Advances in STEM Education
Series Editor: Yeping Li

Judy Anderson
Yeping Li *Editors*

Integrated Approaches to STEM Education

An International Perspective

Springer

Advances in STEM Education

Series Editor

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Advances in STEM Education is a book series focusing on cutting-edge research and knowledge development in science, technology, engineering and mathematics (STEM) education from pre-college through continuing education around the world. It is open to all topics in STEM education, both in and outside of classrooms, including innovative approaches and perspectives in promoting and improving STEM education, and the processes of STEM instruction and teacher education. This series values original contributions that view STEM education either in terms of traditionally defined subject-based education or as an educational undertaking involving inter-connected STEM fields. The series is open to new topics identified and proposed by researchers internationally, and also features volumes from invited contributors and editors. It works closely with the *International Journal of STEM Education* and *Journal for STEM Education Research* to publish volumes on topics of interest identified from the journal publications that call for extensive and in-depth scholarly pursuit.

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Integrated Approaches to STEM Education

An International Perspective

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Judy Anderson is an *Associate Professor in Mathematics Education* at the University of Sydney, Australia, with extensive experience working with undergraduate and postgraduate students. With publications on problem-solving in the school curriculum and teachers' problem-solving beliefs and practices, she has also worked with colleagues from the University of Sydney to investigate middle school students' motivation and engagement. Judy is currently the *Director of the STEM Teacher Enrichment Academy*, an innovative professional learning program for STEM teachers that was established in 2014 by a collaborative team of academics from the faculties of Education and Social Work, Science, and Engineering. A team of 12 academics deliver the program and to date, the Academy has reached over 1250 teachers from more than 240 primary and secondary school settings in NSW, Australia. With her colleagues, Judy has been conducting research into the impact of the STEM Academy program on teachers, school leaders, students, parents, and local communities. Over her career, she has been an active member of several professional teaching associations in which she has held leadership roles including president of the Australian Association of Mathematics Teachers (AAMT) and of the Australian Curriculum Studies Association (ACSA). She is currently the Secretary of the International Group for the Psychology of Mathematics Education (IGPME).

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Chapter 1
Investigating the Potential of Integrated STEM Education from an International Perspective

Judy Anderson and Yeping Li

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1.1 Background: Sharing Common Interests in STEM Education

We are both mathematics educators by training with a keen interest in curriculum and the ways teachers use innovative curriculum to transform students' experiences in classrooms. Having written about mathematics curriculum and conducted research into the ways teachers use the curriculum to design lessons and tasks to meet their students' needs (e.g., Anderson, 2014; Li & Lappan, 2014), we independently developed an interest in integrated curriculum and the ways the mathematics curriculum connects with the other STEM subjects: science, technology, and engineering. We have published in the field of science, technology, engineering, and mathematics (STEM) education, but we agree this is still a contested space and we

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need to encourage our colleagues to take a more critical stance about the role of STEM education in the broader school curriculum (Li & Schoenfeld, 2019; Tytler, Williams, Hobbs, & Anderson, 2019). To pursue the goal of encouraging debate about integrated STEM education, we sought opportunities to discuss the challenges with colleagues at international conferences.

As members of the International Group for the Psychology of Mathematics Education (IGPME), we facilitated a Working Group at the Singapore conference in 2017, followed by a Discussion Group at the Umea, Sweden conference in 2018. Each session was well attended with 25–30 participants from more than 15 countries at each. As participants shared their knowledge and experiences of STEM education, it became apparent many of our colleagues were similarly interested in integrated STEM curriculum and the role of mathematics in connecting the STEM subjects. At each session, we proposed the development of a volume to share our experiences, critique current practices, and propose new approaches to STEM curriculum and instruction. Not wanting to limit the contributions to mathematics educators, we also circulated a call for chapters to a broad audience of STEM educators and this volume is the outcome of this joint effort.

The objective of *Integrated Approaches to STEM Education: An International Perspective* was to showcase international contributions to STEM research and practice with recommendations for researchers, policymakers, and teachers about the future of integrated STEM education. The book aimed to evaluate the efficacy of integrated STEM education as it is currently practised and identify opportunities for further research and potential collaborations in the STEM education research community.

1.2 Inviting International Perspectives on Integrated STEM Education

Researching STEM education has been gaining momentum with increased calls for strategies to improve student engagement and to increase participation in senior schooling in countries where mathematics and science are not compulsory (Freeman, Marginson, & Tytler, 2015; Roth, 2018). At the same time, the diversity of perspectives and approaches (from curricular to pedagogical) challenges the collection of evidence to establish a research base which justifies the funds currently being invested in STEM education (Honey, Pearson, & Schweingruber, 2014). In the USA, STEM education has been extensively supported over the years with national policy and substantial Federal Government funding to develop a STEM focus (Li, 2014; Li, Wang, Xiao, Froyd, & Nite, 2020). Bybee (2013) argues the lack of a common understanding or definition of STEM education has led to a diversity of approaches with scant evidence for the success of many of the initiatives adopted by schools and school systems. In recent reports in Australia, there has been a strong recognition of the importance of STEM thinking and skills for all students and an advocacy of the need to bring school science and mathematics closer to the way science and mathematics are practiced in contemporary settings across the STEM disciplines (Office of the Chief Scientist, 2016; Tytler, Swanson, & Appelbaum, 2015).

Integrated Approaches to STEM Education: An International Perspective provides a platform for international scholars to share evidence for effective practices in integrated STEM education and contribute to the theoretical and practical knowledge gained from the diversity of approaches. Many publications on STEM education focus on one or two of the separate STEM disciplines without considering the potential for delivering STEM curriculum as an interdisciplinary approach (Anderson, English, Fitzallen, & Symons, 2020)—this publication seeks to debate the efficacy of an integrated STEM curriculum and instruction, providing evidence to examine and support various perspectives. The volume focuses on the problems seen by teachers and academics working in the fields of science, technology, engineering, and mathematics and provides a set of valued practices which have demonstrated their use and viability to improve the quality of integrated STEM education.

This volume includes chapters that debate the conceptual basis of integrated STEM education, review historical developments in integrated STEM education policy and practices, describe the outcomes of effective integrated STEM education approaches, including curriculum design and pedagogical practices, and provide recommendations for ways forward for research and practice. This volume offers evidence to a range of stakeholders interested in integrated STEM education. Policymakers can benefit from access to research into integrated STEM education and its outcomes, and teachers can benefit from learning new approaches to the design and delivery of integrated STEM education. Their students can then benefit from opportunities designed and provided to solve real-world problems using knowledge from some or all the STEM subjects. Finally, we expect our readers will benefit from reading about the ways different countries and jurisdictions have approached integrated STEM education over the last few years across all grades of schooling.

Our initial invitation to contribute to the volume welcomed contributions on empirical research, theoretical frameworks, or detailed case studies showing what works in classrooms and what lessons may be learned. We were interested in chapters that investigated diverse contexts and explored a broad range of STEM education issues and challenges. The original list of suggested topics or themes for the volume included:

- Perspectives on integrated STEM education
- Approaches to integrating the separate STEM curriculum disciplines
- Case studies of integrated STEM education in countries or school jurisdictions
- Case studies of integrated STEM education in classrooms or schools
- Developing teachers' integrated STEM education knowledge and practices
- Assessing integrated STEM education
- The role of one of the disciplines in integrated STEM education
- The influence of context on integrated STEM practices
- Involvement with the wider community and other stakeholders in integrated STEM education in schools

- The most appropriate skills and dispositions for integrated STEM education
- Students' and teachers' reactions to integrated STEM education and,
- Approaches to researching integrated STEM education.

We received contributions which explored many of these topics and themes. However, organising this diversity into a coherent volume was a challenge, but we decided to structure the volume into four parts, according to the focus on approaches to STEM integration, designing integrated approaches for students, implementing integrated STEM approaches in teacher education, and future directions. The chapter contributions in each part are described in the next section of this chapter.

1.3 Structuring and Organising the Volume

1.3.1 Reviewing Approaches to STEM Integration

The challenge for teachers and school leaders is to determine how they will design integrated STEM curriculum when faced with separate subject curriculum documents and, typically, separate subject assessment and reporting regimes. The design of integrated STEM curriculum is not a trivial task and requires subject expertise and experience in designing school-based curriculum which focuses not just on curriculum content but on potentially new pedagogical approaches. While designing integrated curriculum is not a new idea (see for example Beane, 1997; Dewey, 1938), focusing on the STEM subjects has meant that schools have had to rally the STEM expertise within the school and to plan ways to work together, particularly in secondary school contexts, where teachers may be located in separate staff rooms. But as Mockler (2018) states,

> … a renewed focus on STEM … both in Australia and elsewhere, might provide us with a new energy for curriculum innovation and curriculum integration. We might add to this the imperatives contributed by the contemporary world, where developing students' capacity to navigate knowledge and information across disciplinary boundaries is increasingly important (p. 229).

In designing integrated STEM curriculum, some describe the level of integration or a continuum of integration suggesting a hierarchy from disciplinary, to multidisciplinary, to interdisciplinary, and finally to transdisciplinary (Beane, 1997; Vasquez, 2015). Like Vasquez's "inclined plan of STEM integration" (p. 13), Gresnigt, Taconis, van Keulen, Gravemeijer, and Baartman (2014) proposed a 'staircase' model of curriculum integration, but they added isolated, connected, and nested levels before multidisciplinary, interdisciplinary, and transdisciplinary. Rennie, Venville, and Wallace (2018) argued against these hierarchical approaches to STEM integration because they imply one end of the continuum is of greater value than the other. Instead, they used categorisations of the kinds of approaches schools adopted based on their extensive experience working with teachers and identified six approaches which they referred to as synchronised, thematic, project based, cross-curricular, school specialised, and community-focused.

Regardless of the level of integration of the STEM subjects, or the approach adopted by schools to design integrated curriculum, curriculum integration is challenging and requires time, effort, collaboration, and commitment by teachers and school leaders. Mockler (2018) described enablers and constraints to designing integrated curriculum when reflecting on the development of the first national curriculum in Australia. She suggested enablers include having broader goals for education than just learning content knowledge, focusing on understanding 'big ideas', and learners ready access to real-world information through digital technologies. Whereas constraints might include a backlash against learner-centred approaches, a desire for standardisation and increased focus on core subjects, and greater accountability particularly through high-stakes testing. While the constraints might dampen the potential for integrated curriculum work, teachers and school leaders continue to seek ways to design more effective learning opportunities for their students and this is particularly evident in the international STEM movement (Anderson, Wilson, Tully, & Way, 2019; English, 2019; Tytler et al., 2019).

The chapters in this first part of the volume consider some of the challenges described here, as well as discipline integrity and policy agendas. Tytler describes the growth of STEM education, particularly from the policy perspective and through a framework of competencies associated with the STEM disciplines; he examines interdisciplinarity in greater depth, particularly as it impacts on the integrity of mathematics. The chapter by Baldinger and her colleagues addresses the concern about the role of mathematics in integrated STEM curriculum by conducting a literature review of recent publications to identify themes from "mathematically-rich integrated STEM studies". Themes include communication, task authenticity, the centrality of inquiry, and the importance of informal learning spaces. Park, Wu, and Erduran analyse science curriculum documents to identify evidence of types of STEM discipline knowledge and understandings. An integrated STEM framework for developing countries is investigated in the chapter by Makonye and Diamini.

Chapters examining the process of, or potential models for, curriculum integration include those by English, Watson, Fitzallen and Chick, and Bennison and Geiger. In her chapter, English explores the role of design in curriculum innovation and integration, presenting evidence from students' design project work. Watson and colleagues propose the potential of statistics to facilitate integration of the STEM subjects and describe several approaches through students' activities. While Bennison and Geiger investigate the potential of numeracy across the curriculum as a new model for STEM curriculum integration with outcomes presented from teachers' lessons. The second part of the volume examines integrated STEM projects developed to support student learning.

1.3.2 Designing Integrated STEM Approaches for Students

While Dewey (1938) and Beane (1997) promoted experiential and connected learning approaches to enhance students' understanding of their world, most countries have separate curriculum documents for each of the STEM subjects. Consequently, most schools present the curriculum as separate learning experiences, particularly in secondary schools, although science, technology, and mathematics teachers may use 'project work' to engage students and provide them with opportunities to tackle real-world problems (Tytler et al., 2019). However, most real-world problems require the use of knowledge from more than one of the STEM subjects. While primary school teachers are better placed to connect knowledge for their students, it seems a wasted opportunity for secondary school STEM teachers not to connect with each other when such projects are offered to the students they teach (Anderson et al., 2020).

Research into the efficacy of integrated STEM education, particularly regarding long-term benefits to students, is still an emerging field. However, evidence is gradually building that an integrated, interdisciplinary approach to teaching science, technology, and mathematics (including engineering-like design practices) supports improved problem-solving skills, increased learning-engagement, and improved science and mathematics outcomes (Becker & Park, 2011; Tytler et al., 2019). Combining inquiry-based learning with an integrated STEM approach provides rich opportunities for students to develop a range of general capabilities, such as critical thinking, self-direction, creativity, and communication (Rosicka, 2016). When the inquiry focuses on a real-world problem that is meaningful to the students, their engagement has been found to extend beyond their immediate learning, to increased interest in further study in the component disciplines of STEM, and in future STEM-related careers (Holmes, Gore, Smith, & Lloyd, 2018).

The chapters in this part of the volume present case studies of integrated STEM program experiences for students, with evidence of impact on student learning and engagement. At the primary school level, Miller, Severance, and Krajcik describe a fifth-grade unit connecting the particle nature of matter with computational thinking. Evidence from students reveals how identifying and using patterns helps students explain and predict the phenomenon of taste. Wang and her colleagues explore the use of robotics in an afterschool setting to identify primary school students' use of scientific language to communicate thinking. Kang presents evidence of impact of a large-scale integrated STEAM education approach in South Korea, which used project-based learning to deliver programs across most levels of schooling. Compared to a control group of students who were not taught the integrated approach, the STEAM students had variable outcomes, depending on the expertise of the curriculum designers.

Several chapters have focused on integrated STEM approaches in secondary school contexts. Skilling uses a transdisciplinary STEM project to investigate students' beliefs and engagement as they build electro-mechanical robots. Steffensen used tenth grade students' discussions and debates about climate change to explore their use of mathematics to argue and critically analyse information. From a different perspective, Ubuz conducted research into teachers' views about whether a Technology and Design course had the potential to contribute to students' STEM capability development. Touitou, Schneider, and Krajcik report on the assessment of students' performance on integrated STEM tasks designed to invoke mathematical and design thinking in a high school physics unit of work. Bartholomew and Williams examine an approach to STEM skill assessment aimed at improving reliability and validity of assessing open-ended STEM projects. Designing effective integrated STEM experiences for students requires substantial support for teachers in both preservice and in-service education.

Studies into student engagement and motivation suggest students begin to disengage from the STEM subjects as early as primary school, although the main shifts appear to occur in early secondary school (Martin, Anderson, Bobis, Way, & Vellar, 2012). Addressing engagement and achievement in the STEM subjects in schools requires support for teachers to design curriculum which enthuses students, challenges their beliefs about the role of the STEM subjects in solving real-world problems, and inspires them to continue to study these subjects into the future (Moore, Johnson, Peters-Burton, & Guzey, 2016). Support for teachers through professional learning is a necessary component for successful implementation of innovative programs.

1.3.3 Implementing Integrated STEM Approaches in Teacher Education

Professional learning programs for primary and secondary school STEM teachers have been designed and implemented in many contexts to support teacher co-construction of integrated STEM curriculum and inquiry-based learning approaches (Nadelson & Seifert, 2017). Informed by research into high-quality, high-impact professional development design principles, effective programs should involve teams of teachers, working collaboratively to design programs suitable for their students (Darling-Hammond, Hyler, Gardner, & Espinoza, 2017; Voogt, Pieters, & Handelzalts, 2016). Designing real-world STEM problems or STEM project-based learning tasks also involves designing assessment rubrics to provide feedback to students on discipline knowledge as well as the key skills of critical thinking, creativity, collaboration, and communication (Care & Kim, 2018).

Some of the contributions in this part of the volume examined the development of STEM knowledge in preservice teacher education. Delen, Morales, and Krajcik develop a Design-based Pedagogical Content Knowledge (DPCK) framework to support teachers using engineering design processes to connect scientific knowledge with pedagogy. Henriques, Oliveira, and Baptista investigate prospective mathematics and physics teachers' development of integrated STEM projects using an authentic integration model.

Other chapters examine the professional learning of practicing teachers, using a variety of approaches. Anderson and Tully evaluate a year-long program for both primary and secondary school teachers as school teams worked together to design, implement, and evaluate a school-based approach to integrated STEM education. Connor and her colleagues present results from a computer programming professional learning program for primary school teachers, using an innovative model to teach coding and collective argumentation. Crowder, Dovi, and Naff also investigate a coding professional development program for elementary school coaches with evidence of the effectiveness of the collaborative, inquiry-based design of the program. Hunter's high possibility classroom model was used in three elementary schools to demonstrate how teachers collaborated in school-based teams to implement new pedagogies to promote integrated STEM. Through a collaboration between researchers in Taiwan, Thailand, and Vietnam, Lin, Chien, and Chang describe an approach to the development of an integrated STEM module, followed by teachers' reactions to a workshop demonstrating the use of the module, while Costa and her colleagues report how coaching by university educators supports elementary teachers' implementation of integrated STEM tasks in classrooms.

All the teacher education programs presented here provide evidence of the potential to impact teachers' knowledge and understanding of STEM and their capacity to implement integrated STEM approaches in their classrooms. However, questions of scalability and sustainability for each of these programs remain. So, what of future directions for research in integrated STEM education?

1.3.4 Identifying Future Directions

Two commentary chapters are contained in this volume from experienced STEM education scholars. We asked them to provide a commentary on the work published in this volume and to offer their suggestions for future directions. Froyd's perspective, from an engineering education scholar, suggests the need for further investigation of the impact of computational thinking on STEM project work, the continued focus on teacher professional learning, and further consideration of the types of assessment approaches appropriate for STEM project work. In their reflections on the volume, Chiu and Krajcik focused on the notion of an iSTEM-plus curriculum, highlighting the opportunities afforded through an integrated STEM curriculum, but also describing the challenges and threats. They present strategies to support the further development of iSTEM-plus environments, concluding with a call for greater international collaboration and sharing of resources and expertise.

While the chapters in this volume provide evidence of the potential of integrated STEM education, many authors also raise questions and possibilities for further research. Some suggestions for further research raised by authors include, but are not limited to:

1. Investigating what models of interdisciplinarty and in what topics lead to engagement of students for particular learning outcomes (Tytler in Chap. 3)
2. Developing programs of assessment that support such curriculum innovations (Bartholomew & Williams in Chap. 18; Tytler in Chap. 3; Wang et al. in Chap. 12.)
3. Exploring the development and cognitive components of systems thinking (English in Chap. 4)
4. Understanding teachers' and students' reasoning strategies in integrated STEM environments (Baldinger et al. in Chap. 5)
5. Comparing longitudinal research on student outcomes focusing on data analysis aspects of integrated STEM activities (Watson et al. in Chap. 6)
6. Researching how teachers can provide greater emphasis on mathematics to promote critical aspects of STEM learning (Bennison & Geiger in Chap. 7)
7. Investigating how mathematics, as a discipline, operates in a wider enterprise of STEM and how it relates to the other three disciplines (Park, Wu & Erduran in Chap. 8)
8. Conducting international comparative studies about diverse and effective ways of developing twenty-first century competencies (Wang et al. in Chap. 12),
9. Exploring issues of subject integrity and inequitable subject representation in STEM project work (English in Chap. 4; Skilling in Chap. 14),
10. Considering issues of teacher implementation of integrated STEM curriculum in diverse contexts (Ubuz in Chap. 16),
11. Researching student transferability of STEM skills beyond the task or unit within which they were demonstrated (Touitou et al. in Chap. 17),
12. Following PSTs into classrooms to examine whether their STEM knowledge is transferred into their classrooms (Delen et al. in Chap. 20; Henriques et al. in Chap. 21)
13. Connecting learning in teacher professional learning about integrated STEM with improved student learning outcomes (Anderson & Tully in Chap. 22).

With these research ideas in mind, we hope readers will continue to explore integrated STEM approaches and contribute to our knowledge of the field. While the STEM movement has continued for some time now, researchers still have a way to go to identify the most effective ways to design and deliver integrated STEM curriculum in schools. Given Bybee's 2020 vision for STEM education published in 2010, it is clear we still have many questions to investigate (Bybee, 2010).

1.4 STEM Education: Now More than Ever?

The title for the final section of this chapter is from a book recently published by Rodger Bybee (2018). Bybee has been a regular contributor to debates about STEM education, with several well-known and highly cited publications in the field. In 2010, he published *Advancing STEM Education: A 2020 Vision*, calling for a ten-year strategic plan to "move beyond the slogan and make STEM literacy for all students an educational priority" (p. 30). The plan recommended developing model STEM units with professional development for teachers and "exemplary assessment at the elementary, middle, and high school levels" (p. 34). He recommended this would need to be followed by systemic changes in policies, programs, and practices at local, state, and national levels, with strategies to evaluate and refine approaches over several years. Even though the contributions in this volume provide examples of model STEM units, successful professional development programs, suggestions for approaches to assessment of STEM project work, and research into national and even international collaborative efforts, there is little evidence that Bybee's 2020 vision has been realised.

While some countries appear to have committed substantial funds to STEM programs, many STEM education efforts are still piecemeal, and conducted at the local or regional levels of school education. Without STEM education becoming an integral component of the mandated curriculum, it is unlikely this will change (Lowrie, Downes, & Leonard, 2017). It seems a major challenge or hurdle which has yet to be overcome is the relationship between learning knowledge, skills, and understandings of the separate STEM subjects versus the benefits of an integrated curriculum that allows students to tackle bigger problems. Efforts to create integrated curriculum experiences in the past have not necessarily been sustained, as was the case with the middle school movement in the 1990s (Beane 1997). There are many reasons why implementing integrated curriculum is challenging, including curriculum structures, assessment practices, teachers' knowledge and beliefs, as well as school structures and historical practices (Wallace, Sheffield, Rennie, & Venville, 2007). But is it time to seriously rethink the purpose of schooling and the knowledge students need to meet the challenges of today's society?

Returning to Bybee's recent book *STEM Education Now More than Ever* (2018). He describes initial concerns about the lack of a clear definition for STEM and the need for citizens to address twenty-first century challenges such as.

> … economic growth, climate change, a reduction in biodiversity, vulnerabilities of the internet, energy efficiency, emerging and re-emerging infectious diseases, clean water, space exploration, and healthy oceans among others—depend on solutions that look at least somewhat to science, technology, engineering and mathematics (p. 6).

He argues "STEM provides opportunities to introduce issues beyond the traditional disciplines, such as citizenship" (p. 7). Given that politicians frequently ignore the advice of scientists, Bybee calls for education to provide increased opportunities for students to develop STEM competencies such as:

- Understanding the nature of science
- Cultivating an understanding and ability to use evidence and form reasonable arguments
- Engaging in civil discourse and,
- Developing twenty-first century workforce skills (p. 146).

With recent international catastrophes, including floods, fires, melting icecaps, and the Covid-19 pandemic, there are good reasons why we do need STEM education now more than ever.

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Part I
Approaches to STEM Integration

Chapter 2
STEM Integration: Diverse Approaches to Meet Diverse Needs

Yeping Li and Judy Anderson

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2.1 Brief Background

The importance of mathematics and science has long been recognized in school education around the world. School mathematics and science have been compulsory subjects for every student in widespread school contexts. For example, the International Association for the Evaluation of Educational Achievement (IEA) conducted a pilot 12-country study in 1960 to investigate the feasibility of undertaking a more extensive assessment of educational achievement (Foshay, Thorndike, Hotyat, Pidgeon, & Walker, 1962). The pilot study focused on five areas: mathematics, reading comprehension, geography, science, and nonverbal ability (see https://www.iea.nl/studies/iea/earlier#section-171). The selection of these five areas represented what was commonly covered and valued in and through school education across different education systems at that time. After this pilot study, the IEA con-

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ducted its first international study with a focus on mathematics in 1964 (i.e., The IEA First International Mathematics Study—FIMS, Husén, 1967), and then follow-up international studies with six specific subject foci in 1970–1971 including science (i.e., The IEA First International Science Study—FISS, Keeves & Comber, 1973). FISS focused on three fields of science: biology, chemistry, and physics. In some countries, the emphasis on school mathematics and science may start even earlier. For example, the School Science and Mathematics Association was established in 1901 in the United States with one of its four goals stated as "advancing knowledge through research in science and mathematics education and their integration" (see https://ssma.org). Its official journal, *School Science and Mathematics*, was founded, also in 1901, to showcase "research on issues, concerns, and lessons within and between the disciplines of science and mathematics in the classroom" (see https://onlinelibrary.wiley.com/journal/19498594).

In contrast, STEM education as explicated by the term does not have a long history. The interest in helping students learn across STEM fields can be traced back to 1990s when the U.S. National Science Foundation (NSF) formally included engineering and technology with science and mathematics in undergraduate and K–12 school education (e.g., National Science Foundation, 1998). It coined the acronym SMET (science, mathematics, engineering, and technology) first, and then changed to the acronym STEM in early 2000s to replace SMET (Li, Wang, Xiao, & Froyd, 2020). The emerging field of STEM (later also STEAM after adding "A" as arts, STREAM after adding "R" as reading, and STEMM after adding "M" as medicine) education is perceived as providing some fascinating opportunities for transforming school education since not only STEM is important for students' learning now and in the future but also STEM brings new perspectives about possible foci and the value of school education (Li, 2018).

Different from simply adding new school subjects in the past, the inclusion of "T" (technology) and "E" (engineering) calls for a broader focus on STEM education with an ever-increasing interest in discipline integration instead of taking each discipline as "silos." Consistently, there have been more and more interests in exploring and understanding different perspectives and approaches to STEM integration in many education systems. It is in this spirit that this part is designated to share and learn about those different perspectives and approaches internationally.

2.2 Investigating Different Approaches to STEM Integration

A total of seven chapters (excluding this chapter) are included in this part. Two chapters are literature reviews of STEM education in general (Chap. 3) and the inclusion of mathematics in integrated STEM education (Chap. 5). Three chapters (Chaps. 4, 6, and 7) present and discuss specific approaches to STEM integration from a curriculum perspective. One chapter (Chap. 8) illustrates the use of a specific approach for analyzing curriculum documents to examine their epistemic nature of

STEM. The final chapter (Chap. 9) discusses a pedagogical framework for implementing integrated STEM education in Southern Africa.

Instead of focusing on a specific STEM integration effort, Tytler (2020) provides a historical overview of STEM education as originated in the United States and then expanded internationally. The chapter summarizes various forms of STEM education that have been developed including, promoting the integration of engineering with science and mathematics in curricula, the inclusion of digital technology in school education, and/or connections between school education and STEM professional work in the real world. In accounting for possible reasons (i.e., “why”) that led to the dramatic development of STEM education, Tytler discusses several drivers that are commonly perceived and highlighted in various documents: the need for improving a nation state’s economic productivity, the need for advancing a nation’s science and technology research and development, and the need for preparing a workforce with STEM competencies. Building upon the discussion about STEM-competent workforce preparation, Tytler discusses a framework of STEM competencies needed in the future (i.e., “what”). The framework includes four types of knowledge (disciplinary knowledge, epistemic knowledge, interdisciplinary knowledge, and procedural knowledge) and three types of skills (cognitive/metacognitive, social/emotional, and physical/practical), attitudes, and values. To develop students’ STEM competencies, Tytler discusses the ongoing movement of developing and using interdisciplinary approaches in STEM teaching and learning (i.e., “how”), with an extended review of possibilities and challenges associated with interdisciplinary mathematics education.

As mathematics is commonly perceived as a discipline that has received the least attention in integrated STEM education, Baldinger et al. (2020) conducted a literature review of articles published in 19 journals from 2013 to 2018. They found that only 32 out of 4072 articles in 12 journals demonstrated mathematically rich integrated STEM at the secondary level. The finding provides empirical support to the common perception and it is also consistent with what has been reported recently by looking at publications in the *International Journal of STEM Education* (Li & Schoenfeld, 2019).

The three chapters on a specific STEM integration from a curriculum perspective are contributed by English (Chap. 4), Watson and colleagues (Chap. 6), and Bennison and Geiger (Chap. 7). English (2020) highlights the use of engineering design as an important approach for STEM integration, with special benefits of engaging students and providing opportunities for them to apply disciplinary knowledge and make knowledge connections across disciplines. Watson, Fitzallen, and Chick (2020) argue that statistics, as part of mathematics, is well positioned for integrating STEM around the fundamental nature of variation across STEM contexts. Bennison and Geiger (2020) present and discuss the use of numeracy, the capability of using mathematics to solve real-world problems, as a rich cross-curricular model for integrating mathematics and science in Australia.

In Chap. 8, Park, Wu, and Erduran (2020) demonstrate the feasibility of using the framework of the Family Resemblance Approach to examine the epistemic nature of STEM disciplines as represented in curriculum documents. As illustrations, they present an analysis of the two science-based curriculum documents from the United States. Makonye and Dlamini (2020) discuss in Chap. 9 special challenges educators and teachers in developing countries, especially in Africa, are facing to begin to develop and implement integrated STEM education. Based on a literature review and interviews with selected teacher educators, they proposed a pedagogical framework that calls for the infusion of local context and culture in STEM education together with political support and professional development for teachers.

2.3 Considering Further Issues

These seven chapters, as discussed above, provide a wide spectrum of what we can learn, ranging from a broad picture related to integrated STEM education based on literature reviews, specific approaches to STEM integration, to specific approaches for curriculum analysis and implementing integrated STEM education.

The three chapters with a focus on specific approaches present different curriculum models for STEM integration. They share a common feature of developing STEM integration with a primary discipline base: design in engineering and technology (Chap. 4), statistics (Chap. 6), and numeracy in mathematics (Chap. 7). These chapters inspire us to think about the possibility of developing other curriculum models of STEM integration with a selection of different disciplines as a primary discipline base, which may be used to serve different educational purposes. STEM integration is not the end, but a means of developing students' competencies needed in the future. At the same time, these approaches tend to be discipline-centric that emphasize knowledge acquisition and application. Thus, further considerations are needed to discuss different types of knowledge (including epistemic knowledge and interdisciplinary knowledge) and skills in these integrated STEM curriculum models, as Tytler discusses in his chapter.

There can be some other perspectives in thinking about STEM integration. As Tytler quotes (Chap. 3), Andreas Schleicher, OECD (Organization for Economic Co-operation and Development) Director of Education and Skills, argued in the 2017 OECD forum:

> What is required is the capacity to think across disciplines, connect ideas and 'construct information': these 'global competencies' will shape our world and the way we work and live together.

An emphasis on the development of thinking is a very important aspect of competencies for the future workforce and STEM education is well positioned to develop students' thinking (Li et al., 2019a). Li et al. (2019a) proposed that thinking needs to be reconceptualized as plural and can be differentiated as multiple models with levels. Specifically, as examples of models of thinking, Li and colleagues further discussed design thinking (Li et al., 2019b) and computational thinking (Li, Schoenfeld, et al., 2020), without subject fixation, that are important for every student to develop and apply in the twenty-first century. STEM integration can be developed and used to help develop students' transdisciplinary models of thinking, such as design thinking and computational thinking. This perspective should provide another direction for developing various approaches, different from discipline-centric approaches, for integrated STEM education.

With a primary focus on integrated STEM curriculum models in this part, readers can certainly want to learn more from reading this book. There are many other important aspects of STEM education beyond curricular issues. We invite readers to read our introductory chapters (Chaps. 10 and 19) for the follow-up parts with specific considerations about students and their experiences (Part 2, see Li & Anderson, 2020a) and teachers and their practices (Part 3, see Li & Anderson, 2020b).

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