Chapter 1
Introduction: Theorizing Future Research for the Science Classroom

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1.1 Interpreting Complexities

Why compile a book on how possible futures in science education research can or should be theorized? After so much intensive research over decades into what, how, and why students learn (or fail to learn) in school science, what remains to be speculated upon, investigated, tested, understood, and justified? We think there are many reasons why such a book is timely. They all relate to the current state of play around multiple theoretical accounts of how this learning is explained and promoted. These accounts draw variously on cognitivist, sociocultural, socio-semiotic, neuroscientific, cultural materialist, and pragmatist theories to justify reputed high-gains approaches to science learning. As noted by Tainter (2006), human efforts at problem-solving (in this case, enhancing science education) tend to generate increasingly complex explanations and solutions in the face of the partial success of past approaches.

The theoretical landscape in science education is now congested. Diverse, complex, multidimensional, and, at times, conflicting prescriptions are made about the how and why of science learning. It is timely then both to revisit these theoretical claims, to consider the possibilities of synergies between them, and, where appropriate, to extend or set new agendas arising from these theories. New agendas may also require fresh research methods. Given the modest success rates of many attempts to reform and improve science learning in recent decades, it is timely to consider the extent to which activity in this field (and its theoretical warrants) needs

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incremental change, fine-tuning, elaboration, reinvention, or a marked recalibration of theories of practice.

In addressing these questions, we invited both high-profile and emerging researchers to offer speculative insights into how effective future school science education should be theorized. While varying in proposed strategies and theories drawn upon, our contributors broadly agreed on several key issues. There is consensus that if theories are to be useful, they must address both epistemological and engagement issues in science learning. They should explain what and how students come to know in science as well as the conditions that enable them to invest in and value this learning. Contributors stress the importance of both (a) the roles and tasks offered to students and (b) the cognitive, symbolic and material tools and resources students need to use to learn and value science. There is also the ongoing question of what teacher perspectives and practices optimize student uptake of these experiences and resources.

Another recurrent theme, in the face of theory proliferation, is the call by several contributors for more dialogue across competing and divergent theoretical perspectives. As is so often noted over the last 20 years, traditional (and more recent embodied) cognitivist perspectives do not always align easily with sociocultural accounts of contextual cultural factors influencing student learning. Researchers within a cognitivist orientation have tended to focus on the key role of mental processes in individual learners, where studies have researched how to optimize student attention, perception, language, reasoning, and problem-solving, to support conceptual change and metacognition (see Duit & Treagust, 2003). By contrast, socioculturalists have tended to focus on broader contextual conditions such as the influence of the forms of inquiry, the purposes for activity, the roles of learners, and the interaction with material tools on learning within groups (Roth & Barton, 2004). Contributors in this book point to the need to acknowledge generative insights across this theoretical divide and the need to undertake the challenging work of researcher-informed theoretical inclusiveness and agility. There is also broad recognition of the socio-semiotic dimension to learning, in that quality meaning-making depends on guided student induction into all the sensemaking resources in science lessons. In identifying the real complexities entailed in understanding (and enacting) positive influences on this learning, we now need to develop workable multi-theoretical perspectives that engage insightfully with these complexities.

1.2 Overview of Chapters

The first three chapters provide big-picture perspectives on key issues. They focus on the range of resources students need to acquire and refine if they are to develop as engaged, successful learners in this subject (Webb & Whitlow, Chap. 2, this volume), meaningful learner roles, purposes and processes for doing science (Gee, Chap. 3, this volume), and multidimensional structural supports needed to optimize cognitive engagement and success in this learning (Graham, Chap. 4, this volume).

Webb and Whitlow (Chap. 2, this volume) note that science education has been broadly influenced by two divergent traditions. The first broadly cognitivist perspective assumes that learning entails restructuring an individual student's mind through guided conceptual growth, expressed through developing representational competence. The second sociocultural approach assumes that students' learning is facilitated through group enculturation into scientific practices. Such learning is therefore context-dependent and specific to the purposes, collective experiences, and tools used for particular practices. As noted by these authors, these differences lead to contrasting views about what should be researched, how, and why. Cognitivist-oriented researchers seek to test and explain conceptual change in individuals, whereas sociocultural researchers seek to explain learning through microanalyses of learner activities, including teacher-guided discussion. In seeking to combine insights and outcomes from both approaches, Webb and Whitlow (Chap. 2, this volume) propose that cognitivist analyses should be applied to the processes and outcomes of immersive sociocultural approaches.

For Gee, science education has a long history of failure to engage learners, with quantitative research methods symptomatic of sophisticated sleepwalking in this and other education domains. As a pragmatist socio-semiotician, his solution to this story of failure is to claim that learning in science should be fundamentally refocused to engage with the ultimate purposes for meaning-making in this subject. Drawing on Wittgenstein (1958), he proposes that science should be understood as a "form of life," a set of values, norms, and actions rather than as the subject-specific knowledge arising from these practices. He claims that the ultimate purpose of science education should be to enable us to participate in "a better form of life with each other." To achieve this, learning experiences in science education should encourage students and citizens to be committed testers who respect evidence and critical discussion. They should encourage humility and a tolerance for the partiality of human judgments and therefore encourage a collaborative rather than adversarial approach to truth-seeking and truth-testing.

In theorizing the many influences on students' writing development in science, Graham (Chap. 4, this volume) draws mainly on cognitivist accounts of learning processes but integrates these insights with sociocultural perspectives on broader conditions that affect all text production in this subject. Learners are embedded in evolving writing communities that shape what they do, with these communities reflecting broader networks of historical, societal, cultural, and political and institutional influences. At the micro-level, his model of writing development incorporates a detailed account of the necessary knowledge bases or resources that guide what and how individuals write, but he also notes that motivational beliefs, emotions, personality traits, and physiological factors play a part in a writer's sense of self. In naming key ways in which writing development can be promoted, he points out how research is still needed on how these ways interact in science learning and how broader influences play out on this development.

Subsequent chapters in different ways take up this challenge of integrating cognitivist perspectives on learning growth within a theorized account of contextual influences. Contributors propose how particular purposes, resources, and learning experiences can be theorized at the micro-level of individuals, and within groups as the basis for understanding (a) current practices, but also (b) to inform how future learning opportunities should be designed, enacted, and reviewed to promote student engagement and learning. While there is a recurrent focus on theorizing the role of writing in science as a key tool for learning, the theoretical discussion is applicable more broadly to learning in the science classroom.

Lamb, Hand, and Yoon (Chap. 5, this volume) note that the theory espousal of what influences learning in school science continues to outstrip theory testing, with many studies generating competing descriptive models based on qualitative evidence. To address this problem, they propose the use of neuroimaging to identify cognitive processes and dynamics more directly than is usually proposed through retrospective testing of learning, interviews, or student self-reporting. They argue that neuroimaging offers real-time measurement of brain activity in writing tasks, and therefore provides more precise evidence for claims made for learning outcomes from different writing tasks. On this basis, through image analysis, they report that summary writing tasks make more demands on critical thinking abilities than argumentative writing. They suggest that this research technique for tracking cognitive processing, when aligned with other contextual research methods, provides (a) testable outcomes to confirm and complement models of learning arising from different writing tasks and (b) offers further leads for research that is process-oriented rather than product-dependent.

In acknowledging the complex dimensions to scientific practices in and beyond schools, Tang (Chap. 6, this volume) proposes that actor-network theory provides a useful framework to theorize human/nonhuman and linguistic/non-linguistic influences on student learning in science. This theory seeks to integrate cognitivist, sociocultural, and semiotic perspectives. Students here are understood to engage in a sequence of connected multimodal literacy events in learning any science topic, where multiple influences shape and reshape what is learnt. These influences include the students' own purposes and inquiry processes, as well as their interactions with teachers, peers, material resources, and revisable inscriptions during the course of the topic. Tang suggests that future research is needed to identify how and in what ways this network of classroom "actors" aligns with or differs from the practices of scientists. This research agenda aims to focus more precisely on what are generative alignments between the two set of practices, with implications for future design of science learning experiences.

Hand, Cavagnetto, and Norton-Meier (Chap. 7, this volume) claim that there is a need for future research to develop theoretical constructs related to the development of epistemic cognition when students are immersed in argumentation in this discipline. They propose that epistemic cognition (or knowing how and why to generate knowledge claims in science) should be conceptualized as drawing on four knowledge bases. These are science content knowledge around relevant concepts; argument knowledge or how claims are made in science and viewed as valid or invalid; language knowledge or all the representational forms of concepts; and knowledge of the learning environment or knowing how and why to participate. These bases together provide the grounds for students to "live the languages of science." The researchers argue that more research is needed on all the influences on the science classroom environment to determine what affects the development and use of the proposed knowledge bases. On this issue, like other contributors, they see the necessity to acknowledge the value of multiple theoretical perspectives. These include cognitive, linguistic, representational, sociocultural, and epistemological frameworks to interpret conditions for effective student immersion in science practices.

In conceptualizing writing as an epistemological tool for learning in science, Chen (Chap. 8, this volume) proposes three interlocking perspectives. Writing can be a form of personal sensemaking (cognitive perspective), a form of disciplinary induction, and a sociocultural resource within a community of shared practices. From the first perspective, individuals learn from writing in science depending on the degree of perceived challenge and cognitive work entailed in the writing task. From the second perspective, students learn from writing when they learn how and why to use its disciplinary forms and purposes in science. From a sociocultural perspective, writing is one communicative resource among many for students to enact roles in a disciplinary community. He asserts that further research is needed to identify what individuals and groups draw upon, and how, to learn, when this learning is conceptualized as interactions across these three perspectives.

Yoon (Chap. 9, this volume) suggests a model for the development of individual and collective student reasoning capabilities in science based on the complex interplay between learning resources and task demands in this subject. Resources include cognitive, sociocultural, semiotic, and material supports in a particular situation or inquiry, whereas demands are conceptualized as the expected scientific literacy practices to be achieved through the use of these resources over time. The context in which all these resources are used to address demands is characterized as a "discourse space," with learning outcomes dependent on the extent to which students utilize all possible resources to address the developmental demands implied in scientific literacy practices. Yoon suggests further research is needed in micro-level analyses in how individuals learn in this space and the role of representations in this learning. By implication, such research can support future design of pedagogical approaches to guide the development of learners as scientific reasoners.

Prain (Chap. 10, this volume) analyzes the multiple roles of representations in student learning in science, focusing particularly on student generation of these signs. He notes that the divide between cognitivist and sociocultural theories about learning from this sign-making has generated persuasive diverse insights, and that both perspectives, despite differences, converge on the catch-all explanatory value of affordances in this learning. He argues that researchers need to continue a focus on what kinds of tasks, representational challenges and choices, teacher guidance, and student improvisations (a) strongly engage students in creative claim-making and critique dimensions of scientific practices and (b) support student learning through utilizing particular affordances in this activity.

Emerson (Chap. 11, this volume) focuses on negative influences on the formation and maintenance of teacher and student beliefs and attitudes toward writing in science. She attributes this pattern to both early and subsequent school experiences but also to how curricular documents tend to view writing as a communicative rather than an epistemological tool. In concurring with many other contributors to this book, she argues for the need for teachers to understand and enact a focus on student writing as a crucial resource for knowledge speculation, clarification, and sensemaking in science.

Kelly (Chap. 12, this volume), in reviewing key themes in the preceding chapters, suggests that contributors engage in three crucial types of critical dialogue to advance science education research. The first discourse entails specifying groups' central theories, assumptions, and empirical scope. The second discourse entails assessing the value of different research traditions, and the third focuses on what can be learnt from analyzing differences and potential complementarities across contrasting traditions.

1.3 Concluding Remarks

These brief chapter summaries offer at best an orientation to the complexities covered by contributors around theorizing the future of research into school science learning. However, they also point to many broad areas of agreement despite the diversity of theoretical starting points, assumptions, and proposed foci for research and research methods. All contributors recognize that learning science should be about students engaging in meaningful ways with the purposes, processes, values, and multiple cognitive, semiotic, and sociocultural resources of this domain. This engagement is theorized as both individualized and collective. If students are to be more than reluctant bystanders in this subject, then they need sustained, guided immersion in how particular practices in science enable them to generate, judge, share, and value knowledge in this subject (Prain & Hand, 2016). The focus of this book is on student rather than teacher learning, but many chapters, by implication, point to the key roles of teachers in designing and facilitating student learning.

In recognizing the real complexities in theorizing future research in school science learning, our contributors do not converge on a single agreed theoretical prescription. Rather they identify key dimensions that need to inform theory-building, multi-theoretical reasoning, and enactment. Our book is intended to contribute to theory clarification and renewal, noting that theoretical perspectives and research tools are needed that are multi-focused and supple enough to explain the complexities of learning in this subject, and facilitate future pedagogical strategies and design.

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