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School Science Reform: An Overview and Implications for the Secondary School Principal

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Central to science education reform efforts in secondary schools for nearly a half century has been a focus on the content and concepts to be taught, on how teachers should teach, and, more recently, on issues of systemic approaches to science teaching and learning. This article highlights reform efforts and outlines their important implications for the secondary school principal in maintaining an effective school science program.

For nearly a half century, science education in U.S. schools has been the focus of ongoing concern. An early stimulus to this concern was the successful launch of Sputnik I, an Earth-orbiting satellite, by the former USSR in 1957—an event that energized a reform movement in science education never before witnessed in American public education. Subsequent to Sputnik, critics voiced fears about losing the technology race with the Soviet Union and questioned the adequacy of the U.S. education system to prepare students to work in technical fields. Many critics argued that the secondary school science curriculum was not relevant to students' lives, was too fragmented, was often outdated, lacked rigor and conceptual unity, and was often presented as isolated bits and pieces of information to be memorized without developing a sense of the relationships between broader ideas (Bybee and DeBoer 1994).

In response to Sputnik, the federal government committed millions of tax dollars to the National Science Foundation (NSF) and other agencies to develop curriculum projects that were unique to all levels of science education. Programs were offered to update and enhance science teachers' content knowledge. Some programs were designed to familiarize teachers with the content and methods of a specific curriculum project; other sessions focused on training teachers to implement a particular innovative project. Unfortunately, an overwhelming amount of money was spent on developing new programs rather than on training teachers to use and implement the new projects in individual science classrooms. Even though these new curriculum projects combined strong science content, a view of science as inquiry, and innovative instructional approaches, only a small percentage of teachers received adequate training to effectively implement the new projects.

Nevertheless, several features of these early reform efforts had a positive influence on the science curriculum of the 1960s and 1970s. According to Quick (1978), the early science programs updated subject matter content to more adequately reflect the state of the scientific discipline, organized content around fewer topics that are central to understanding the discipline, and used an activity-oriented approach to science education. In addition, the early programs were more rigorous than their predecessors. Although the early science programs had an important impact on the science curriculum of the 1960s and 1970s, it was perhaps the hands-on and activity-oriented approach of the NSF-funded programs that most influenced science education during this era (Bybee 1997).

As the 1970s came to a close, science educators had a plethora of curricular materials and ideas from which to choose. Hundreds of NSF-funded projects such as the Elementary School Science Project, Earth Science Curricular Project, CHEM-Bond, Biological Science Curricular Project, and Physical Science Curricular Project had produced a wealth of information that helped develop a new perspective on science teaching and learning. Nonetheless, students were not performing well on standardized achievement tests and they were not pursuing degrees and careers in science and engineering. Science education in this country seemed to be failing, and the public asked why the investment of tax dollars and best efforts of the scientific community did not result in improvement of the nation's science education program.

By the early 1980s, a perceived crisis in American education loomed on the horizon as reflected in the document A Nation at Risk (National Commission on Excellence in Education, NCEE 1983). This publication provided numerous recommendations for improving teaching and learning. During this time several professional subject area organizations were examining their disciplines. Emanating from these concerns during the 1980s, a serious reform effort in science education began. The best indicators of what educators have learned concerning science, mathematics, engineering, and technology education are outlined in documents such as Curriculum and Evaluation Standards for School Mathematics (National Council of Teachers of Mathematics, NCTM 1989); Science for All Americans (American Association for the Advancement of Science, AAAS 1989); Scope, Sequence, and Coordination of Secondary School Science (National Science Teachers Association, NSTA 1992); and National Science Education Standards (National Research Council, NRC 1996). Other organizations and agencies such as the National Center for Improving Science Education (1991), the National Commission on Mathematics and Science Teaching for the 21st Century (2000), and the American Council on Education (1999) have outlined their own recommendations and standards for improving science education. Taken together, these documents and research studies paint a picture of how current thinking in science education is both similar to and different from the ideas promoted by the NSF-supported science programs following Sputnik.

How Current Reform Differs from Earlier Reform Efforts

A theme of many of the previously mentioned documents was that past science reforms had failed to consider the importance of developmentally-appropriate activities that mirror real-world problems and situations. The new science standards placed more emphasis on the interrelationships across scientific disciplines and on integrating mathematics and technology with science. There was a solid emphasis on the personal and social relevance of the subjects, not just on abstract structures of the disciplines as organized and practiced by scientists (DeBoer 1997).

A major thrust of the post-Sputnik science agenda was aimed at elevating the perceived need to increase the pool of potential scientists. As a result, many science projects developed during that period targeted students who were academically gifted. By contrast, today's science reform strongly advocates providing a strong science program for all students. In contemporary science reform, excellence and equity are inseparable (AAAS 1998).

Focus on National Science Education Standards

According to National Science Education Standards, "Learning science is something that students do, not something that is done to them. In learning science, students describe objects and events, ask questions, acquire knowledge, construct explanations of natural phenomena, test those explanations in many different ways, and communicate their ideas to others" (NRC 1996, 20). This approach is consistent with constructivist pedagogy, which considers students active constructors rather than passive receivers of knowledge who bring their own view of the world into the classroom.

Accordingly, students are encouraged to be actively engaged in the learning process. An important role of the teacher in this process is to create learning environments that allow students to engage in problem solving and higher-order thinking so that they can integrate information and build on their own understanding of a particular topic or idea (Anderson 1998). As constructivist approaches have gained support, additional means of assessing students have gained prominence. Traditional assessment techniques such as multiple-choice and paper-and-pencil tests have effectively evaluated student knowledge of facts and concepts. However, an inquiry-oriented approach to teaching science has led to interest in developing a variety of assessment strategies such as portfolios, projects, work samples, and lab practicals to aid teachers in planning instruction and making classroom decisions.

The science standards help to define what it means for students to be scientifically literate. The standards provide criteria for judgments regarding all elements of the educational system, including teaching, professional development, assessment, and content. They also promote high standards for all students, depth rather than breadth of content coverage, and active engagement of students in the subject area. However, another important lesson learned from the science reform efforts of the 1960s, 1970s, and 1980s is that reform strategies do not occur in isolation and changing any one component is insufficient to bring about real reform (Raizen 1998). Current science education reform promotes the idea that all parts of the system must be in place to meet the goals as outlined in the standards documents.

The Isolated Classroom Versus Systemic Change: Implications for the School Principal

The teaching and learning of science are generally believed to take place in the context of an individual teacher working with a group of students in an individual classroom. Teaching, however, is not a solitary activity. There are many dynamics that affect the teaching and learning of science in a school or even in a single classroom. Having a clear set of standards for classroom practice is an important part of the equation, but real, long-lasting change involves a great deal more. There are the matters of teacher time, structural arrangements, cultural norms, and professional development to support teacher learning, all of which affect student learning, either directly or indirectly. The principal who recognizes the crucial importance of school- and district-based initiatives can use his or her influence, power, and authority to help shape these variables as outlined in figure 1. According to Smith and O'Day (1991), systemic approaches to science reform focus on three main ideas: promoting high standards for all students, creating policies that support effective instruction for successful students, and aligning governance systems to achieve stated goals.

Examining the Principal's Role in Science Education Reform

The instructional management role of the principal is complex, and many issues shape and constrain leadership by the principal; however, current reform initiatives in science education compel the secondary school principal to think of new ways to accomplish standards-based reform in his or her school. Changes in educational practices seldom are implemented quickly, and pervasive and permanent changes are rarely imposed from without. Successful programs involve many participants playing different roles, including teachers, science coordinators, and administrators (NRC 1996). Indeed, nearly every major document advocating science education reform in recent years has focused on the important role of the principal along with teachers and other players in promoting effective school science programs (AAAS

1993, 1998; NSF 1996).

The role of the principal in today's school is ideally one of supporting change. Change efforts are more likely to germinate and take root in a school when principals provide effective leadership through collegiality and communication, allow risk taking and failure along the path toward success, and reward innovation (Sparks and Loucks-Horsley 1990). Principals can augment change by setting aside time for teachers to network, share ideas and concerns, provide feedback, and constantly revisit and revise goals (Showers and Joyce 1996). As facilitators of change, the principal and teacher working side by side are able to define and address needs better than each one working in isolation. The principal's support of an innovation and the subsequent degree of implementation are correlated (Fullan and Pomfret 1997).

Leadership is shared and broadly exercised when principals and teachers work together to achieve commonly accepted and agreed-upon goals. When principals are actively engaged in facilitating standards-based science programs with teachers from the beginning, both teachers and administrators are more likely to take ownership of the innovation.

Implementing standards-based science may increase equipment and personnel needs and therefore have a direct impact on the school budget. It is the principal's responsibility to provide those structural changes needed to support the science program. Meaningful support of the school administrator stems from a clear understanding of the science program, including the program's philosophy, goals, content, pedagogy, and instructional equipment. Principals should understand how core ideas underlying current reform efforts differ from earlier attempts to improve science programs and why the new science standards and goals should be adopted and implemented. Knowing the resource requirements for appropriate instructional materials that support a coherent presentation of science concepts is essential.

Observing the Standards-Based Science Classroom

What should the principal look for when observing a science classroom? Obviously, teachers use various approaches to teach science. There is more than one way in which students learn science; there is more than one way to teach it. However, current concepts of science learning differ from those of the past. The science standards set clear expectations for student learning. Students should have an integrated understanding of the concepts and processes of science. Students should have a firm grasp of the nature and structure of the discipline. Traditional instructional practices have not always been successful in delivering these student outcomes. Current learning theory suggests that the classroom should be more student centered and less teacher centered than in the traditional instructional models. Research (Rhoton and Bowers 2001; Shymansky et al. 1997; Smith and Neal 1991) has revealed teaching strategies that support the goals and instructional practices outlined in National Science Education Standards. Such practices include the following:

- Using inquiry and problem-solving lessons, active student participation, and frequent teacher-student interactions
- Creating learning environments in which risk is supported and open discussion and use of student ideas takes place
- Implementing lessons that provide an accurate portrayal of content knowledge, the nature of science, and the structure of the discipline
- Selecting and adapting curriculum to meet the needs of all students
- Implementing learning environments that challenge students' misconceptions
- Using discrepant events to facilitate student learning

- Using a variety of techniques to assess student learning.

Perhaps there is no greater challenge facing science education reformers than helping teachers move from current practices to the strategies described here. The importance of teachers being well grounded in both science content and pedagogical skills cannot be overemphasized; teachers who demonstrate content and pedagogy knowledge are better prepared to create effective learning environments that allow students to engage in the excitement of science and move to an inquiry-based science classroom. A teacher-centered classroom is typically dominated by lecture, overreliance on the textbook, student memorization of isolated facts, and teacher-directed small-group learning. As advocated in the national science standards, an inquiry approach goes beyond "science as process" to focus on students learning to use the process, along with substantial scientific knowledge (NRC 1996). Table 1 presents the changes in science instruction as supported by the standards.

Engaging in inquiry helps students to understand scientific concepts; develop an appreciation of how scientists know what they know; understand the nature of science; develop skills to become independent thinkers about the natural world; and develop the skills, abilities, and attitudes associated with science. Given this scenario, professional development plays an increasingly important role in helping teachers develop their knowledge and beliefs about content and pegagogy.

Professional Development

Teachers are the crucial link between the curriculum and students; therefore, professional development is an essential element in developing teacher leadership skills. Professional development prepares the teacher to take a more informed leadership role in the implementation or improvement of the instructional program, motivated by the desire to improve student learning. School administrators should create an environment that supports teacher growth and instructional improvement. Teachers must have the opportunity to rethink their notion about the nature of science, be willing to develop new views about how students learn, construct new classroom learning environments, and create new expectations about student outcomes (Nelson and Hammerman 1996).

Although educators recognize the importance of new training models for improving science teaching practices, professional development strategies remain largely unchanged, detached from the realities of the classroom, and ineffective for promoting long-term change. Professional development sessions continue to be dominated by stand-alone workshops and short after-school meetings. Moreover, teachers have typically perceived inservice education programs as ineffective, poorly planned, and lacking in relevance to their instructional activities (Sparks and Loucks-Horsley 1990).

What the Principal Should Know About Professional Development

Effective principals play an important role in promoting the schoolwide science program by supporting professional development programs that allow teachers to expand their knowledge about the instructional and programmatic changes within the school, including improved skills and knowledge in teaching, learning, and curriculum. Further, science teachers need teamwork skills to be able to influence policies and practices within the school and district. For example, science teachers can work closely with principals and other administrators who are formally responsible for decisions about expenditures, resources, the allocation of time for professional development, and curricular changes.

The challenge for principals and teachers is to promote and design professional development programs that encourage the effective teaching practices addressed previously. The knowledge base continues to grow as a range of professional development strategies are used and tested (Loucks-Horsley et al. 1998); current literature identifies particular approaches that may result in more effective professional development programs. The research summarized by Rhoton et al. (1999) identifies such approaches:

- Professional development addresses issues of concern recognized by teachers themselves. One-size-fits-all professional development does not, in fact, meet the needs of all teachers. Teachers at different stages in their teaching career will require professional development to meet their specific needs.
- Professional development is connected to classroom practices. It should address issues and immediate concerns relevant to the classroom, such as teaching practices and working with differing ability and motivation groups.
- Professional development includes sustained support and takes place over an extended period of time. Lasting change usually occurs only when teachers are given the sufficient time, resources, and training to carry out the innovation.
- Professional development helps teachers learn science content in new ways. These experiences allow teachers to genuinely address change and renewal and reach beyond the "make and take" workshop and the "idea swap" session to more global, theoretical conversations that focus on teachers' understanding of the processes of science teaching and learning and of the students they teach.
- Professional development challenges pedagogical beliefs and practices. Teacher perceptions about student learning, confidence in subject matter understanding, and pedagogical beliefs will affect student learning.
- Professional development promotes incremental change. Although large-scale change may be needed, incremental change allows teachers to retain existing effective practices.
- Professional development encourages collaboration. Teachers consistently rank professional development activities that take place close to the working environment as the most important, whereas workshops by outside experts are ranked as the least important. Change usually occurs in small pockets within the school.

When school leaders implement the preceding approaches to build the professional development infrastructure, the school's culture and climate will be more conducive to practices that allow teachers to interact with their professional peers, to enhance student learning, and to meet schoolwide and systemwide goals. However, school administrators must commit to creating a professional development climate that nurtures lively learning environments for communities of teachers.

Leadership Behaviors: Implications for the Principal

In maintaining an effective school environment conducive to developing and sustaining a viable science program, the principal has to juggle a variety of roles. The principal's role has evolved from direct instructional leadership to orchestrating decision making through teams of teachers, science coordinators, and other stakeholders in the science program. In addition, principals are being called upon to make decisions they have never made before. Changing educational technologies and their implications for student learning, shifting political climate, and changing student populations influence the design of science programs. To cope with these complexities, the science leader will have to adapt his or her actions and decisions in response to a changing world.

Principals and teacher leaders need to know how to help science teachers develop and maintain an effective standards-based science classroom. The research synthesized by Druckman, Singer, and Van Cott (1997) and Darling-Hammond and McLaughlin (1995) suggests several behaviors of an effective leader, all of which are relevant to maintaining a standards-based science program:

- Uses skills to clarify roles and objectives, define job responsibilities, assign tasks, set performance goals, and provide support on how to accomplish the task
- Uses a variety of behaviors to show acceptance of and concern for subordinates' needs and feelings (supportive leadership increases the satisfaction and productivity of the people involved)
- Creates flexible and practical strategies to accomplish the task
- Stimulates teachers to think in new ways and question old assumptions and beliefs that may be no longer valid
- Uses feedback to monitor progress on how well goals and objectives are being met (in this way growth and change is documented and reported to teachers)
- Uses tangible awards or praise for achievement and contributions to the group goals (this type of reward is more likely to be effective when it is based on observable contributions and not used to discriminate or manipulate)
- Is willing to share information with other in order to achieve shared goals
- Develops and maintains networks of people, resources, and information and knows how these services can be delivered to optimize program needs.

Summary

Although teachers are integral to the science education reform process, they should not be placed in a position of carrying the entire load of science education reform. Science teachers will need to work within the context of policies that are "supportive of good science teaching" (NRC 1996, 27). The principal plays a role in the process of developing and sustaining healthy science education programs and practices by supporting professional development. In this way, the principal can create opportunities for teachers to become actively engaged in curriculum development and assessment as well as in setting standards and evaluating practices—processes that allow teachers to take more control of teaching practices. To a large extent, the desired changes in science education have not been fully realized because they have not been totally effective in influencing the classroom. Moreover, change that is championed by individual teachers and implemented in individual classrooms has a greater chance for success (Sprinthall, Reiman, and Thies-Sprinthall 1996). Policies calling for change in practice have not always aligned with teachers' needs. Teachers have also lacked the resources to deliver an effective science education program. However, resources and funding are not enough; both teachers and administrators must play leadership roles in the creation and maintenance of an effective standards-based science education program.

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