary' mean when there are no bounded disciplines at play in the first place, as tends to be the case in authentic problems? As Engeström (2016, most recently) wisely points out, the whole point of new knowledge is that it is new, it is not known in advance. Nonetheless, each of the papers in this section succeeds in defining STEM in meaningful ways for the purposes of teaching and learning. The papers do this by deciding what characterises thinking in interdisciplinary situations, and then devising activities designed to generate such thinking processes. Each illustrates interdisciplinary STEM activities, and each identifies opportunities for more focused attention on developing reasoning by students.

Another key cross-cutting concept pervading the chapters in this section is the idea of mathematics reaching out to other disciplines. All the authors have addressed the difficulty of pinning mathematical reasoning down—where and when it occurs, what it looks like, and how it can be encouraged. Mayes unpacks, and presents problems, that develop thinking, Sokolowski identifies, through examining student responses to a prediction problem, ways in which students' mathematical reasoning is deficient, pointing to an ideal that he argues should be encouraged. LópezLeiva et al. show how mathematical modelling is integral to the students' design process.

Technology generally cuts across, intersects with, and underpins STEM, and it is indeed technological settings that provide the opportunities for thinking that both Mayes and LópezLeiva et al. consider integral. Sokolowski, however, has offered what seems to start with as a more traditional classroom task, that of predicting the particularities of a rolling basketball, data-gathering using conventional tools of stopwatches and tape measures. This chapter, rather than integrating STEM, attempts to unpick the mathematical reasoning component, and identify students' approaches to mathematical reasoning, with a view to developing ways of teaching this reasoning.

The combination of high level thinking skills with lower level of competence remains, possibly, one of the most significant challenges for organisers of educational experiences, is particularly acute in the case of mathematics, and pervades practice at every level of expertise. We see individual educators addressing this here as best they can, and in stimulating and inspiring ways. But there is an overall challenge in scaling up educational change from individual practices, however exciting, successful, and informative these may be. Innovative practice and thinking shows us what is possible and we can use these ideas for inspiration. What is also necessary is a detailed understanding of contexts for mathematical reasoning, so that organisational curriculum strategy can build contexts in which mathematical reasoning occurs. Sokolowski points out that teachers need this understanding, and suggests the need to encourage professional development for teachers, through engaging them also with investigative experiences.

## 6.2 Description of the Papers in the Section

Sokolowski describes an activity explicitly designed for high school students in one school to bring together practical, mathematical reasoning, and predictive skills. Scientific methods within interdisciplinary activities were designed to activate students' mathematical reasoning skills. Rather than moving from the observational task of observing a rolling basketball to generating a function to account for the movement of the ball, in this activity students were encouraged to think predictively in the first place before observing the ball in practice. This brought some success in so far as students were generally able to predict some aspects of the motion of the ball, such as its linearity. However, only a small proportion used explicitly mathematical reasoning, i.e. constant rate of change of distance with respect to time. Other responses, although intuitively correct, are more general, and in some cases entirely qualitative, and Sokolowski argues that the activity for students at this level of understanding provides a specific opportunity to focus teaching on mathematising the predictions.

Mayer's contribution draws on a larger scale Real STEM Project in 20 partner middle and high schools, in which beautiful exemplar problems are presented to develop five specific forms of reasoning modality evident in the problem-solving practices of professional scientists, engineers, and mathematicians. The problems, chosen to be 'interdisciplinary' in the sense that each is not bounded by specific disciplines, are explained in detail and aligned with each reasoning modality developed, namely complex systems, scientific model-based, technologic computational, engineering design-based, and mathematical quantitative. Teachers will recognise the passion in Mayer's chapter for the increased engagement and motivation shown by students when tackling 'real' problems. He argues though, that whilst quantitative reasoning has the potential to underpin authentic problem solving, students do not have the skills to adopt it confidently, thus raising the perennial question: which students are 'authentic' problem solving activities actually for? As Dowling (1998)

pointed out, so many years ago now, the everyday tends to provide opportunities to practice mundane skills, and the esoteric is for more highly performing students.

LópezLeiva, Pattichis & Celedón-Pattichis take, as their starting point, that schools often do not promote comprehensive understanding of computers and computer programming, and that engineering education is frequently an elective course or simply not offered whatsoever. They argue that this needs to be challenged and present a case of a successful out-of-school technology project in which middle school, predominantly Latinx students, programmed digital videos around self-generated topics. In so-doing, the students engaged in science, technology, mathematics and engineering. Mathematics practices were encouraged through model-eliciting activities, drawn from a framework developed by Lesh, Hoover, Hole, Kelly, and Post (2000) in the early 21st century. The authors' claim is that, through a creative and collaborative process of 'design, model, implement', computational thinking processes emerge through synergies between mathematical modelling, engineering design, computer programming, and student goals.

LópezLeiva et al. point out that technology and engineering practices in schools are not part of the main curriculum. Furthermore, there is a paucity of STEM programs in schools that are inclusive of students from underrepresented groups such as low socio-economic (SES) groups, ethnic minorities, and girls. They suggest that interdisciplinary open-ended problem-solving approaches open to student input are needed to be inclusive of these student populations. An out-of-school project that has recruited largely middle-years Latinx students to learn and practice computer programming adds value to an institutional curriculum provision.

### **6.3 The Empty Half of the Glass**

Implicit in each of these papers is an underlying unease with what STEM means in practice, and discomfort with how practice translates into teaching STEM in schools. Indeed, LópezLeiva et al. argue directly that when schools provide open-ended interdisciplinary activities with student input, students have opportunities to learn challenging mathematics and computer programming and are held to high standards. With the appropriate support to meet these standards and windows to promote student action, underrepresented students can engage at these levels of a demanding curriculum and meet high expectations. This is a two-fold critique, of both curriculum organisation, and participation strategy, each component of which offers a big challenge to STEM policy and design in schools. It is very difficult indeed to organise interdisciplinary STEM activities in educational institutions whose very *raison d'être*, currently, is the achievement of pre-determined and specified outcomes. But this is not to say that it is not worth doing: the imagined lives of practitioners in STEM, can only be enhanced by more detailed understanding of what they actually do, at all levels, in different cultural settings with contemporary problems. People with STEM qualifications work in a whole range of occupations; and conversely, a whole range of non-STEM occupations require some STEM skills, particularly in

ICT, mathematics, and data handling. As the current Chief Scientist of Australia, Dr. Alan Finkel, recently remarked “As time moves on it becomes increasingly difficult to decide who is, and isn’t, a ‘STEM worker’” (Office of the Chief Scientist, 2016).

Each chapter has focused on what is identifiable from practice, in practice, and through engagement with social practices, in which mathematical reasoning elides with what might be called STEM problems. The chapter by Mayes goes some way to addressing the challenge through the identification of systems in which STEM features, advocating ways of thinking in these systems. However, as Mayes asserts almost as an aside, students’ mathematical skills are less well developed than their scientific thinking skills. From this, arises the other significant educational challenge, that of providing opportunities for engaging in STEM, that are inclusive and enable participation whatever the level of mathematical attainment. This challenge is partially addressed by LópezLeiva et al. who describe their project activities as specifically motivated by the need for inclusivity to draw in younger students’ input within high-level curricular tasks. Their data show students can engage in higher levels of the curriculum when provided the opportunity to do so. Their account of the out-of-school project is inspiring, as it suggests ways that informal educational settings (such as those provided via youth clubs) can contribute to educational culture building, enable participants to devise new identities, and expand student self-development expectation.

As asserted earlier, inspiring projects in themselves are not enough to enable curriculum organisers to scale up authentic practice. Is the glass half empty? Well if it is, to identify cross-cutting skills we need to look at the empty half, what is not so far examined here, as well as the full half. The chapters each conclude with a summary of what researchers, practitioners, or policy-makers, should attend to in their future work as a result. LópezLeiva et al. argue for a transformative pedagogy that capitalises on who students are and what they know, mixing with new goal-oriented, open-ended challenges and experiences that enable access to new knowledge, particularly on computer programming and coding. Mayes identifies a lack of STEM expertise in schools, and points to new ways of collaborative working, and ways of extending knowledge, within, and across, schools, specifically identifying the need for explicit opportunities for mathematical modelling. Sokolowski is keen to identify, and focus on, known mathematical weaknesses of students, in particular algebraic thinking. These are all cross-cutting, but they are not skills, for as system needs they go far beyond that. More broadly STEM development in educational settings would include relations between teachers and teachers, learners and learners, and teachers and learners. It would include more emphasis on mathematics for social justice that is studying connections between mathematical reasoning and social division. It must not remain the case that STEM in school serves to minoritise students. It must not remain the case that an absence of confidently qualified teachers means that student access to STEM is of variable quality, even within a single institution. Less qualified teachers need support and training in mathematics if their subject knowledge is weak. Those bringing up-to-date industrial ideas and application need pedagogical support. The cases described in this section each bring both good examples and well-

grounded ways of thinking about thinking. It is time now to support a wider network in achieving this.

## 6.4 Afterword

In editing this section I have been struck by two things. The enthusiasm of the paper authors and their willingness to contribute to this volume as it has taken shape over time has been hugely impressive. Partly this is, I feel, because we all believe in the importance of this volume in making a coherent contribution to the field of interdisciplinary mathematics education. The second striking thing is that there is almost no overlap between the references cited by each author, for although some work on mathematical modelling by Lesh and colleagues over the ten years 1997–2007 has been built upon by both Sokolowski and LópezLeiva et al. clearly there are currently no seminal texts, no shared body of work on which to build our understanding. Thus, I would emphasise the need to develop a research agenda in interdisciplinary mathematics education that begins with a systematic and international review of the field.

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