A Model for Extending Hands-On Science to be Inquiry-Based

Richard A. Huber
Watson School of Education
University of North Carolina - Wilmington
601 South College Road
Wilmington, NC 28403-3297
phone: 910-962-3561
fax: 910- 962-3988
e-mail: huberr@uncwil.edu

Christopher J. Moore
Saint Mary Catholic School
217 South Fourth Street
Wilmington, NC, 28401-3297
phone: 910-392-5594
e-mail: moorechr@bellsouth.net

Running Head: Extending Hands-On Science

Abstract

Many popular hands-on science activities, as traditionally implemented, fail to support inquiry-based science instruction, because the activities direct teachers to terminate lessons prematurely. This paper presents a model describing one approach for extending seemingly limited hands-on activities into full-inquiry science lessons. The strategy involves (a) discrepant events to engage students in direct inquiry; (b) teacher-supported brainstorming activities to facilitate students in planning investigations; (c) effective written job performance aids to provide structure and support; (d) requirements that students provide a product of their research, which usually includes a class presentation and a graph; and (e) class discussion and writing activities to facilitate students in reflecting on their activities and learning. The paper presents the model as a tool for facilitating science teachers' efforts to understand and implement the type of powerful, effective, and manageable inquiry-based science instruction called for in the National Science Education Standards.

With paternal compassion, the guru of classroom management, Harry Wong, urged educators to give novice teachers permission to engage their students in pedagogically questionable textbook- and worksheet-driven activities (Wong, 1998; Wong & Wong, 1998). Such activities, according to Wong, are relatively harmless, provided that teachers eventually move beyond them. Wong contended that novice teachers rely on textbooks and worksheets as their “primary survival tools,” and they should be given them permission to do what they must do to survive. Research on teaching practices suggests that Wong’s advice is well founded. Both novice and experienced teachers appear to rely heavily upon textbooks when making decisions about what and how to teach (Bellen, Bellen & Blank, 1992; Roth, Roffie, Lucas & Boutonné, 1997; Sánchez & Valcarcel, 1999). For example, in a survey of experienced and novice teachers in Spain, researchers Sánchez and Valcarcel, (1999) found almost all of the teachers (92%) used textbooks as a basic reference for their planning units. Textbooks served as the only guide for 33% of the teachers, and for most of the teachers (59%), textbooks served as the “basic pillar of the lesson” (p. 499).

Unfortunately, hands-on activities recommended by many science textbooks and worksheets are typically presented as step-by-step instructions. As discussed in the National Science Education Standards (National Research Council, 1996), when science teachers move beyond worksheets and step-by-step procedures in order to engage students in inquiry, they must constantly struggle to guide student inquiry toward curriculum goals. As pointed out by Crawford (1999), this ongoing demand for improvisation during teaching can be expected to create a substantial stumbling block for novice science teachers. Concerns about the substantial challenges inherent in implementing inquiry-based science instruction, as called for in the Standards, are substantial and well documented (Lederman & Niess, 1998), and it is hardly surprising that the challenges are especially problematic for novice teachers.

While worksheets or textbook-based instructions may eliminate some of the known stumbling blocks for novice teachers, they also lead to the elimination of true inquiry. Thus, supporting novice science teachers in making the transition from surviving hands-on instruction to mastering inquiry-based instruction presents a particularly difficult challenge.

Clearly, worksheet- and textbook-based hands-on activities provide valuable structure to novice teachers, who are in the process of learning how to teach science and manage classroom activities. However, there are at least three substantial risks associated with an over reliance on these tools. First, as pointed out by Wong, teachers may become complacent and start confusing survival with teaching. Rather than making the transition into mastery teaching, these teachers begin believing that the maintenance of a smooth classroom environment evidences effective teaching. Second, the presentation of science as a process of following step-by-step instructions and filling in blanks on worksheets promotes erroneous and impoverished concepts regarding the nature of science. The hands-on activities tend to be dominated by the mechanical tasks characteristic of the work of laboratory technicians rather than the creative endeavors of scientists. Finally, and perhaps most problematic, the written directives deprive students of ownership over their investigations. Rather than designing and carrying out investigations to answer their own questions, they are following instructions to find out if they guessed the correct answer to the teacher's questions.

Fortunately, however, many of these activities are not inherently flawed, but merely fall short of supporting full inquiry, because the activities direct teachers to terminate the explorations prematurely. Consequently, science instruction can be enhanced by providing novice science teachers with an integrated set of tools designed to provide an easy means of extending traditional hands-on activities into full-inquiry investigations. The National Science Education Standards define “full inquiry” as a process in which students (a) pose a productive question; (b) design an investigation directed toward answering that question; (c) carry-out the investigation, gathering the applicable data in the process; (d) interpret and document their findings; and (e) publish or present their findings in an open forum (National Research Council, 1996). The following model below is designed to move teachers from worksheets into this type of full-inquiry-based instruction.

In this paper a model is presented for facilitating student inquiry, which provides teachers with structure and students with guidance and a framework for conducting inquiry. The model represents one approach to bridging the gulf from mundane worksheet-driven, hands-on activities to true inquiry. While there is a reasonable body of literature suggesting that traditional methods might be extended into inquiry, much of that literature is of limited value to novice teachers, because it is too specific, too modest, or too ambitious in its approach.

A significant body of literature provides highly specific accounts of lessons, units, or projects in which teachers have extended a relatively traditional starting point into a more valuable inquiry-based instructional unit. Examples can be found on every topic, from lessons centered on paper airplanes (Greene, 1998) to lessons on environmental toxins (Crawford, 1998) to gardening projects (Eick, 1998). Case studies such as these may be of value to teachers planning on starting a teaching unit on a particular article-targeted topic from scratch. However, this literature base does not provide much in the way of useful guidance that can be readily generalized into broadly applicable strategies for converting existing textbook (or worksheet) materials into inquiry-based instructional explorations. Further, in contrast to the model proposed in this article, many of the activities described within this literature have decidedly long-term project or unit orientations. Consequently, implementation of the ideas proposed in this literature is apt to require a substantial commitment of instructional time and resources, both of which are likely to be in short supply for novice teachers.

Other literature describes broadly applicable strategies for extending science lessons toward inquiry, but fails to provide sufficient guidance on how to take a humble starting point all the way into a full-inquiry exploration. For example, in a paper directed toward helping novice teachers, Eick and Samford (1999) described an approach for extending traditional lecturing techniques. While the proposed approach is no doubt an improvement over straight lecturing, it falls far short of taking teachers and students into full-inquiry as described in the Standards. In fact, this particular extension toward inquiry attempts to do little more than take students beyond being passive recipients of a lecture to the point of the students being (hopefully) more engaged but still relatively passive recipients of a lecture followed by a teacher-conducted demonstration or the showing of a video.

Finally, some approaches to extending science instruction into the realm of inquiry appear to offer both (a) strategies and techniques that are reasonably broadly applicable and (b) reasonably ambitious goals. For example, the “Search, Solve, Create, and Share (SSCS)” model, created by researchers at the University of Iowa, uses strategies similar to those in the model proposed here (Abell, 1989; Pizzini, Shepardson & Abell, 1992; Pizzini, Abell & Shepardson, 1988).

The model proposed in this article contrasts with approaches such as the SSCS model in that it goes further toward making inquiry-based instruction practical and manageable for novice teachers. For example, both the SSCS model and the model proposed in this article recommend that teachers divide the class into cooperative groups. However, under the SSCS model, each group might be inquiring into a unique research question. Thus, the teacher could be put in the position of needing to manage a half dozen or more small groups, each of which is conducting an inquiry distinctly different from the others. In contrast, under the model proposed in this paper, each cooperative group within the class would be exploring different aspects of the same problem. Consequently, although the groups are not performing identical tasks, they are all using similar equipment in similar ways in order to try to answer similar and related questions. The resulting homogeneity and connections among the work practices of the groups leads to substantial simplification of logistics for the teacher--classroom management, materials management, and lesson pacing are all greatly simplified.

In summary, the model proposed in this article is intended to meet needs not met by other approaches by offering a coherent set of strategies that are (a) broadly applicable, (b) reasonably ambitious, and (c) designed to meet the particular needs of novice teachers. We have found this model useful for facilitating student inquiry at the middle school and upper elementary levels and for introducing teachers to inquiry. We have used the model successfully in grades 3 through 8 science classrooms and have successfully introduced both preservice and in-service teachers to the model.

In a pre- and posttest study of the effectiveness of an in-service teacher workshop, improvements were found in elementary grade students’ perceptions about the nature of science after their teachers received training in the use of strategies incorporated within the proposed model (Huber & Burton, 1995). More recently, the impact of an in-service teacher workshop was assessed that offered training in the proposed model, along with instruction on equity issues in science education. The results of pre- and post testing indicate that both teachers and students benefited from the training. Teachers responded favorably to the model and students of teachers who had been trained in the use of the model showed improvements in their attitudes towards science and in how they saw themselves as practitioners of science (Huber, Smith, & Shotsberger, in press).

Similar findings have been reported in assessments of the SSCS model, which, as noted above, is similar to the model proposed here. The SSCS model was found to increase the frequency and quality of inquiry-based teaching activities implemented by teachers who were trained in the SSCS approach (Abell, 1989; Pizzini, Shepardson, & Abell, 1992; Pizzini, Abell, & Shepardson, 1988).

A particular strength of the model proposed in this paper is that it provides teachers with means of constructing their own productive understandings of inquiry as they make the transition from textbook- and worksheet-based instruction to inquiry-based instruction. As teachers practice and internalize the component structures incorporated within the model, they are more quickly making the transition from merely surviving the delivery of hands-on science instruction to mastering inquiry-based instruction.

This type of constructivist hands-on approach to supporting the professional development of science teachers is highly consistent with the National Science Education Standards positions on the professional development of science teachers. Specifically, the Standards call for teachers to be supported in implementing inquiry-based science instruction through professional development opportunities that (a) are themselves inquiry-based; (b) whenever possible occur within the contexts where the teachers' understandings will be used; and (c) support teachers as intellectual reflective practitioners who are sources of change, rather than as technicians who are targets of change (National Research Council, 1996). The strategy proposed in this article supports teachers toward these ends.

A Model for Extending Traditional hands-on Instruction Into Hands-On Inquiry

Selecting an Activity

An ideal activity for hands-on, inquiry-based instruction focuses on the science content students are learning (Deal, 1994; National Research Council, 1996) and can be introduced with a counter-intuitive observation or “discrepant event.” When used in this manner, discrepant events not only capture students’ attention and stimulate interest, but also create Piagetian cognitive dissonance, which motivates students to challenge their existing mental constructs and misconceptions (Edwards, 1997; Elstgeest, 1985; Martin, 2000; Liem, 1987; Science Media Group, 1995; Chiappetta, 1997). A good activity for a starting point should also offer promising opportunities for productive exploration within the constraints of the classroom environment. Finally, for purposes of the model outlined here, it is also advantageous for the activity to lend itself to explorations that can be quantitatively analyzed by students. Many popular traditional hands-on activities, typically associated with textbooks or worksheets, fit this profile and are therefore suitable for expansion into inquiry-based activities through the approach outlined in this paper. Among the many popular traditional hands-on activities meeting these criteria is, “Dancing Raisins,” which is used in this article to illustrate the proposed model.

Dancing Raisins provides an excellent vehicle for illustrating how traditional approaches can be extended into constructivist oriented, inquiry-based science lessons

(Martin, 2000). The Dancing Raisins activity is based upon the discrepant event resulting when a raisin is dropped into a glass of carbonated beverage. The raisin, being slightly denser than the liquid, initially sinks to the bottom of the glass. Surprisingly, however, the raisin does not stay on the bottom of the glass. Carbon dioxide bubbles in the beverage will attach themselves to the submerged raisin, creating buoyancy, which causes the raisin to bob up to the surface. When a raisin reaches the surface, the bubbles on the top of the raisin break, the raisin rolls over, the remaining bubbles break, and the raisin sinks. Although raisins will dance in a variety of carbonated beverages it is necessary to use a “clear” soda, such as such as Sprite or carbonated water, in order for the students to be able to observe how the bubbles stick to the raisins causing it to float. An example of a worksheet that might be used to drive a traditional implementation of this lesson is shown in Figure 1. Using a worksheet such as this, students would observe a teacher demonstrated introduction to the discrepant event and then follow the teacher’s directions to count how many times their raisins bob to the surface in a pre-established time interval and complete their worksheets. As an examination of this worksheet suggests, the traditional implementation attempts to do little more than show students that bubbles help objects float and provide practice with making bar graphs. The activity can be readily extended beyond this humble starting point through the effective use of challenge questions, which encourage students to explore the phenomena observed more rigorously. The students should be allowed to discover the discrepant event rather than have the teacher demonstrate it. For example, students might be led into the discovery of how the raisins “dance” during the course of hands-on explorations of either density/buoyancy or (at upper grade levels) gas laws.

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insert Figure One about here

Presenting the Challenge.

The extension of the traditional hands-on activity takes a decided turn toward full inquiry when the teacher (or a student) poses a "Can you think of a way to" question as a precursor to a "Can you find a way to" question. In the case of Dancing Raisins, the question takes the form, "Can you think of a way to make the raisins dance faster?" The question is used as a springboard for a brainstorming session, which the teacher facilitates. The objective is to elicit the students' ideas and write down every possibility the students come up with on a chalkboard or flipchart. For example, students may predict that squished raisins dance faster than normal raisins, that raisins dance faster in colder or warmer beverages, etc. The rules of brainstorming apply--ideas should be documented and should not be critiqued this point. The goal is to get the ideas down, not to evaluate them.

The brainstorming and accompanying listing of ideas is essential for three reasons. First, the aspects of brainstorming that make it a useful tool when working with adults are even more critical when working with children. Elementary and middle school science students often do not know how to get started when tasked with framing a scientific question or investigating an idea scientifically. The brainstorming activity capitalizes on their natural enthusiasm and creativity, validates the worth of their ideas, and moves them into designing an experiment before they realize what is happening. Second, students can benefit from structure that constrains and channels inquiry toward manageable tasks. Brainstorming allows students to "choose" what will be investigated from a finite number of options. Finally, as explained in the following section, information gathered in this activity provides part of the structure essential later in the inquiry. Thus, students retain ownership while being provided structure, in part, because they (perhaps unwittingly at first) are major contributors in the strategy of building the structural framework itself.

Planning the Inquiry.

The brainstorming activity naturally stimulates inquiry and often generates controversy about which methods would be most effective in achieving the goal (in this case, making raisins dance faster). Through the brainstorming, the teacher should (a) facilitate each group of students in choosing the strategy they will explore (in this case, the technique for making raisins dance faster), (b) facilitate the students in planning an investigation, and (c) provide whole-group instruction as needed to prepare students for conducting the inquiry.

The teacher directs each cooperative group to select, from the list generated in the brainstorming session, the one item (variable) they want to test. Although the listing activity has limited the options to a finite set, students are still likely to have difficulty in achieving group consensus. Teachers can facilitate students' efforts in various ways. For example, requiring students to obtain the special materials needed to test their ideas can narrow the range of options. Also, teachers can (and usually should) help the students identify the items that are particularly impractical or problematic.

Teachers can begin facilitating students' efforts to plan an investigation as they change the focus of inquiry from theory (can you think of a way) to application (can you find a way). Even though different groups are testing different ideas, everyone is interested in the same question-- "How can we make the raisins dance faster?" The question, "Faster than what?" naturally leads students to articulate their ideas in the form of a hypotheses. The teacher can focus inquiry on these issues and guide it toward discussion of experimental design involving test conditions, controlled conditions, dependent variables (how "faster" is measured), independent variables (items selected from the list), and control variables (everything else in the list).

Once the decision is made to try to answer the question with a direct test (experiment), establishing the reporting and product requirements of the assignment is essential. Students should be required to record the question(s) they are trying to answer, and the steps they will need to take to find an answer, the results to be recorded, etc. Students should also be required to present and defend the results of their investigations to their classmates, and a graphical representation of the research findings should be required. An example of the type of graph that students might produce is shown in Figure 2. As discussed in the Standards, these requirements are an important tool for helping students understand the nature of scientific inquiry--for example "the greater value of evidence and argument over personality and style" (National Research Council, 1996, p. 36).

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insert Figure Two about here

Through class discussions and additional direct instruction, provided as necessary, the teacher continues working with the class in this manner to provide the instruction necessary to prepare the students for conducting the investigations. This instruction includes both establishing the protocols for working in cooperative groups and ensuring that the product and reporting requirements are fully and clearly understood.

While guiding students through this planning process and the rest of the hands-on activity, the teacher should also provide instruction on the nature of science. A growing body of research suggests that successful completion of the Standards’ goals associated with promoting students understandings of the nature of science requires more than merely providing students with opportunities to practice inquiry. This research suggests that, if students are to learn particular aspects of the nature of science, these aspects must be explicitly taught, rather than left to chance in the hope that the students will pick them up on their own (Abd-El -Khalick, Bell, & Lederman, 1998; Lederman, 1999; Luft, 1999; Mathews, 1994, 1998; Yager, 1993). Additionally, literature from the Philosophy for Children movement suggests that even very young children are capable of learning about the philosophical underpinnings of science and benefiting from gaining better understandings of the nature of science (Dawson-Galle, 1990; Lipman, 1991; Lipman & Sharp, 1978; Mathews, 1998).

Important science process skills include observing, measuring, classifying, communicating, making predictions and inferences, representing data, controlling variables, and experimenting. While an operational definition of the nature of science is necessarily more complex than is a simple listing of important process skills, the nature of science can be defined in general terms that are both generally agreed upon among scientists and philosophers and accessible to and relevant to K-12 students. For example, Abd-El-Khalick et al. (1998) proposed that in the K-12 setting students should be taught that science, by its nature, is

- Tentative (subject to change).
- Empirically based (based on or derived from observations of the natural world).
- Subjective (theory-laden).
- Partially the product of human inference, imagination, and creativity (involves the invention of explanation).

- Socially and culturally embedded.
- Partially shaped by the distinctions scientists make between observations and inferences.
- In part, structured by the functions and relationships of scientific theories and laws.

According to Mathews (1998), productive instruction on philosophical dimensions of scientific inquiry begins when students and teachers slow down the science lesson sufficiently to allow time for meaningful questions to be asked and explored. Teacher-guided, student-centered planning activities, such as described here, promote a lesson pacing appropriate for such questioning and subsequent instruction. For example, during the Dancing Raisins activity, teachers can facilitate students' in learning how the activities provide good examples of the classic controlled experiment--with instruction on the associated vocabulary incorporated into the lessons (e.g., control condition, experimental condition, independent, control, and dependent variables, etc.). As noted above, such terminology can be readily incorporated into the planning discussion. Further, students can continue to apply the terms and concepts throughout the experimental planning and, later, within the post investigation and post presentation discussions and reviews of the activity. For example, the concepts of dependent and independent variables can be reinforced in discussions of how graphs should be designed (with the dependent variable plotted on the vertical axis, and the independent variable plotted on the horizontal axis).

Through discussions and questioning, teachers can also draw students' attention to comparisons of the activity with other types of scientific investigations. For example, the class might discuss the similarities of and differences between the controlled experiment inquiry and descriptive research projects the class has previously undertaken (which, while not allowing for control and manipulation of variables, were nonetheless scientific in their approach). Teachers can further infuse instruction on the nature of science through questions highlighting the specific attributes of scientific knowledge, such as those listed previously. For example, teachers can lead students to reflect upon how the list generated in the brainstorming session (listing changes that might make raisins dance faster) is incomplete--and that it would be impossible to create a list that contained every change that could ever be made. Once students accept this premise, it is a small step to help them see how scientific knowledge is tentative by its very nature (e.g., why a hypothesis about what makes raisins “dance fastest” can be supported or disproven but never proven). Teachers can reinforce this lesson by ensuring that students use appropriate terminology when reporting their results during class presentations and ensuring that they understand why they should not report that they “proved” their hypotheses.

Instruction on the process skills should overlap with and support student learning about the nature of science. For example, teachers can emphasize the important role of empirical evidence in science as they help students develop observation skills. Teachers can also teach students about the importance of distinguishing between observations and inferences as they help students learn how to make inferences from their observations. The value of this instruction can be enhanced by activities in which the students engage in reflective writing and reflective discussion of their own application of the skills and on what they have learned about the nature of science (Mathews, 1998; National Research Council, 1996). Although reflective writing and discussion should occur throughout the investigation process, it is especially valuable near the end of an inquiry--when students have a more comprehensive collection of experiences to reflect upon. Thus, within the model described here, reflective learning activities are particularly important within the “considering implications for future research” section of the model.

Conducting the Inquiry

With the framework previously outlined in place, students can be assigned to work in cooperative groups to attempt to answer their questions through hands-on investigations. The Standards and other resources provide excellent information on facilitating students engaged in this type of process. Consequently, this discussion is limited to a few specific nuances relevant to this particular strategy for extending student inquiry of a discrepant event.

It is likely that students will still benefit from considerable support at this point in the process. Although it is imperative that the activity be inquiry rather than worksheet based, it is usually necessary to meet some students' needs for structure and support with a written job performance aid. We have found the form shown in the appendix effective in meeting this need.

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insert Figure Three about here

Students may benefit from conducting a control-condition experiment at this stage of the process before conducting the modified experiment that tests their ideas. For example, students would repeat the Dancing Raisins activity at this point and carefully measure the rate at which the raisins bob up and down under the original conditions. Unlike the initial activity, students will need to control variables (e.g., measure the volume and temperature of the beverage in the container), measure the rate of dances (count the number of bobs during a given time interval) and document their findings. Additionally, teachers can provide specific direction and instruction to enhance learning, (e.g., direct students to observe how the raisins roll over before sinking). This hands-on activity can be followed by activities helping students reflect upon how the increased scientific examination of the event affected their understandings and learning (e.g., reflective writing and class discussions). Finally, the students work through the activity a final time testing their own ideas and prepare a class presentation of their experiment and findings.

Interpreting and Presenting Results

As pointed out in the Standards, the process of presenting their findings to a critical audience is an important part of full-inquiry investigations. Thus, it is essential that students interpret their data, document their interpretations in an appropriate format (e.g., a bar graph for this activity), and conclude their activity with class presentations and discussions. Teachers should use the class presentation requirement as a tool for focusing and directing students' attention throughout the activity. For example, questions such as, "How will you explain that in your class presentation?" can be effective in encouraging students' critical thinking and attention to detail during the hands-on work. It is also generally appropriate to provide additional whole-group instruction (or review) on the oral presentation component of the lesson after the hands-on portion of the work has been completed.

Considering Implications for Future Research

As stressed in the Standards, it is vital in inquiry-based instruction that students reflect on the activities in which they engage (National Research Council, 1996). Thus, the model used to provide structure to hands-on inquiries must include structure that supports this need. Two ways in which teachers might facilitate students in this reflective learning are (a) promoting reflections and analysis of the activity in whole group discussions and (b) supporting students in reflective journal writing. In both of these cases, the teacher can point out to students that scientists often conclude a research activity by considering the implications of their efforts on future research. As always in inquiry-based instruction, teachers should rely heavily upon questioning strategies to guide students through this stage of the process.

During reflective activities, Mathews (1998) recommended that teachers direct student's attention to modest questions, such as the following:

- What is a scientific explanation? (E.g., “Can you explain the results of your raisins investigation using the terms, ‘density’ and ‘buoyancy’?”)
- What is a controlled experiment? (E.g., “In science the use of a test such as the first one we did in class, before we changed variables to make the raisins dance faster, is called an `experimental control.’ Why do you think it was important that each group in class used the same experimental control? Why do you think it is called a “control?”)
- How much confirmation does a hypothesis require before it is established? (E.g., “What other experiments could we do to make sure we have interpreted our observations correctly? Are those experiments necessary? Would it be worth our time to do them or would you rather move on to explore our next topic?”)

Additional examples of the types of questions teachers might ask, which can serve as starting points for novice teachers, are suggested below. While Dancing Raisins is used for specific examples of the types of questions posed, similar questions could be asked of virtually any activity.

Did the inquiry answer all of our questions? In posing this question for Dancing Raisins, the teacher may wish to draw students’ attention to the nature of the data collected and presented among the different cooperative groups. Did any one independent variable clearly emerge as the best way to make raisins dance faster? For individual variables, are the results highly consistent or is there a great deal of variance (e.g., did all five raisins injected with helium dance about the same number of times over the course of 5 minutes?)? These questions can be directed toward helping students appreciate the need to control variables and ensure that scientific research is replicable.

Did the inquiry raise new questions? In a review of Dancing Raisins, the teacher might stimulate discussion through questions such as, "Now that you have learned more about density and buoyancy, do you have any other ideas about what might make raisins dance faster (or slower, or differently in some other way)?" Questions such as these help students construct well-connected and richly structured knowledge (National Research Council, 1996). Additionally, as teachers draw students' attention to the theoretical foundations of their understandings (e.g., how their improved understandings of buoyancy and density inform their predictions and understandings), teachers can also help students see how this manner of subjective (theory-laden) reasoning is an inherent component of the nature of science.

Of particular importance, the teacher should ask questions to help students consolidate what they have learned about conducting scientific inquiry-- "If you had it do to over again, what would you do differently when conducting the investigation you just finished?" Teachers can also directly teach specific science process skills, such as observation, forming hypotheses, controlling variables, representing data, etc., and guide students in writing in their science journals about how they used those skills in the activity. Finally, teachers can explicitly prompt students to reflect upon the nature of science through questions such as, “How did this activity show why scientific knowledge is always subject to change?”

Additional Applications

The Dancing Raisins example illustrates a number of broadly applicable techniques for conducting hands-on inquiry integrated into a strategy for extending students observations of discrepant events. Discrepant events are frequently used as attention grabbing devices in traditional hands-on activities, and in many cases the model illustrated in this article can be applied to extend those activities into full-inquiry science lessons. "Sympathetic Pendulums" (Huber & Probst, 1995) provides another example of an excellent hands-on activity ideally suited to this type of extension. Two pendulums are suspended from a string, as shown in Figure 3, and one of them is set in motion. Students are usually amazed at the behavior of the pendulums as the energy is transferred from one to the other. The pendulums will begin to move together and, as the transfer of energy continues, the first pendulum will slow to a stop while the other will swing independently. The kinetic energy will continue to transfer back and forth until it finally dissipates as heat. In this case, the challenge question might be, "Can you make the observed transfer of energy/motion happen more quickly?"

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insert Figure Four about here

The model can also be modified to effectively extend other traditional hands-on activities that do not perfectly lend themselves to every detail of the Dancing Raisins model. Consider, for example, how this strategy could be applied to the popular transpiration activity conducted with a stalk of celery placed in a jar of water containing a few drops of food coloring (red works best). Over time, some of the leaves take on a red tinge, and the veins carrying the water up the stalk become visibly dyed when a cross section of the stalk is cut. Natural extensions of this activity can be initiated with questions such as, "Can you think of a way to make the red color brighter/cover more of the leaves/occur more quickly?" In this example, the student investigations may not lend themselves to objective measurements, indicating that it would be inappropriate to direct students to graph their findings. Nonetheless, the extended activity provides an excellent means of teaching students how to conduct full-inquiry investigations and focusing students' hands-on investigations on what they are learning about plants and water cycles. Students may reasonably predict, for example, that a wilted celery stalk will yield the most striking results.

As teachers adapt the strategy to a broader range of applications, they will be eased into the process of problem-solving for themselves while adapting curriculum to meet student needs. Some inquiries may require more direct teacher intervention at various stages within the process, and teachers will need to reflect upon the nature of the activity and their goals when deciding how best to implement the general model in a specific situation. For example, as compared to Dancing Raisins, the celery transpiration activity is somewhat more cumbersome to set up, and the discrepant event is less provocative--some hours after setting up the demonstration, the leaves slowly begin changing colors. Thus, in this lesson the teacher may wish to set up the activity as a demonstration and only engage the students in hands-on activities after the results start becoming manifest. In this case, the hands-on activities may begin with students examining the stalks (including cross-sections under a microscope) and making entries in their science journals documenting their observations.

The approach can be used to create a lesson directly from any number of discrepant events. A number of resources, in addition to textbooks and old lesson plans, provide a rich resource base to stimulate ideas. For example, in Invitations to Science Inquiry, Liem (1987) provided examples of over 400 discrepant events that can be used to initiate inquiry on virtually any science topic from the upper elementary to the secondary level.

Conclusion

Hands-on does not guarantee inquiry. However, many seemingly limited hands-on activities can be extended into the realm of inquiry using a model that involves (a) discrepant events to engage students and direct inquiry; (b) teacher-supported brainstorming activities to guide students in planning investigations; (c) suitable written job performance aids to provide structure and support; and (d) the requirement that students provide a product of their research, which typically includes a class presentation and a graph.

The model addresses several pronounced needs at this stage in the standards-based reform initiative. First, the need for inquiry-based instruction is too pressing for teachers to wait for new curriculum materials to be developed and promulgated. Teachers need strategies, such as described in this article, that allow them to move forward toward the realization of the Standards' vision. Existing textbooks and corpus of noninquiry lesson plans may prove a significant resource in implementing the Standards. Second, for many traditionally oriented teachers, the first steps towards inquiry-based instruction may be the most difficult. As noted by one convert, the initial uncertainty associated with stepping into inquiry-based instruction can make veteran teachers feel like they are first-year teachers all over again (Science Media Group, 1995). There may be substantial benefit to allowing teachers to step into that new world using extended, but nonetheless familiar, activities and lesson plans. Furthermore, such lesson plans may well be an ideal resource for helping these teachers understand the differences between what they were doing and what they could be doing through inquiry-based instruction. These benefits are consistent with the National Science Education Standards' strategy and goal of using inquiry-based approaches to support teachers as agents of educational reform.

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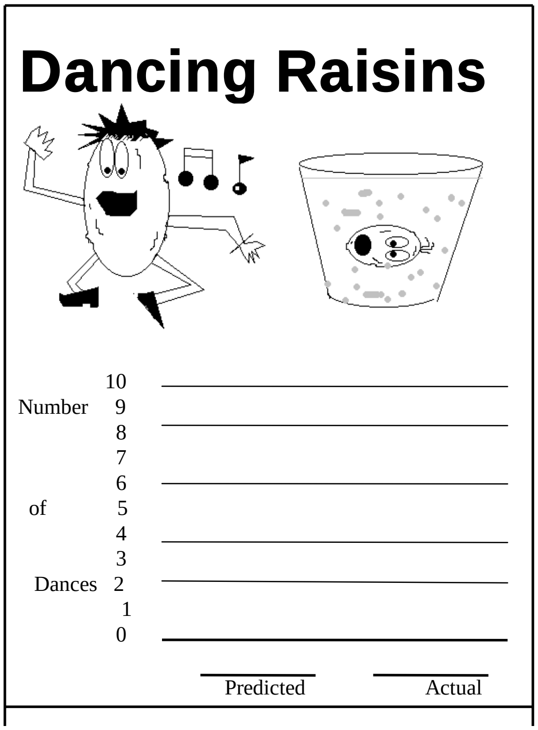

Figure 1. Traditional worksheet for "Dancing Raisins" activity.

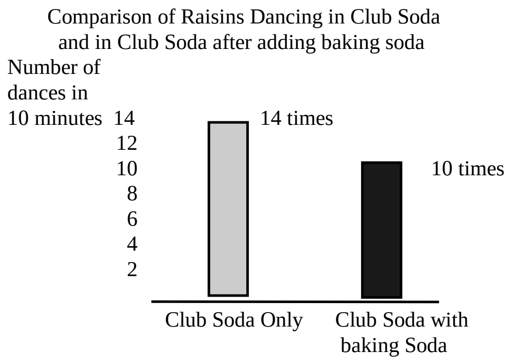

Figure 2. Sample of student-generated graph.

Planning Form For Hands-on Science Exploration

Group Members

____________________ ____________________ ____________________
____________________ ____________________ ____________________

We observed this event:

____
____
____

And it made us wonder about:

____
____
____

We are going to investigate this question:

____
____
____

We predict these findings:

____
____
____

To answer this question, we will do these things:

____
____
____
____
____

During our investigation, we will record the following:

____
____
____

Appendix. Job Performance Aid that can be used with activities such as Dancing Raisins.

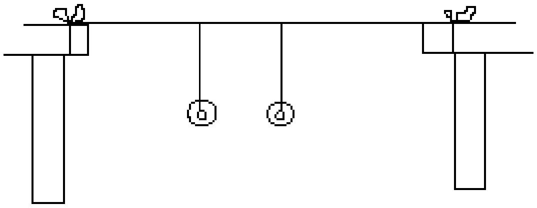

Figure 3. Set-up for "Sympathetic Pendulums" investigation based on Huber & Probst (1995).