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Promoting Inquiry-Based Science Instruction: The Validation of the Science Teacher Inquiry Rubric (STIR)

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The National Science Education Standards recognize that inquiry-based instruction holds significant promise for developing scientifically literate students. The Science Teacher Inquiry Rubric (STIR) was developed based upon the National Science Education Standards' essential features of inquiry instruction (NRC, 2000). A pilot study using a purposive sample of ten science teachers was conducted to establish the rubric as both an observation tool and a self-reflection instrument. While the overall correlation of the instrument (r=.58) does not support its use as a self-assessment instrument, a perfect correlation between two raters (r=1) established the STIR as an effective observation tool. Additionally, the validation of the instrument provided various insights into the teaching of inquiry in science classrooms.

Introduction

Scientific literacy has become a critical issue for all citizens of the United States. To gain the status of lifelong literacy, it is no longer enough to have reading and writing skills. Science and technology have become so important in modern life that the ability of citizens to understand and use science can spell the difference between prosperity and decline, between security and vulnerability (National Research Council [NRC], 1996). Helping students to develop into scientifically literate citizens is a perennial objective noted in recent science education reform initiatives (American Association for the Advancement of Science [AAAS], 1990, 1993; NRC, 1996; National Science Teachers Association, 1982). Scientific literacy is often recognized as the knowledge of significant science subject matter, the ability to apply that knowledge and understandings in everyday situations, and an understanding of the characteristics of science and its interactions with society and personal life. Scientific literacy as defined by AAAS's (1990) *Project 2061* addresses the understandings and habits of mind that enable people to grasp what those enterprises are up to, to make some sense of how the natural and designed worlds work, to think critically and independently, and to recognize and weigh alternative explanations of events. According to the National Science Education Standards (NRC, 1996) [henceforth *Standards*], the development of scientifically literate students involves providing classroom learners with a science curriculum that teaches science as a body of knowledge and as a way of knowing about the natural world based on evidence from observation and experimentation.

Implementing a standards-based science curriculum is a formidable challenge for elementary teachers, most of whom are not science specialists. Furthermore, science, as a separate subject, is generally given a smaller amount of instruction time in comparison to other subjects. A survey conducted by Fulp (2002) showed that "grade K-5 self-contained classes spent an average of 25 minutes each day in science instruction, compared to 114 minutes of reading/language arts, 53 minutes in mathematics and 23 minutes in social studies" (p. 11). In addition to the limited instructional time spent on science, there are other factors that influence science teaching in elementary school classrooms:

- Teacher perception of the importance of science in an elementary curriculum
- Limited content knowledge held by elementary teachers
- Limited experience through formal coursework in participating in and presenting hands-on science
- Lack of administrative support for the teaching of science (Abell & Roth, 1992)

Science educators have long recognized that teaching science is a complex subject. Successful science teachers strive to help their students understand and apply scientific concepts, participate in scientific inquiry, and understand the nature of science. Furthermore, the *Standards* call for a pedagogical shift from a teacher-centered to a student-centered instructional paradigm. Teacher-centered instructional strategies such as large-group instruction, recitation, drill, and opportunities for independent practice are successful for tasks that demand rote memorization; they have not been shown to be effective for teaching higher-order thinking and problem solving (Anderson, 1997). The *Standards* advocate a change in emphasis from students memorizing facts and terminology to students investigating nature through active learning that will result in making science accessible to all students, which will then lead to a more scientifically literate citizenry.

Inquiry-Based Teaching and Learning

Science educators have long recommended that learning with inquiry be placed at the core of science instruction to actively engage learners in the processes of science (AAAS, 1993; DeBoer, 1991; NRC, 1996). As early as the 1960s, Schwab (1962) suggested that the teaching of science inquiry be a priority in science education, that teachers teach students both to conduct investigations in inquiry and to view science itself as a process of inquiry. More recently, the *Standards* include science inquiry as one of eight categories in their content standards.

One of the NRC's reasons for advocating inquiry mirrors the rationales offered by Schwab (1962): Instruction in inquiry promotes student understanding of the nature of science. Currently, the *Standards* present a description of inquiry instruction that includes the nature of science as well as "science as a process," in which students learn skills such as observation, inference, and experimentation. According to the *Standards*,

> Inquiry teaching requires that students combine processes and scientific knowledge as they use scientific reasoning and critical thinking to develop their

> understanding of science. Engaging students in activities of and discussions about scientific inquiry should help them to develop an understanding of scientific concepts; an appreciation of "how we know" what we know in science; understanding of the nature of science; skills necessary to become independent inquirers about the natural world; and the dispositions to use the skills, abilities, and attitudes associated with science. (p. 6)

The inquiry process, however, is a multifaceted approach and its emphasis has important pedagogical implications for science educators. Inquiry is a complex process that encompasses many different dimensions, including fostering inquisitiveness (a habit of mind) and providing teaching strategies for motivating learning (Minstrell & van Zee, 2000). Scientific inquiry refers to "the diverse ways in which scientists study the natural world and propose explanations based on the evidence derived from their work. Inquiry also refers to the activities of students in which they develop knowledge and understanding of scientific ideas, as well as an understanding of how scientists study the natural world" (NRC, 2000, p. 23). Teaching students science as inquiry (AAAS, 1993) involves engaging them in the kinds of cognitive processes used by scientists when asking questions, making hypotheses, designing investigations, grappling with data, drawing inferences, redesigning investigations, and building as well as revising theories. Whereas the *Standards* offer several examples of inquiry-based instruction, they do not provide specific prescriptions for how to conduct inquiry in the classroom.

The *Standards* do, however, define five essential features of inquiry-based teaching:

1. Learners are engaged by scientifically oriented questions.
2. Learners give priority to evidence, which allows them to develop and evaluate explanations that address scientifically oriented questions.
3. Learners formulate explanations from evidence to address scientifically oriented questions.
4. Learners evaluate their explanations in light of alternate explanations, particularly those reflecting scientific understanding.
5. Learners communicate and justify their proposed explanations. (NRC, 2000, p. 14)

These features may be incorporated into the science classroom in a highly structured format, with teachers and/or materials that direct students towards known outcomes, or they may take the form of open-ended investigations that are learner-centered. Current teaching and learning techniques that use inquiry include engaging students with authentic questions for local and global investigations (Crawford, 2000; Feldman, Konold, & Coulter, 2000), project-based science instruction (Krajcik, Blumenfeld, Marx, & Soloway, 1994; Krajcik, Czerniak, & Berger, 1999), or role-playing debate simulations (Bodzin & Park, 1999). These techniques seek to engage students with meaningful questions about everyday experiences, emphasize using a method of investigation to evaluate some form of evidence critically, and engage learners in a social discourse to promote the knowledge-construction process. The proponents of such inquiry-based approaches argue that they provide learners with the opportunity to learn scientific practices by actually engaging in them. In addition, implementing inquiry-based curricula may result in higher average student achievement, making it a powerful vehicle for students to learn scientific content (Schneider, Krajcik, Marx & Soloway, 2002).

Implementing inquiry-based instruction, particularly in the elementary classroom, demands a significant shift in what teachers typically do in a science lesson. Orchestrating this kind of nontraditional, inquiry-based instruction is complex, and many teachers have not embraced the essence of this mode of learning in which students begin to think scientifically (Fradd & Lee, 1999). It is important, therefore, to provide teachers with professional development and other kinds of support to implement the essential features of inquiry-based instruction into the classroom.

Loucks-Horsley (1987) recognized the importance of professional development in assuring that teachers had the appropriate skills, knowledge, and instructional strategies to help students achieve science standards. The challenge of professional development for teachers of science is to create optimal collaborative learning situations in which the best sources of expertise are linked with the experiences and current needs of the teachers: "Whenever possible, the context for learning to teach science should involve actual students, real student work, and outstanding curriculum materials. Trial and error in teaching situations, continual thoughtful reflection, interaction with peers, and much repetition of teaching science content combine to develop the kind of integrated understanding that characterizes expert teachers of science" (NRC, 2000, p. 9).

There have also been attempts to develop inquiry instruments for teachers to use in these professional development settings. These instruments have focused on various aspects of constructivist learning models of science instruction (Burry-Stock, 1995; Yager, 1991). Another group used the *Standards* to develop rubrics to assist in identifying the characteristics of classroom instruction that are anchored in inquiry (Council of State Science Supervisors [CSSS], 2002). While these instruments help teachers to see the "big picture" of inquiry-based instruction, they portray this type of pedagogy as a daunting task, in some cases, specifying 20 or more descriptors.

The Science Teacher Inquiry Rubric (STIR)

To assist teachers in understanding and implementing inquiry-based science instruction into their classrooms in a comprehensive, yet manageable way, a Science Teacher Inquiry Rubric (STIR) was developed (see Figure 1). This instrument was developed to serve as a self-assessment tool for elementary school teachers to understand how they implement the essential features of inquiry into their classroom instruction.

The STIR was derived from the Web-Based Inquiry for Learning Science [WBI] Instrument (Bodzin & Cates, 2002). The WBI instrument was designed to identify and classify Web-based inquiry activities for each of the five essential features of classroom inquiry and their variations based on the amount of learner self-direction and direction from materials (NRC, 2000). This continuum of essential features of inquiry instruction continues to provide the framework for the development of a rubric to be used as a teacher observation tool. Many of the indicators in each cell serve as descriptions of teacher behaviors. Additionally, this continuum describes the instruction of classroom learning environments that ranges from teacher-centered instruction on one end to student-centered learning on the other end.

Figure 1

Science Teacher Inquiry Rubric (STIR)

Directions: Reflect on the science lesson that you taught today. In your reflection, consider each of the following categories and the six statements on the left, written in bold. After looking at each bold statement, assess today's science instruction based on the categories delineated for statement. Place one "X" in the corresponding cell for each bold-faced statement. If there is no evidence of one of the statements in today's lesson, place a slash through the bold-faced statement. When you are finished, you should have six total responses.

Learner Centered ⟷ Teacher Centered

Learners are engaged by scientifically oriented questions.					
Teacher provides an opportunity for learners to engage with a scientifically oriented question.	Learner is prompted to formulate own questions or hypothesis to be tested. ☐	Teacher suggests topic areas or provides samples to help learners formulate own questions or hypothesis. ☐	Teacher offers learners lists of questions or hypotheses from which to select. ☐	Teacher provides learners with specific stated (or implied) questions or hypotheses to be investigated. ☐	No evidence observed. ☐
Learners give priority to evidence, which allows them to develop and evaluate explanations that address scientifically oriented questions.					
Teacher engages learners in planning investigations to gather evidence in response to questions.	Learners develop procedures and protocols to independently plan and conduct a full investigation. ☐	Teacher encourages learners to plan and conduct a full investigation, providing support and scaffolding with making decisions. ☐	Teacher provides guidelines for learners to plan and conduct part of an investigation. Some choices are made by the learners. ☐	Teacher provides the procedures and protocols for the students to conduct the investigation. ☐	No evidence observed. ☐
Teacher helps learners give priority to evidence which allows them to draw conclusions and/or develop and evaluate explanations that address scientifically oriented questions.	Learners determine what constitutes evidence and develop procedures and protocols for gathering and analyzing relevant data (as appropriate). ☐	Teacher directs learners to collect certain data or only provides portion of needed data. Often provides protocols for data collection. ☐	Teacher provides data and asks learners to analyze. ☐	Teacher provides data and gives specific direction on how data is to be analyzed. ☐	No evidence observed. ☐

Figure 1 (cont.)
Science Teacher Inquiry Rubric (STIR) (continued)

Learners formulate explanations and conclusions from evidence to address scientifically oriented questions.					
Learners formulate conclusions and/or explanations from evidence to address scientifically oriented questions.	Learners are prompted to analyze evidence (often in the form of data) and formulate their own conclusions/explanations. ☐	Teacher prompts learners to think about how analyzed evidence leads to conclusions/explanations, but does not cite specific evidence. ☐	Teacher directs learners' attention (often through questions) to specific pieces of analyzed evidence (often in the form of data) to draw conclusions and/or formulate explanations. ☐	Teacher directs learners' attention (often through questions) to specific pieces of analyzed evidence (often in the form of data) to lead learners to predetermined correct conclusions/explanations (verification). ☐	No evidence observed. ☐
Learners evaluate the explanations in light of alternative explanations, particularly those reflecting scientific understanding.					
Learners evaluate their conclusions and/or explanations in light of alternative conclusions/explanations, particularly those reflecting scientific understanding.	Learner is prompted to examine other resources and make connections and/or explanations independently. ☐	Teacher provides resources to relevant scientific knowledge that may help identify alternative conclusions and/or explanations. Teacher may or may not direct learners to examine these resources, however. ☐	Teacher does not provide resources to relevant scientific knowledge to help learners formulate alternative conclusions and/or explanations. Instead, the teacher identifies related scientific knowledge that could lead to such alternatives, or suggests possible connections to such alternatives. ☐	Teacher explicitly states specific connections to alternative conclusions and/or explanations, but does not provide resources. ☐	No evidence observed. ☐
Learners communicate and justify their proposed explanations.					
Learners communicate and justify their proposed conclusions and/or explanations.	Learners specify content and layout to be used to communicate and justify their conclusions and explanations. ☐	Teacher talks about how to improve communication, but does not suggest content or layout. ☐	Teacher provides possible content to include and/or layout that might be used. ☐	Teacher specifies content and/or layout to be used. ☐	No evidence observed. ☐

While each of these essential features may vary in the scope of their implementation, science instruction that makes full use of inquiry embeds all five of these features. As described in *Inquiry and the National Science Education Standards* (NRC, 2000), each of these features provides an important aspect of instruction to the inquiry process. The STIR was designed to translate each of these features into descriptors that capture the essence of the feature; a format mirroring the WBI instrument. While a complete and thorough explanation of each essential feature is not included on the rubric, it gives teachers a springboard definition for beginning the inquiry process in the classroom. For example, the STIR supports the use and analysis of data in the formulation of explanations. Yet, conclusions and/or explanations should be more than simple data analysis and reporting. Scientific explanations are based on reasoning: "They provide causes for effects and establish relationships based on evidence and logical argument" (p. 26).

The language of the STIR, while simplistic, was designed for a wide range of audiences. It was primarily intended to accompany inquiry-based science professional development. Even so, teachers with a limited knowledge of the inquiry criteria can use the rubric to guide their instruction as seemed to be the case in the validation of the STIR.

The content of the STIR was validated using the Delphi technique (North & Pyke, 1969). The Delphi technique is a "set of procedures for eliciting the opinion of a group of people, usually experts, in such a way as to reduce the undesirable aspects of group interaction" (p. 75). In this process, three science educators with expertise in teaching and learning with inquiry reviewed and evaluated the rubric for accuracy, importance, and validity of the content. They provided feedback and suggestions, and these were incorporated into the instrument. All three unanimously agreed on the content, providing content validity to the instrument.

Methodology

The STIR was piloted with a purposive sample of five elementary-certified middle school teachers and five secondary science-certified senior high school teachers in a suburban school district. Two observers rated each teacher during their inquiry instruction. The purpose of selecting this type of sample was to ensure variability on this construct.

The researcher randomly selected five middle school and five high school teachers. The teachers were contacted via e-mail to solicit their participation in the observation of an inquiry lesson.

The researcher and the district's K-12 Supervisor of Staff Development served as the raters for the observations. It is important to note that both the researcher and the Supervisor of Staff Development have considerable experience in the observation of teachers. The researcher has close to five years experience in the supervision of teachers while the Supervisor of Staff Development has approximately 25 years. Both observers have spent their careers as elementary teachers and principals. Neither observer has had any specialized training in inquiry-based science instruction, however.

After the participants agreed to the observation, one rater contacted each teacher to determine a mutual observation time. The teachers were asked to plan their usual science lesson; however, in order to allay any anxiety regarding the observation, the STIR was shared with each teacher via e-mail. The teachers were not asked to deliver an inquiry-based lesson, but it is important to note they were aware that the focus of the observations would be characteristics of inquiry-based instruction. The observers entered each classroom with no prior knowledge on the content of the science lessons. The raters observed each lesson and rated it according to each essential feature of inquiry on the instrument. The teacher did the same at the conclusion of the lesson. After all ten observations were completed, a comparison of teacher self-assessments to the rater scores was conducted to establish the reliability of the instruments as a self-assessment tool.

Results

During the first two lessons, the observers discussed the instructional qualities of each lesson as they watched. Subsequently, they completed the rubric as they talked through each category and indicator. These two sessions, in essence, provided the observers with a training session, enabling them to recognize, discuss, and solidify their understanding of the language of the STIR in relation to the instruction occurring in the classroom.

The remainder of the observations commenced with a brief dialogue between the two observers focused on the teacher's instructional behaviors. The STIR analysis was completed independently and then shared between the two observers. They matched their placements with 100% agreement on each row.

In addition to the observers' rating, the classroom teacher used the STIR to self-assess his or her instruction at the close of the lesson, returning the rubric to the observers later during the day. It should be noted that some lessons did not contain each essential feature of inquiry.

An analysis was conducted by matching observer 1's rating on each row of the rubric to observer 2's rating on each row thereby establishing a correlational relationship of the observation to the rubric. The resulting correlation of observer to observer for each row placement on the STIR was strong (r=1), establishing the instrument as a validated observation tool for inquiry-based science instruction. The opportunity to discuss the instruction of a few lessons, specifically the first two, provided a vehicle for the observers to establish firmly their understanding of the descriptors in each cell as they related to the instruction that was occurring in the classroom. In addition, the observers' experiences in the area of teacher observation probably contributed to the strong reliability findings between the two observers.

A second correlational analysis was conducted of the classroom teacher's rating and the observers' ratings on each row of the STIR. This analysis was intended to establish the STIR as a self-assessment instrument for teachers implementing inquiry in their science classrooms. The correlation (r) of the matches (N=60) between the observers and teachers was .58. This seems to indicate that the STIR may not constitute a reliable self-assessment tool for teachers wishing to reflect on their inquiry-instruction.

Table 1 displays the percentage of matches and adjacent matches between observers and teachers on the STIR for each essential feature of inquiry. As the table shows, the placement match of teachers and observers in the first three instruction descriptors on the STIR indicates a strong correlation. The percentages of the adjacent placement matches combined with the exact matches between observers and teachers were 80%, 90%, and 100%, respectively. The last three instruction descriptors did not correlate as strongly as the first three, however. While the combined matches and adjacent matches of the observers and teachers in descriptor #4 and #6 were 90% and 80%, respectively, the data certainly does not demonstrate the strength in reliability as the first three descriptors.

Table 1
Percentage of Matches and Adjacent Matches for Each STIR Feature

Essential Features of Inquiry-Based Instruction Descriptors	Percent Match Between Observers and Teacher	Percent of Adjacent Matches Between the Observers and Teacher
#1 Teacher provides an opportunity for learners to engage with a scientifically oriented question.	70%	10%
#2 Teacher engages learners in planning investigations to gather evidence in response to questions.	70%	20%
#3 Teacher helps learners give priority to evidence that allows them to draw conclusions and/or develop and evaluate explanations that address scientifically oriented questions.	80%	20%
#4 Learners formulate conclusions and/or explanations from evidence to address scientifically oriented questions.	50%	40%
#5 Learners evaluate their conclusions and/or explanations in light of alternative conclusions/explanations, particularly those reflecting scientific understanding.	40%	10%
#6 Learners communicate and justify their proposed conclusions and/or explanations.	40%	40%

There was a significant lack of correlation of the combined matches in descriptor #5, raising an interesting discussion regarding this essential feature of inquiry. Not only was there a low correlation of matches between the raters and the observers, most of the matches occurred in the "not observable" category on the STIR. Additionally, this feature on the STIR seemed to display the most "scatter"—that is, the teacher and observers' description of the inquiry instruction was, in many cases, placed in non-adjacent cells. This suggests that this feature of inquiry is not as widely understood or, perhaps, as widely implemented as the others.

Conclusion

"The meaning of the term inquiry-based instruction when applied to classroom practice often becomes muddled, and the integrity of the inquiry-based instruction can be lost" (Crawford, 2000). Teachers need tools that help them to explore, design and reflect on their science instruction practices, particularly as they relate to student-centered, inquiry-based teaching.

The validation and reliability of the STIR clearly demonstrates its use and effectiveness as a teacher observation tool for supervisors, principals, or other change agents who wish to assess teachers' use of inquiry-based instruction in the classroom. Unfortunately, the STIR is not reliable enough to use as a self-assessment instrument by elementary school teachers teaching science. This finding is not surprising. While Koziol and Burns (1986) noted that focused teacher self-reports can gather reliable data on instructional practices, Newfield (1980) reported that only under certain conditions can teachers accurately report their own behavior. This raises the question of how widely understood and implemented is inquiry-based science instruction?

As the data from the science classroom observations suggests, there is evidence of inquiry-based instruction occurring in sampled classrooms, both teacher-directed and student-centered. In many cases, teachers were able to effectively assess where their instruction was placed on the continuum. We believe that the STIR has much potential to be used as a tool for teachers to assist them in gauging their inquiry-based classroom instructional strategies.

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