# Preface

Science and technological advances continue to play a pivotal role in improving the quality of living standard throughout the world. It is eminent that the long-term prosperity of a nation is dependent upon scientifically literate persons as consumers together with talented innovators in the science and technology fields. The emphasis on learning science must accelerate in order to provide a solid foundation of scientific knowledge to its citizens. This book builds upon the international success of the publication *Fostering Scientific Habits of Mind: Pedagogical Knowledge and Best Practices in Science Education* (2009, Sense Publishers) and takes a closer look at the contemporary and innovative practices in teaching and learning science.

This book examines the opportunities, challenges, and barriers to the development of innovative curriculum models, promising teaching strategies, and authentic assessment in science education to prepare future students for the 21st-century economies. The chapters in this volume also feature cutting-edge research endeavours, seamless integration, and intelligence use of technology tools, including modeling and games, conceptual frameworks, developmental processes that are directly transferable to classroom practices, and a range of new visions and future scenarios. This book is designed to promote meaningful conversations, encourage synergistic collaborations, and exchange useable knowledge among academics, researchers, teachers, and school administrators on the next generation learning science. This book is divided into four sections. They deal with the specific aspects and approaches and strategies in next generation science learning. The theoretical foundation and conceptual frameworks are presented in section 1 and followed by the use of modeling, simulation, and games in section 2 of the book. The chapters in section 3 deal with the curriculum innovations in science courses, and section 4 covers evaluation and assessment issues.

## THEORETICAL FOUNDATION AND CONCEPTUAL FRAMEWORKS

In Chapter 1, Erin Peters-Burton describes self-regulated learning as a method to develop scientific thinking. She notes that the development of skills and rationale behind scientific thinking has been the important goal in science education. In so doing, the research found that teaching the nature of science explicitly and reflectively can develop scientific thinking. The chapter presents a literature review on the methods used to teach the nature of science in the classrooms. She notes that learning the nature of science should not take the place of learning science content, rather they should be taught simultaneously. She urges secondary education must pursue instruction that intertwines both content instruction and instruction on ways of knowing in science. The chapter discusses how research in self-regulated learning theory has furthered this finding. The author presents that self-regulation frames student learning as cycling through three phases: forethought (cognitive processes that prepare the learner for learning such as goal setting), performance (employment of strategies and self-monitoring of progress), and self-reflection (evaluation of performance with the goal). She notes that it is possible for teachers to help students in setting goals for scientific thinking by making it explicit how scientists and science function. In this way, teachers also explicitly set a standard against which students can self-monitor their performance during the learning, and self-evaluate their success after the learning. The chapter concludes that self-regulation of the nature of science has great potential to support students in developing appropriate strategies to become more science-minded learners.

Sara Salloum from Long Island University presents the multiple perspectives for the study of science in Chapter 2. The purpose of the chapter is to elucidate a framework for understanding teaching practice as more than an arena for the application of theoretical knowledge and sets of practical-moral knowledge. When outlining the framework, the author uses the Aristotelian concept of phronesis/practical wisdom. The chapter begins with providing assumptions about teacher knowledge from a constructivist and sociocultural perspective. This is followed by an explanation on the Aristotelian notion of phronesis (practical wisdom), especially in terms of how it differs from other characterizations of practical knowledge in science education and how it relates to practical-moral knowledge. The author discusses how the very nature of such practical-moral knowledge deems it ambiguous and hard to articulate. The author proposes a hermeneutic model that explores teachers' practical-moral knowledge indirectly by investigating teachers' commitments, interpretations, actions, and the dialectic interactions between them. Implications for research and teacher education are also discussed. The chapter concludes that a virtue-based view of knowledge is not meant to replace others, but as a means to enrich our understandings of the complexity of teacher knowledge and to enhance our effectiveness as teacher educators.

"Teaching a Socially Controversial Scientific Subject: Evolution" by Hasan Deniz (Chapter 3) discusses what educators need to consider when teaching evolution. He points out the four domains that educators need to know when teaching evolution. These are conceptual, epistemic, socio-cultural, and religious domains. Deniz explains each domain in detail within the chapter. He then addresses students' alternative conceptions about evolution, such as all evolutionary change is adaptive, progressive, and teleological. Then Hassan explores why students' attitudes towards evolution are a direct result of students' religious perspectives, naïve nature of science views, and social-cultural backgrounds. The author argues that in order for students to change their view about evolution, they need to move from their alternative conceptions toward scientifically accepted conceptions. He adds that for the condition of conceptual change to take place, the learned need to go through four stages according to Posner, Strike, Hewson, and Gertzog (1982). These are: (1) dissatisfaction – this condition requires that the learner fails to make sense of some event with his/her existing conception; (2) intelligibility – this condition necessitates that the learner has some understanding of the new conception; (3) plausibility – this condition is satisfied when the learner accepts the new conception; and (4) fruitfulness – this condition emphasizes that the learner should be able to use the new conception to explain novel situations as well as the situations that were formerly explained by the new conception. Then, the author compares when teachers accept the evolution theory to when teaches do not accept and how that impacts the amount of time teachers' spent teaching the evolution theory. The author supports his argument by looking at the work of Berkman and Plutzer (2010), who explore the correlation of the adoption of the NAS positions and the instructional time spent on evolution. Finally, the author warns that the conceptual change model can be a problem when it comes to "assimilate students into the culture of Western science at the expense of their indigenous culture."

In “A Theoretical and Methodological Approach to Examine Young Learners’ Cognitive Engagement in Science Learning” (Chapter 4), Meng-Fang Tsai and Syh-Jong Jang argue that young learners lack “sufficient linguistic competence to accurately articulate the cognitive strategies involved in their science learning.” They note that current measures for cognitive engagement are scarce and usually better suited for older students. Furthermore, scientific studies of young children’s cognitive development are also rare. This results in a lack of understanding about how young children learn science. The chapter is divided into five parts. First, the authors give background on the theoretical framework, definitions of cognitive engagement, similar theories, and introduce the question or the problem of study. Tsai and Jang then explore several definitions for cognitive engagement for the purposes of the study. For example, Fredricks, Blumenfeld, and Paris (2004) define cognitive engagement as “originated from school engagement that includes three types of engagement: behavioral, emotional, and cognitive.” Later they argue, “behavioral engagement is defined as students’ behaviors identified in relation to their engagement such as school attendance, and participation in school activities.” On the other hand, Pintrich and Schrauben (1992) defined cognitive engagement “as to include cognitive and motivational component.” The authors then look at similar theories, such as perspectives of children’s development, information processing theory, and Vygotsky. After looking at several methodological approaches, the authors introduce a new methodological approach to study how young learners engage in science. The new method codes qualitative data and statistical analysis to quantify traditionally qualitative data.

## MODELING, SIMULATION, AND GAMES

The chapters in section 2 present the use of modeling, simulation, and games to enhance science learning. “Argumentation and Modeling: Integrating the Products and Practices of Science to Improve Science Education” by Clark and Sengupta (Chapter 5) argues that science education should focus on epistemic and representational practices of scientific inquiry and support their argumentation by examining the work of Duschl (2008), as well as Lehrer and Schauble (2006). The main focus of the chapter is argumentation and computational modeling. The authors believe that engaging students in inquiry-based activities that support the learning of complex science requires having argumentation and computational modeling. This can help to improve “higher academic achievement in schools, increased self-efficacy in science, and an overall increased interest in science.” The chapter provides a theoretical framework for engaging students in argumentation and uses agent-based modeling as an example to demonstrate modeling. The authors also provide free technologies that can be adopted in science classrooms when students are exploring argumentation and modeling. According to Clark and Sengupta, students should understand three core ideas in order to grasp the implication of Argumentation and Modeling in the teaching and learning of science. “First, modeling is the central enterprise, purpose, and goal of science. Second, argumentation is the practice that allows scientists to determine the fit of their models with the world. Third, communities of scientists evaluate models, methods, and evidence through argumentation using shared criteria and analytical approaches developed and agreed upon by the community.” For the first core idea, the authors agree with Hestenes (1993) that modeling plays a great role in facilitating the understanding of complex concepts in science. As for the second core idea, how argumentation facilitates in determining how the module fits, the authors use the Argument-Driven Inquiry (ADI) approach to show how modeling can be applied in a real world setting. Finally, the authors believe that their proposed approach, ADI, can be evaluated by the scientific community to illustrate the third insight.

In Chapter 6, Campbell and his colleagues present reification of five types of modeling pedagogies with Model-Based Inquiry (MBI) modules for high school science classrooms. It has been documented that practicing science is aptly described as making, using, testing, and revising models. Modeling has also emerged as an explicit practice in science education reform efforts. Modeling has been highlighted as an instructional target in the recently released *Conceptual Framework for the New K-12 Science Education Standards* and it states that students should develop more sophisticated models founded on prior knowledge and skills and refined as understanding develops. Reflecting the purpose of engaging students in modeling in science classrooms, Oh and Oh (2011) have suggested five modeling activities, the first three of which are based on van Joolingen's (2004) earlier proposal: (1) exploratory modeling, (2) expressive modeling, (3) experimental modeling, (4) evaluative modeling, and (5) cyclic modeling. This chapter explores how these modeling activities are embedded in high school physics classrooms and how each is juxtaposed as concurrent instructional objectives and scaffolds in a progressive learning sequence. Through the close examination of modeling in situ within science classrooms, the authors expect to better explicate and illuminate the practices outlined and support reform in science education.

In Chapter 7, Shane Tutwiler and Tina Grotzer from Harvard Graduate School of Education discuss why immersive, interactive simulation belongs in the pedagogical toolkits of next generation science. They note that pedagogical tools such as demonstration and simulation have long been integral parts of science education, and science teachers found that these tools are helpful to make salient unseen or complex causal interactions, for example during a chemical titration. Understanding of complex causal mechanisms plays a critical role in science education (e.g. Grotzer & Basca, 2003; Hmelo-Silver, Marathe, & Liu, 2007; Wilensky & Resnick, 1999), but few curricula have been developed to address this need. It seems that in recent years, content designers developed simulations that are both immersive and engaging, and which allow students to explore complex causal relationships deeply. In their chapter, they highlight various technologies that can be used to leverage complex causal understanding. They analyze the interactive simulation program, SimCity 4, which offers a virtual simulation experience with the underlying complex causal structures. They also introduce another simulation program, EcoMUVE, which they have built and are testing. EcoMUVE was designed to teach ecosystem science concepts and to help students develop expert patterns of scientific reasoning about the causal dynamics within the ecosystem. Drawing upon research from both cognitive science and science education, the authors conclude the chapter with suggested curricular framework to use immersive and interactive simulation programs effectively.

Interest in game-based learning has grown dramatically over the past decade. There have been numerous research articles published not only in educational research journals but also in other interdisciplinary publications. Educators recognize that if the games are properly embedded and used in the curriculum, they can be an effective educational tool for teaching digital generation students. However, current application of games stresses students' involvement in the instructional process, but most of the focus has not included teachers. In Chapter 8, Martinez-Garza and Clark first summarize the theoretical research on game-based learning and the implications of that research for the role of teachers. The authors next review the game-based learning literature that has specifically articulated a role for teachers or achieved an empirical description of teacher action within a game-based learning context. The authors then connect these accounts with more general research on teachers and technology use, elaborating on points of contact and identifying differences that may signal special challenges. They point out that teachers should have more input into the forms and content of learning games, but the current situation still relies on the commercial game developers. The chapter concludes that although games hold potential to enhance education, teachers have not been sufficiently supported in using games for learning in the classroom. It also finds that teachers' expertise have not been optimally leveraged in the design of games for learning. The authors suggest that teachers have much to offer to the game design process, and if the teachers and games designers work together, instruction that focuses on engaging and deep meaningful learning for students can become a reality.

## CURRICULUM INNOVATIONS

"Opening Both Eyes: Gaining an Integrated Perspective of Geology and Biology" by Renee M. Clary and James H. Wandersee (Chapter 9) focuses on the idea of integrating geology and biology in teaching science subjects. The authors start the chapter with a brief history about the integration of geology with biology. The authors then outline several benefits of this integration, such as providing natural opportunities for students to do an authentic scientific inquiry. Throughout the chapter, Clary and Wandersee explore the literature on the integrated geobiological science learning approach—in middle school, secondary, and college classrooms, laboratories, and field studies. In middle and secondary schools, the authors suggest having "Interdisciplinary scientific portals, the use of active learning and inquiry-based projects, and the incorporation of the history and philosophy of science." Teachers can easily adopt most of the activities for middle school for high school by making it more rigorous. By analyzing students' survey responses, Clary and Wandersee discover strong interest in the local landscape, large magnitude events, and unusual specimens during the high school years. Moreover, according to the authors' previous work (Clary & Wandersee, 2008a), fossils, dinosaurs, and sand can help to address several scientific constraints in high school science classrooms. The authors also suggest "*student-led* inquiry in which students generate their own questions and design subsequent investigations" as a pedagogical approach where teachers try to connect scientific concepts for high school students. Moreover, the authors argue that in order to have an effective student-led inquiry, teachers have to tap into students' prior knowledge and try to link it with their existing cognitive frameworks. In university courses, the authors mention the lack of inquiry learning by looking at the work of Drew (2011). University science courses tend to be lecture-driven and intensive in mathematics. The authors did a study of 515 students over three semesters using their Petrified Wood Survey (PWS). The results show that students gained conceptual understanding in the areas of geologic time, evolution, and fossilization processes. The content area with the smallest gains was geochemistry, according to the study. The authors recommend a gradual introduction of their approach in a curriculum. They point out that when integrating geology and biology, teachers benefit by having more motivated and interested students in classrooms. As for students, integration will help to facilitate active learning, a holistic understanding of how science actually works, and a more accurate understanding of the nature of science. Finally, students will benefit of having an "in-depth understanding of carefully selected, important scientific constructs."

"Promoting the Physical Sciences among Middle School Urban Youth through Informal Learning Experiences" by Angela M. Kelly (Chapter 10) looks at the issue of underrepresentation of minorities in Science, Technology, Engineering, and Mathematics (STEM) careers. Kelly traces the problem back to the types of courses that students are taking in middle and high school. She notes that most students do not take chemistry and physics as electives in high school and that most middle schools focus on life sciences rather than physical sciences. According to the authors, this has resulted in the under representation of minority students in STEM careers. To address this concern, Kelly introduces a study that explores the effectiveness of exposing middle school students in underserved urban communities to informal physical science experiences. The study took place over a weekend. The activities in the study included "incorporated authentic applications from the urban setting, field visits to scientists' laboratories and museums, advanced educational technology tools, and learning complex scientific concepts." The result of the study shows significant improvements in students' attitudes, knowledge, and appreciation of the physical sciences. Improved students' academic self-efficacy, confidence, and persistence in science, and positional advantage were also noted. The chapter is divided into three sections. The first section explores studies of trends in physical sciences among American high school students and the importance of chemistry and physics in STEM. The author states that there has been an increase in the number of student enrollments in high school sciences in the U.S. as whole. For example, a study done by The National Science Board (2006) that looks at transcripts between 1990 and 2000 shows that the percentage of high school graduates completing a chemistry course rose from 45% to 63% and a physics course rose from 21.5% to 31%. The second section of the chapter explores the context for the study, which is the program structure of the physics and chemistry coursework at the Bronx Institute. Finally, the author concludes the chapter by examining the effectiveness of the program and possible future replication.

In Chapter 11, "Rooted in Teaching: Does Environmental Socialization Impact Teachers' Interest in Science-Related Topics?" Lisa Gross, Joy James, and Eric Frauman describe a research study about Environmental Socialization (ES) and try to answer the question, does significant life experience affect adult activities or career interests. The authors observed that very few previous studies examine the impact of childhood experience on curricular interests of pre-service and in-service teachers. The chapter explores what "ES factors of teachers raised in rural and/or non-rural environments reveal about their interests in science-topics and field-based learning opportunities." The study investigates differences between teachers who grew up in a non-rural environment versus a rural environment and their respective interest in: 1) field-based learning and environmental education, 2) teaching science related topics, 3) environmental socialization, and 4) field-based learning and environmental education. The instrument was developed by students enrolled in an undergraduate level recreation assessment course, two representatives from environmental education facility, and three faculty members representing two college departments (education and recreation). The survey instrument had 27 questions and included demographic information, environmental socialization measures, and field-based topic interest questions. The sample size for the study was 88 teachers and student teachers, 45 with rural upbringings and 39 non-rural. The result of the study indicated that teachers who grew up in a non-rural environment have slightly higher interest in field-based learning and environmental education compared to teachers from a rural environment, which was contrary to what the authors anticipated. With respect to interest in teaching science-related topics, non-rural teachers expressed greater interest in 6 out of 10 of the science-related topics compared to rural teachers, which was also contrary to what the authors anticipated to find. The results also indicated a similarity in both rural and non-rural teachers in terms of environmental socialization experiences. Finally, the results showed similarity in both groups in terms of their interest in science-related topics as well. In other words, those teachers who are interested in environmental experiences tend to be more interested in science-related topics in general.

"Analysis of Discourse Practices in Elementary Science Classrooms during Whole-Class Discussion" by Matthew J. Benus, Morgan B. Yarker, Brian M. Hand, and Lori A. Norton-Meier (Chapter 12) explains the discourse practice in eight elementary science classrooms that applied the "Science Writing Heuristic (SWH) approach to argument-based inquiry." The chapter looks at the discourse that takes place after finishing a topic in science and before moving to a new topic. The study uses Reform

Teaching Observation Protocol (RTOP) to rate the teacher engagement with the reform-based science teaching practices. According to the authors, the outcome of the study indicates that whole-class dialogue in argument-based inquiry classrooms differed across classrooms based on the degree of implementation of RTOP. Low-level RTOP implementation was correlated with a low level of student engagement in "discourse around scientific reasoning and justification." In addition, the authors emphasize that in order to fully develop elementary-aged students with reasoning in scientific arguments takes time, courage, and ongoing professional development for teachers. Moreover, the authors argue that teachers ultimately determine the success of discourse practices in classrooms.

## EVALUATION AND ASSESSMENT ISSUES

Lyon, in Chapter 13, begins by highlighting the recent release of science education documents such as *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas* (National Research Council, 2012). that mark the transition into a new generation of science education. This requires science educators to look at how pre-college science teachers will assess a diverse group of students in ways that are consistent with science education reform. In the chapter, the author notes that in enhancing next generation science assessment, teacher educators need to consider challenges science teachers will face when employing assessment in the diverse and dynamic classroom. The author identifies current research in science assessment and employs assessment coherence, assessment use, and assessment equity as guiding principles to address the challenges of putting science assessment research into classroom practice. To exemplify these challenges, the author describes a study where a research instrument designed to measure scientific reasoning skills was translated into a high school science classroom assessment. The study took place as part of the Assessing Scientific Inquiry and Leadership Skills (AScILS) project. This project was developed to study high school and undergraduate programs that promote entry into biomedical careers, especially for minority students. The chapter aims to stimulate conversation in the science education community (researchers, assessment developers, teacher educators, administrators, and classroom teachers) about how to put science assessment research successfully into practice and to describe what next steps need to be taken, particularly around assessing diverse student populations.

In Chapter 14, "A Tool for Analyzing Science Standards and Curricula for 21$^{st}$ Century Science Education," by Danielle E. Dani, Sara Salloum, Rola Khishfe, and Saouma BouJaoude argue that conceptualizations of scientific literacy in the curricula in the 20$^{th}$ century is not enough to prepare students for the 21$^{st}$ century because the set of skills that were required for the 20$^{th}$ century are not the same as those needed in the 21$^{st}$ century. The authors then discuss the essential understandings and skills that are needed for the 21st century. They support their argument by looking at work that was done by the American Association for the Advancement of Science (1993), Bybee (1997), and the National Research Council (1996). Moreover, the authors argue that the Framework for the Analysis of Education Programs (FAEP) is inadequate for analyzing science standards and curricula. Hence, the focus of this chapter is the process of developing a new framework, the Tool for Analyzing Science Standards and Curricula (TASSC), to analyze science standards and curricula. The chapter explores the application of TASSC in multiple contexts such as two US states (Ohio and New York) and two Arab countries (Lebanon and Qatar). The study used middle school students rather than high school for two reasons. First, the unified nature of science courses in middle school compared to high school and because all middle school students have to take science courses. Secondly, students in middle school are just starting to develop "attitudes and dispositions towards science" compared to high school students. The result of the study indicated that all four contexts are at different stages in meeting the essential understandings and skills for the 21st century. Finally, the authors make it clear the intention for developing TASSC is not "for rank-ordering states with respect to the degree to which they incorporate 21st century essential understandings and skills," but to help reformers and curriculum designers focus on areas for further development.

Jeff Marshall's chapter (Chapter 15) draws attention to measuring and facilitating highly effective inquiry-based teaching and learning in science classrooms. The chapter begins with the importance of high-quality inquiry-based instructional practice into science classrooms as part of the educational reform efforts. As the National Research Council's (2012) framework for K-12 science education documented, new visions of teaching and learning include inquiry forms of instruction and integrate cross-disciplinary concepts and core ideas in learning. Marshall argues that for science this includes bringing effective inquiry-based instruction into all classrooms as a means to engage the learner. However, all inquiry instruction is not equal in terms of improving student achievement and conceptual development. This chapter explores how four critical constructs to learning (curriculum, instruction, discourse, and assessment) can be effectively measured and then used to guide more effective instructional practice. The Electronic Quality of Inquiry Protocol (EQUIP) is an instrument that can be used to measure and then to frame the discussion regarding the quality of inquiry-based instructional practice. Specifically, this chapter provides an overview of EQUIP, details the reliability and validity of EQUIP, shares a sample lesson that is analyzed using EQUIP, explores ways that EQUIP can help with teacher transformation relative to inquiry instruction, and addresses the relationship of EQUIP scores and student achievement data. There is a very high correlation between teacher performance on EQUIP and the ensuing student growth noted during an academic year. The author notes that the use of EQUIP as an instrument will guide teachers in their practice to a greater quantity and quality of inquiry-based instruction.

## CONCLUSION

As pointed out by Lyon (in this book), recent publications of the National Research Council (2012) recommend a framework for K-12 science education that is built around three major dimensions. These include "scientific and engineering practices, crosscutting concepts that unify the study of science and engineering through their common application across fields, and disciplinary core areas of physical sciences, life sciences, earth and space sciences, and engineering, technology, and application of science" (p. 29). Based on this framework, next generation science standards are being developed that will enrich the content and practice across disciplines and be internationally benchmarked (Achieve, 2012). Inputs from stakeholders, science teacher educators, and researchers will assist in implementation these standards. This book explores the approaches and strategies of next generation science learning from multiple perspectives. The contributors in the volume articulate theoretical foundations and conceptual frameworks, explore the use of pioneering technologies, and propose curriculum innovations. They also discuss assessment issues pertaining to science standard and curricula for 21st century science education. It is hoped that this book will be a valuable resource for science teacher educators, science teachers, researchers, and administrators who have a goal of enhancing teaching and learning in next generation science to prepare students for the future workforce.

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