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Managing Inquiry-Based Science: Challenges in Enacting Complex Science Instruction in Elementary and Middle School Classrooms

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Abstract Effectively enacting inquiry-based science instruction entails considerable changes in classroom management practices. In this article, we describe five interconnected management areas that need to be addressed when managing an inquiry-oriented K-8 science classroom. We introduce a pyramid model as a framework for thinking about these management areas and present a brief review of what the research literature says about each area. We propose that enacting inquiry-based instruction requires a different kind of approach to classroom management that takes into account the close-knit relationship between management and instruction. This perspective recognizes the pervasive nature of managing the classroom for inquiry learning.

Keywords Inquiry-based science · Science instruction · Classroom management · Elementary and middle school science · Science teaching · Science education reform

Introduction

How teachers manage their classrooms is critical for student learning. National science education reforms emphasize the important role of teachers in creating and sustaining classroom conditions that provide all students with opportunities for learning science through inquiry (National Research Council [NRC] 1996, 2000). Scientific inquiry as a basis for instruction draws from the idea that students learn

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science best when they are provided with opportunities to do science in ways that mirror the authentic practices of scientists (Minstrell and van Zee 2000). A central message of reform is that teachers should spend less time with recitation and seatwork, and more time actively involving students in scientific practices, such as designing and carrying out investigations, to deepen their learning of science content and broaden their understanding of the nature of science. Recent research provides some support for reform recommendations. For instance, research shows that when teachers incorporate recommended reforms into their instruction, student learning improves (Geier et al. 2008; White and Frederiksen 1998; Williams and Linn 2002), and student interest, engagement, and motivation in science is enhanced (Engle and Conant 2002; Mistler-Jackson and Songer 2000; O'Neill and Polman 2004). Yet, research has also shown that enacting inquiry-based instruction is demanding for teachers (Holbrook and Kolodner 2000; Magnusson and Palincsar 2005; Marx et al. 1997) and that many teachers are not well prepared for inquiry-based teaching (Weiss et al. 2001). One considerable challenge for teachers is to learn new ways of managing the classroom to position students for learning through inquiry.

In this article, we consider the issues that elementary and middle school teachers must attend to in order to effectively manage inquiry-based science learning in their classrooms. Examining what it takes for teachers to reconfigure their classrooms to promote science learning through inquiry is vitally important to gain insight into how better to prepare teachers for ambitious science instruction. The need for attention to K-8 science instruction has taken on greater significance with the recent expansion of the No Child Left Behind Act (NCLB) to include science assessments (Marx and Harris 2006). Adding to the growing interest and concern in early science instruction is the recent report by the National Research Council, *Taking Science to School* (Duschl et al. 2007), that calls for a dramatically different way of conceptualizing instruction for young science learners.

We begin with a brief overview of new directions in K-8 inquiry science instruction and background on contemporary perspectives on the complexities of classroom management. We then introduce a model for thinking about issues of managing inquiry-based science. With this model as a frame, we draw from the literature on what is currently known about what is involved for teachers to enact inquiry in their classrooms and consider some of the practical problems that emerge as teachers manage students, materials, tasks, science ideas, and the overall social context of their inquiry learning environments. We close by considering implications of our model and offering recommendations to prepare elementary and middle school teachers to address the multifaceted task of managing inquiry science instruction.

New Directions in Inquiry Science Instruction

Inquiry instruction has been a hallmark of recent science education reform efforts (e.g., American Association for the Advancement of Science 1993, 2001; NRC 1996, 2000). Yet, the science education community is still grappling with what inquiry should look like in diverse classroom settings, the kinds of instructional experiences and practices that can best position students for inquiry learning, and how to design inquiry curricula that support the development of science content and practices over the K-8 years (see, for example, Anderson 2002). What may prove to be a seminal work in how we conceptualize inquiry for young learners is the National Research Council's recent report on teaching and learning science in K-8 classrooms (Duschl et al. 2007). The report, drawn from current instructional research, offers a new perspective on what it means to be proficient in science that emphasizes using and applying knowledge in the context of scientific activity. According to this view, students are more likely to advance in their understanding of science when they have opportunities to participate in science as practice. This is because engaging in scientific activity provides students with a context for thinking about and using scientific knowledge. As students use their ideas, they deepen their conceptual understanding of content as well as their understanding of how to do science. This science-as-practice perspective (Lehrer and Schauble 2006) brings together content knowledge and process skills in a manner that highlights their interconnected nature.

A key recommendation of the report is that K-8 science instruction should integrate doing and learning through four strands of scientific practice. The strands, supported by contemporary research literatures on teaching and learning science, articulate the practices that students need to engage in to develop scientific proficiency. The first strand, *know, use and interpret scientific explanations*, emphasizes the use of ideas to explain the natural world. This strand recognizes that acquiring factual information is important, but that learning is most powerful when children are helped to bring together new information and organize it in a way that allows for a deeper understanding of natural phenomena. This occurs when students have opportunities to apply ideas in scientific activity, use ideas to explain and predict phenomena, and make connections between ideas. The second strand, *generate and evaluate scientific evidence and explanations*, focuses on the important role of evidence as part of scientific practice. This includes designing and conducting investigations, analyzing data, and using evidence to draw conclusions, support arguments, or determine next steps in an inquiry. A central component of this strand is building and refining models and explanations based on evidence.

The third strand, *understand the nature and development of scientific knowledge*, focuses on students' understanding of how scientific knowledge is constructed, including their own ideas about the natural world. This strand emphasizes reflection—students are more likely to deepen their understanding of scientific knowledge and its nature when they have opportunities to experience science as practice and reflect on their own ideas (and the ideas of others) as they generate evidence, learn new facts, and develop new models and explanations. The fourth strand, *participate productively in scientific practices and discourse*, is concerned with creating a science learning community in the classroom that mirrors a scientific community. This strand emphasizes the importance of participation for learning the norms of science, including how to represent ideas, use scientific tools, and interact with peers in the scientific community of the classroom. Central to this strand is the need for students to view science as interesting and motivating, and to develop mental habits such as persistence and inquisitiveness that help students acquire a positive stance for science learning.

Taken together, the strands provide a picture of science instruction that promises to provide students from the earliest grades onward with rich opportunities to engage in scientific practice, thereby helping them to better grasp what it means to understand and use science. For this type of ambitious instruction to be enacted effectively in K-8 classrooms, teachers will need to manage their classrooms very differently.

Science Classroom Management

Classroom management is often conceptualized as a matter of maintaining control of students and their activities so that instruction and learning can occur (McCaslin and Good 1998). Many teacher education textbooks describe classroom management as a set of strategies and behaviors that help keep students on task and limit disruption (Bullough 1994), and teachers often view classroom management as separate from instruction (Woolfolk Hoy and Weinstein 2006). This approach to management is particularly well suited for teacher-centered science instruction characterized by seatwork, lecture, and teacher led discussion.

Rather than promoting a climate of controlling student behavior, classroom management in inquiry classrooms should be aimed at creating conditions that support students' reasoning around conceptual issues and complex problem solving. In such student-centered environments, the work of the teacher changes from the traditional role of information delivery to effective scaffolding that supports students in integrating and applying ideas. Students assume more responsibility as they collaborate and communicate around authentic tasks and investigations, and participate in a community of scientific practice. Many classroom-based researchers (e.g., Brophy 1999; Evertson and Neal 2006; McCaslin and Good 1998; Mergendoller et al. 2006) have recognized the need for an expanded view of classroom management that encompasses the goals and social complexity of student-centered environments. Mergendoller et al. (2006), for instance, have coined the term *pervasive management* to describe a view of classroom management that goes well beyond maintaining classroom order. Pervasive management is intertwined with instruction and involves sustained support for student learning. From a pervasive management perspective, it is difficult to distinguish between instruction and management because elements of effective instruction such as sparking and maintaining student interest and engagement, enacting intellectually meaningful activities, and scaffolding student learning also require ongoing management.

Our view is that orchestrating complex science instruction that engages students in the strands of scientific practice, as recommended by *Taking Science to School*, will require pervasive classroom management by teachers. Contemporary science education research shows that teachers play an essential role in shaping how learning unfolds in inquiry-based classrooms. This research also provides insight into what is involved for teachers to manage their classrooms for science as practice. By looking across a range of studies, we have identified several common areas of management that require a pervasive management style. Management areas for

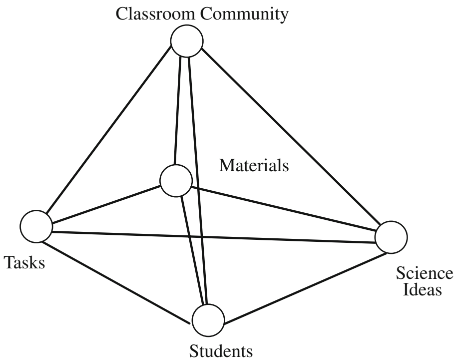

Fig. 1 Management interactions in inquiry-based science learning environments

teachers include students, instructional materials, tasks, science ideas, and the overall social context of their inquiry learning environments. Figure 1 presents a pyramid model that illustrates the interdependent nature of these management areas. Each point in the pyramid identifies a management area that needs to be attended by teachers during inquiry-based science instruction in order to support and sustain learning. The five interconnected management areas work together in such a way that the effectiveness of any one area is influenced by how the other areas are managed. For instance, a particular way of managing a science learning task may not work as effectively when management decisions in another area, such as the instructional materials, are not taken into account. Similarly, a change in one management area may have repercussions for others. At the apex of the management pyramid is community. Its placement atop the pyramid highlights the vital importance of managing the overall social context in which science instruction takes place.

The pyramid model also illustrates important dimensions to take into account when thinking about issues of managing inquiry-based science learning environments. Within traditional teacher-centered environments, management interactions typically unfold around activities that stress information transmission, with students concerned with receiving information from either the teacher or text materials. Quite differently, within inquiry-based environments the management interactions are meant to engage students in scientific activity that serves as a context for thinking about and using scientific knowledge. Students are expected to build their understanding as they participate with one another and their teacher in scientific practice. Consequently, the management interactions are more complex and each management area in the pyramid presents unique challenges for teachers. In this next section, we draw from the promising research base to examine each management area and explore what we presently know about what it will take for teachers to pervasively manage their classrooms for ambitious science instruction.

Managing Inquiry-Based Science

In recent years, researchers have designed and studied a small number of inquiry-based instructional interventions that engage students in various aspects of scientific practice. The emerging evidence shows that students, even in the primary grades, can carry out scientific investigations, weigh evidence, and propose explanations for their findings (e.g., Magnusson and Palincsar 2005; Metz 2004). There is broad agreement that student success in such inquiry learning environments is dependent upon skilled and thoughtful guidance from teachers. Yet, this research also tells us that teachers encounter substantial dilemmas in teaching science as inquiry. Here we draw from research on these programs to examine the complexity that teachers face in managing students, instructional materials, tasks, science ideas, and the overall classroom community in order to help their students develop sophisticated understandings of science content and scientific practice.

Students

Researchers have found that learning science through inquiry is a very different way of learning for students. Inquiry instruction places higher demands on students in terms of participation, personal responsibility for learning, and intellectual effort (Blumenfeld et al. 2006). Students are expected to “talk science” (Lemke 1990) as they work together to plan and carry out investigations, and engage in discussion and debate with each other and the teacher. This shift in classroom expectations can be overwhelming for many students, especially those who have limited science experience, content knowledge, and familiarity with inquiry skills. For this reason, students often need extensive support by their teachers to become comfortable in their new classroom roles (Fradd and Lee 1999; Holbrook and Kolodner 2000; Palincsar and Magnusson 2001). To orient students to new ways of learning, teachers need to help students develop the skills and stance necessary for engaging in inquiry. This changes the role of the teacher from a manager who is concerned primarily with content delivery, to a scaffolder who is concerned with creating conditions for students to learn as they engage in scientific activity.

A key dilemma that teachers face is how much guidance or independence to give students. For example, too much independence during lessons without adequately structuring the science learning situation or providing feedback can cause confusion and frustration, resulting in less learning. Too much guidance, on the other hand, characterized by over emphasizing procedures, being overly explicit in a way that leaves little or no room for student sense-making, and limiting student autonomy can diminish cognitive engagement with important science ideas. Pervasive management of students entails strategically scaffolding (Davis and Miyake 2004) activities so that students understand how to think as they engage in tasks as well as acquire the procedural knowledge of how to do them, how to collaborate with classmates, and how to critically reflect on their learning. This specialized support requires that teachers be attentive to and respond to students in a manner that changes over time as students become more adept in their thinking, planning, and performance in the inquiry process (Pea 2004).

Instructional Materials

National science reform documents have guided the development of a new generation of standards-focused curriculum materials to support teaching and learning through inquiry (see, for example, Singer et al. 2000; Songer 2006). Inquiry-based science programs often provide comprehensive curriculum materials to enable teachers to create inquiry learning environments in their classrooms. However, these materials are typically not scripted in ways that allow for simple step-by-step teaching. Instead, teachers are expected to interact with curriculum materials to make instructional decisions that meet the needs of their students (Davis and Krajcik 2005). Following lesson descriptions step-by-step may not directly translate to success in inquiry classrooms. Yet, straying too far from the intended curriculum risks that students will not have experiences that align with learning goals or match with the theoretical frame of the particular instructional program. The latter is what Brown and Campione (1996) refer to as a *lethal mutation*. This occurs when teachers make changes in the enactment of curriculum materials that deviate substantially from the intent of the materials.

Pervasive management of instructional materials involves making adaptations consistent with learning goals, appropriate for students' learning, and in line with the essence of inquiry. Schneider et al. (2005) demonstrated that a range of enactments can be expected when teachers use instructional materials specifically designed to support science inquiry instruction. Often times, teachers new to teaching science as inquiry will enact inquiry materials in ways that mirror their own long-standing practices. A concern arises when teachers adopt the superficial features of an inquiry-based approach and fail to take on the instructional stance required to fully support learning.

Another aspect of instructional materials management is managing technology to support student learning. In many inquiry-based classrooms, students are using innovative technology tools and resources such as Internet search engines and databases, model building software, handheld technologies, and a wide array of data collection and communication tools to engage in real-world investigations and communicate findings. Increasingly, students are using the same technology tools that are used by practicing scientists. Observational research has shown that teachers can quickly become preoccupied with troubleshooting technology problems (Songer et al. 2002), leaving little time to attend to students' thinking and learning while students are using the technology. Teachers need technology expertise, including knowledge of how to use and maintain the technology as well as the pedagogical knowledge of how to use the technology with students to leverage learning.

Of note is that there is increasing interest in embedding scaffolds in software tools to support learners as they engage in scientific activity (Reiser 2004). Software, with built-in scaffolds such as prompts, guides, and advanced organizers can help students focus their efforts. Software scaffolds can also structure student work by providing workspaces for planning and conducting investigations (Puntambekar and Hubscher 2005). These are promising features to help teachers overcome some of the challenges in using technology to support learning.

Tasks

A distinguishing feature of inquiry instruction is the use of tasks that are authentic to the discipline of science. Authentic tasks in inquiry classrooms engage students in scientific activity in a manner similar to how scientists conduct their work, but in ways that are appropriate and meaningful for students and with carefully structured support (Lehrer and Schauble 2006). In elementary and middle school classrooms, this might entail actively guiding students as they investigate the air and water quality of their neighborhoods, the biodiversity of their schoolyard, or how electricity makes everyday things work. Authentic science experiences, in which students observe, investigate and explain real-world phenomena, can help students relate scientific ideas to their everyday physical world and allow them to test the plausibility of scientific ideas.

Authentic tasks have the potential to reshape classrooms into places where students engage in complex work that is personally meaningful, relate to real world situations, and develop usable knowledge and robust understandings (Harris and Salinas 2009). However, teachers can be challenged in enacting authentic science tasks if they are not familiar with the practices of scientists and have never participated in authentic scientific activity themselves. Another challenge for teachers is supporting sustained engagement with tasks and ideas. In contrast to typical science classroom tasks, authentic science tasks are carried out over days or weeks rather than minutes or hours. Teachers need to carefully sequence activities so that students acquire the appropriate skills and knowledge as they work over time. Furthermore, effective participation in authentic tasks often involves solving problems in which there are no quick and easy solutions. Students can become discouraged with the difficulty of completing tasks. If teachers are to use authentic tasks effectively, they must address the challenges of organizing instruction and supporting students.

Of central importance for learning in inquiry classrooms is the pervasive management of authentic tasks so students can acquire the relevant knowledge and skills as they participate in them. Two important components are providing purpose and making clear the learning goals for tasks. Providing purpose supports the process of learning by making public the underlying reasoning for tasks. Students need to be aware of the purpose behind tasks if worthwhile learning is to be achieved (Hart et al. 2000). Pervasive management of tasks also entails orchestrating instruction around learning goals. Barron et al. (1998) point out that when teachers have a learning goal in mind and organize instruction around that goal, students are more likely to understand what they are trying to learn, which may in turn help them to direct their learning when they are engaged in inquiry tasks. Thus, when teachers make explicit the intended learning target for a task as well as the relevance of the task for the intended learning, they increase the likelihood that students will grasp the learning benefit of engaging in tasks.

Science Ideas

Because of the variety and pace of activity in inquiry-based classrooms, the coherence of lessons is vitally important. Effective inquiry instruction requires that teachers create a series of coherent learning experiences that help students to build understanding of scientific ideas over time (NRC 2000). Coherence refers to the manner in which activities are sequenced to work together in a lesson to support the learning process. Teachers need to choreograph the sequence and flow of activities in a manner that helps students make progress toward understanding the key science ideas of an investigation.

Pervasive management of science ideas involves building and sustaining coherence within and across lessons. The unfolding of a lesson during instruction creates a story line that can help students follow the logic of the lesson. A challenge for teachers is to create a comprehensible story line for students to follow and make sense of the learning experience. Presenting accurate science ideas and providing motivating and engaging tasks are important, but if the ideas and tasks are not woven together in a way that allows for fluid sense making, students run the risk of missing key points or picking up discrete bits of information that cannot be easily recalled and put to use (Bransford et al. 2000).

Another important aspect of managing science ideas is eliciting students' prior knowledge and previous experiences for use while they are engaged in scientific practice. When students are helped to draw from previous experiences and prior knowledge, they can use this as a foundation for subsequent learning (Bransford et al. 2000). Furthermore, Moje and Hinchman (2004) have demonstrated that when connections are made between science and students' own backgrounds, everyday experiences, and interests, students are more likely to find value and meaning in their classroom science tasks and activities. To help students activate their prior knowledge and make relevant connections, teachers must effectively manage the interaction of prior knowledge and new science ideas by encouraging students to make sense of new information in light of what they already know or have experienced.

Pervasive management of science ideas also requires ongoing and active assessment of students' thinking and ideas during instruction. This can be challenging when students are engaged in investigations with classmates and teachers are faced with managing multiple groups of students simultaneously. Teachers often find themselves monitoring students during group work to ensure that students are on task and on pace for completing work, leaving little time to address the science ideas meant to be at the forefront of investigations (e.g., Holbrook and Kolodner 2000). This is especially true when students have difficulty self-regulating and staying on task. Often times, important ideas are not addressed until after the collaborative work is completed and students are engaged in whole class discussion with their teachers. Sometimes, the group work extends too long leaving little or no time at the end of a lesson for teachers to fully address the important science ideas with their students.

Classroom Community

In inquiry classrooms, the tenor of classroom life is vital because students and teachers are expected to collaborate on investigations, discuss and debate ideas, and communicate findings. A classroom learning community describes a situation where teachers and students are engaged in a collective process of learning that produces shared understandings (Brown 1997; Brown and Campione 1994). Science education reform efforts promote the idea of creating a learning community with a shared purpose of making sense of scientific ideas and practices (NRC 1996). A learning community requires that students be actively engaged in the classroom, open to communicating their ideas, and willing to learn from each other. Such an environment features a social context that allows students to feel comfortable asking questions, seeking help, and responding to questions.

Pervasive management of the science classroom community entails creating a comfortable and respectful environment that fosters collaboration and encourages participation for learning the norms of science. Management actions that lend to a comfortable and respectful environment include teachers relating to students and promoting students relating to each other; expecting attention and participation; being accepting of students' responses; encouraging and communicating respect for students' questions and ideas; and holding students accountable for doing class work. To foster collaboration and create appropriate norms, teachers must help students learn to work together productively and emphasize scientific norms for conducting scientific work, representing ideas, and interacting with peers in the scientific community of the classroom. This complex interaction pattern takes time to develop and sustain. Crawford (2000) suggests that this kind of management, where the teacher is striving to create and sustain a community for inquiry, requires substantially more teacher involvement and effort than that of traditional science teaching.

Teacher involvement and effort is especially needed in managing discussions, a central mode of discourse in science learning communities. All too often, discussions in science classrooms follow a pattern of teacher-led initiate-reply-evaluate (IRE; Mehan 1979), in which the teacher poses a question, calls on a student to respond, and then carefully listens before evaluating the response. To effectively manage classroom discussion for meaningful learning requires that teachers break from the three-turn exchange of IRE and purposively use questioning to elicit and foster student thinking. This entails asking and promoting questions that help clarify observations or inferences, extend or apply ideas, justify answers, generate new knowledge or perspectives, and help students monitor their own learning (Minstrell and vanZee 2003). Such a shift in community discourse involves teachers orchestrating extended conversations between themselves and students and students with each other. While doing so, teachers need to balance the tensions between students' ideas and scientific knowledge, and ensure that conversation is directed toward understanding important science ideas and practices (Crawford et al. 2000).

Implications

An important part of science teaching is managing the classroom to position students for learning. In this article, we described five interconnected management areas that need to be addressed when teaching science as practice. We introduced a pyramid model as a framework for thinking about these management areas and presented a brief review of what the research literature says about each area.

Managing inquiry-based classrooms is complex, requiring that teachers attend to students, materials, tasks, and ideas—often simultaneously—as well as the social context that serves to shape the overall climate of their inquiry learning environments. Our view is that enacting the ambitious instruction outlined in *Taking Science to School* will require a different kind of approach to classroom management that takes into account the close-knit relationship between management and instruction. This perspective recognizes the pervasive nature of managing for inquiry learning and calls attention to both structural elements (such as tasks, time, and materials), and conceptual elements (such as science ideas, questions, and prior knowledge) in the classroom.

We hold that our pyramid model has promise as a useful framework for educators to better understand the complexities of managing inquiry-based instruction. An assumption is that the model will support teachers in anticipatory thinking about how to create and sustain classroom conditions more aligned with the essence of inquiry. The pyramid model also has promise as a framework for researchers both to study management interactions in inquiry-based classrooms and identify strengths and weaknesses in science classroom management. An assumption is that observational schemes designed around the central features of the model will enable researchers to examine management interactions in a manner that reflects the multifaceted nature of inquiry classrooms. We are currently using the model in an ongoing curriculum design research project that involves providing ongoing professional development support for teachers and studying video records of these teachers enacting the inquiry-based curriculum materials. One of our goals is to explore the practice and research assumptions underlying the model.

It is important to emphasize that pervasive management may not look the same in every classroom. The manner in which an inquiry classroom can be managed effectively may in fact depend on a range of factors, such as students' familiarity with science and prior content knowledge, teachers' familiarity and comfort with inquiry instruction, and the resources and constraints of the classroom setting. For this reason, outlining a prescriptive set of management techniques is not a suitable professional development approach for preparing teachers to engage students in the strands of scientific practice. Nor is it a suitable research goal. Instead, models of how teachers can successfully manage the complexity of inquiry instruction in a range of settings are needed. Though small in scope, there is some very promising work on helping novice and experienced teachers move themselves and their students toward more inquiry-oriented instruction (e.g., Huber and Moore 2001; Lee and Luykx 2005; Marx et al. 1998). Additionally, more work needs to be done on discerning effective pervasive management practices and specifying the situations in which they are most likely to be effective in inquiry-based classrooms.

A related issue is how to prepare new teachers for pervasive science classroom management. Teacher preparation programs usually designate classroom management as a separate course, with attention given to basic management principles that apply across a range of instructional approaches and settings. New teachers still need the familiar management strategies of setting clear expectations, using wait time, reinforcing positive behavior, establishing procedures and routines, and so forth. In addition, we see a need for incorporating the topic of pervasive management into science education methods coursework. Videocases (Schwille et al. 2007) are one promising way to help prospective teachers begin to understand and appreciate the multifaceted task of managing inquiry science instruction. Another approach is to provide guided opportunities for beginning teachers to conduct authentic science inquiry themselves (Windschitl 2003) coupled with reflection, discussion, and practice on how it can be effectively managed in elementary and middle school classrooms. Finally, educative curriculum materials (Davis and Krajcik 2005) with built-in supports for pervasive management, may be another promising way to support new teachers as well as experienced teachers new to inquiry in creating and sustaining conditions that favor learning science through scientific practice.

Conclusion

New views on teaching and learning science are beginning to reshape the landscape of classrooms. Though lecture, whole-class IRE discussion, and seatwork are still prevalent in many classrooms, there has been a shift in emphasis from teacher-centered classroom environments to learner-centered classrooms that support students' engagement with complex science ideas and participation in scientific activity. Managing inquiry-based learning environments has a host of challenges, illustrating that this kind of instruction is not easy. A great deal of work remains to be done to understand management interactions in science inquiry classrooms and how to support teachers in addressing the areas highlighted in this article.

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