ABSTRACT

How can science instruction engage students in 21st-century skills and inquiry-based learning, even when doing simple labs in the classroom? We collaborated with teachers in professional development workshops to transform “cookbook” activities into engaging laboratory experiences. We show how to change the common classroom activity of DNA extraction of wheat germ to integrate cooperative group strategies, graphic organizers, and classroom discussions. Teachers found these strategies helpful as they worked to adapt instruction that prepared students with the knowledge and skills necessary to succeed in 21st-century Science, Technology, Engineering, and Mathematics (STEM) careers.

Key Words: Laboratory activities; inquiry-based science; 21st-century skills; DNA extraction; STEM teaching strategies.

Helping students engage in inquiry-based classroom laboratory activities can be a daunting task for many secondary science teachers. It is not uncommon to hear myriad reasons why inquiry-based instruction is difficult to enact in the classroom, ranging from “I don’t know how to plan for that” to “My students can’t do inquiry.” To address the challenges of delivering rich content and promoting critical-thinking skills, we worked with high school teachers in a series of professional development courses to develop strategies that (1) scaffold student thinking in lab activities and (2) help prepare them for science inquiry in the classroom.

It is not uncommon that classroom lab activities are arranged as “cookbook” labs (Peters, 2005). These types of activities have been criticized as being hands-on and minds-off, in essence, students are not required to think critically because the lab activities have assumed the cognitive load for the students. Reform-based science teaching, represented in the National Science Education Standards and advocated by agencies like the National Institute of Environmental Health Sciences, emphasizes that science teaching and learning should reflect skills fundamental to research science. In an inquiry setting, where content (what) and process (how) must be blended (Chiappetta & Adams, 2004), students take greater responsibility for their own learning by designing experimental procedures and communicating their understanding and reasoning.

To address the challenges of teaching, we use the DNA extraction lab to demonstrate Bybee’s (2009) description of 21st-century learning skills and Peters’ (2005) strategies for transforming cookbook lab activities. This transformation leads to partial inquiry; it guides students to use skills associated with inquiry, such as problem solving and communication.

○ Overview: 21st-Century Skills, Inquiry-Based Learning, and the 5 E’s

21st Century Skills

The 21st-century-skills movement is drawing much attention in education (Senechal, 2010). Bybee identified 21st-century skills as adaptability, complex communication and social skills, nonroutine problem solving, systems thinking, and self-management. These skills are necessary to prepare students for life beyond the classroom. For example, many careers in Science, Technology, Engineering, and Mathematics (STEM) require an understanding of technical skills and conceptual understanding of biotechnology tools (for a description of careers that use biotechnology, see the Bureau of Labor Statistics at http://www.bls.gov/k12/science.htm). As students interact with other students while developing their content knowledge in science, they can enhance specific skills that will help them prepare for STEM careers, such as environmental science, cosmetics research, and genetic counseling.

Adaptability. Adaptability is “the ability and willingness to cope with uncertain, new, and rapidly-changing conditions on the job, including responding effectively to emergencies or crisis situations and learning new tasks, technologies, and procedures” (Bybee, 2009). As students are placed in real-world situations, they need to be able to modify and readjust themselves so that they can respond to changes. They must acquire the skills to analyze new conditions as they arise,
identify what will be required to deal with these altered conditions, and independently develop a strategy that responds to these changes.

Complex communication/social skills. A skilled communicator knows how to select essential portions of complex ideas and express them in multiple ways, such as in words and images, to create a shared understanding among people (Levy & Murnane, 2004). The process of communicating concepts in multiple ways aids science learning and teaching (Lemke, 2000). When students communicate clearly, they not only express ideas comprehensively, but also make sense of information through listening and talking (Bybee, 2009).

Nonroutine problem solving. A student who is skilled in problem solving uses “expert thinking to examine a broad span of information, recognize patterns, and narrow the information to reach a diagnosis of the problem” (Bybee, 2009). Students must be creative and able to generate new ideas that can be integrated with existing information. They have to be able to navigate through various forms of information gathering (reading, listening, etc.) and correspondingly ask appropriate questions that lead them to an appropriate solution.

Self management/self development. Self-management skills require that students understand how to be self motivated and work independently. Even when students participate in collaborative and cooperative learning (Lazarowitz & Hertz-Lazarowitz, 1998), they gain skills to motivate themselves when work requires learning outside of those groups.

Systems thinking. Curriculum materials designed to provide a “big picture” require students to learn content and science inquiry skills through the research of relevant issues and application of appropriate solutions through projects. It is important that students understand the concepts of how systems work – how an action, change, or malfunction in one part of the system affects the rest of the system – and thereby adopt a “big picture” perspective of their learning.

Using the 5 E’s during Inquiry-Based Learning

This paper focuses on transforming the DNA extraction from wheat germ laboratory activity. We introduce strategies to transform this activity in order to engage students in inquiry-based practices and develop 21st-century learning skills.

Scientific inquiry involves engaging learners in scientific practices such as asking scientific questions, experiencing phenomena by designing and conducting investigations, collecting and analyzing data, constructing explanations based on evidence, and sharing findings with others. One way of applying inquiry is by using the 5 E’s (Engage, Explore, Explain, Elaborate, Evaluate) (Bybee et al., 2006). Here, we briefly describe each E in the model, as they relate to the laboratory activity, while recognizing that not every E will be used in one lesson. Each E represents a particular phase of teaching and learning and, therefore, allows the teacher and students to use and build on prior knowledge and experience, to construct meaning, and to continually assess their understanding of a concept.

Creating a Classroom Culture That Approaches Inquiry

DNA extraction is not a new classroom lab activity (for DNA extraction protocols, Google “DNA Extraction of Wheat Germ”). If not carefully planned, this activity may lack rigorous scientific content and scientific processes. While working with pre-service and in-service science teachers, we redesigned the DNA extraction lab activity using Peters’ modification strategies; merging 21st-century skills and the “5 Es” instructional model. During this collaboration, teachers participated as students as a way to understand student experiences and plan for instruction.

We started the DNA extraction activity by thinking about ways to engage students and explore what they initially know about cell structure and function. Activities like the think–pair–share and KWL (what do you know, what you want to know, and what did you learn?) are straightforward ways to get students thinking and talking about cell structure and function and create a need-to-know that mentally engages students in the concepts and skills related to the DNA extraction activity.

Following the exploration of student prior knowledge, a cookbook-altering strategy that can engage students in uncertain situations is to mix the steps of the lab to encourage students to learn how to adapt to new situations (see Table 1). The teacher can provide the students with an envelope with each extraction step on a different strip of paper (see Figure 1). Because the outcome of this lab is directly dependent on the properties of the cell structures and the order in which the steps are carried out, students must explore concepts to identify cause-and-effect relationships. In groups, the students can work together to determine the best sequence of steps to successfully extract the DNA from wheat germ. Because the steps are on strips of paper, the students can explore a variety of sequences and determine the most correct protocol order to try.

Nonroutine problem solving requires students to examine a broad span of information. In the five Es, there is an opportunity for students to explore their procedures as they identify key concepts of cell structure and function, and the relationship between the procedures of DNA extraction (see Table 1). Concept maps are important to help students identify and explain the key content necessary for solving nonroutine problems. For example, students can construct a concept map showing how their sequence of steps leads to successful DNA extraction, using the arrows connecting the nodes to indicate scientific properties associated with the steps and outcomes (see Figure 2).

Also, when students use a concept map to show the relationships between the procedural steps of the DNA extraction lab, teachers can evaluate them as they check for understanding of cell structure and function. For example, during the professional development workshops, teachers used concept maps to show that the addition of detergent causes the breakdown of the cell wall. However, in Figure 1 (left) and Table 2, the teacher incorrectly wrote that the addition of isopropanol came before the addition of the meat tenderizer. In the classroom, the teacher can point out to the students that this ordering is scientifically unsound (the precipitation of the DNA should not come before breaking down the nuclear membrane), then review cell structure with the students.

Additionally, students can evaluate their own thinking as they learn to diagnose problems (identify information and solutions to the problem with the links in the concept map), determine the science concepts associated with the information identified, and analyze results on the basis of whether DNA was successfully extracted.

Once students have decided on a final order of procedures and completed the DNA extraction, they can demonstrate complex communication and social skills by explaining why their procedures produced or did not produce DNA. For example, professional
development teachers used the round-robin strategy (Peters, 2005) to report their results within their groups. During a round robin, each student is required to provide a portion of the complete explanation of their proposed lab procedures. This would require students to communicate throughout the laboratory activity. These explanations should include evidence from the activity and should refer to their concept maps. The intergroup explanations can be the starting point for a whole-class discussion.

In the whole-class discussion, students draw on systems thinking (see Table 1). Through the discussion, students can Elaborate on the steps of DNA extraction of wheat germ.
their ideas, question other group ideas, and make modifications to their approaches. To organize the discussion, the teacher can assign cognitive roles to the students before they engage in the discussion (such as Role 1: Provide evidence for the DNA extraction success, Role 2: Explain the science behind the steps, etc.). Each group then will take turns to describe their concept maps and how they got their results.

During the discussion, students from other groups should be encouraged to ask questions about their data and outcomes, such as “How did you know that?” and “What relationship are you making between step 1 and step 2?” Students should direct their questions to each other and rely on the teacher only to facilitate the discussion (making sure that disagreements are resolved, communication etiquette is maintained, etc.). For example, through intergroup discussions, the professional development teachers learned that in order to communicate their graphic organizers effectively, they needed to specify the relationship between each step. Without this interaction between groups, this piece of understanding may have been neglected. As students engage with each other, they transfer the knowledge-bearing authority onto each other while potentially modifying their own ideas and thought processes. Although this strategy shows great potential for student learning, it is important to note that classroom discussion skills are developed over time and require consistent and regular classroom norms that not only encourage these skills, but also nurture them (Cazden, 2001; Trilling & Fadel, 2009).

Conclusion

One factor that determines whether 21st-century learning skills are a fad or an innovation is the actual teaching strategies that teachers use (Senechal, 2010). At the beginning of this article, a number of challenges for inquiry-based teaching were mentioned. In an attempt to address these challenges, we have described various strategies to promote inquiry-based processes and thinking. In our work with teachers, we used the 5 Es to help organize the process of inquiry and target important 21st-century skills. We showed that adaptability can be as simple as mixing the steps of the lab so that students use their knowledge of the science to formulate a successful lab protocol. As students use nonroutine problem solving to reorganize the steps, they can create concept maps to show cause-and-effect relationships between steps of the protocol, which provides an assessment tool for the teacher.

Throughout the lab activity, students are required to interact and communicate with one another, thereby creating a cohesive understanding of complex systems in science. Although using inquiry-based science has its challenges, teachers who have enacted this type of teaching and learning have shared how student achievement has increased. Students become lifelong learners and are more prepared for future problem-solving experiences. We hope that teachers can use this article as a guide to help them begin to structure and manage inquiry-based laboratory activities, allowing for future integration of complex STEM concepts.

Table 2. Example data table of cause–effect relationships.

<table>
<thead>
<tr>
<th>Cause</th>
<th>Effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lab step 2: Addition of detergent.</td>
<td>Breakdown of cell wall: The detergent breaks down the lipids in the cell wall and disrupts the bonds that hold the cell wall together.</td>
</tr>
<tr>
<td>Lab step 3: Place in water bath for 5 minutes.</td>
<td>The heat from the water bath softens the cell membrane in order to release the nucleus.</td>
</tr>
<tr>
<td>Lab step 4: Stir in sodium bicarbonate.</td>
<td>Sodium bicarbonate maintains a neutral pH.</td>
</tr>
<tr>
<td>Lab step 5: Stir in ice-cold isopropanol.</td>
<td>The alcohol precipitates the DNA from the solution. The alcohol makes the DNA less hydrophilic and causes it to separate from the water.</td>
</tr>
<tr>
<td>Lab step 6: Add meat tenderizers to the mixture.</td>
<td>Breakdown of the nuclear membrane: The enzymes in the meat tenderizer break down the nuclear membrane and release DNA.</td>
</tr>
</tbody>
</table>

Figure 2. Example of a teacher-generated concept map.
Acknowledgments

We thank Susan Pearson of Wayne State University for assistance in the development of this article and support on this project. We also thank the teachers who worked with us to transform the DNA-extraction lab activity. The work described in this article was supported by the National Institutes of Environmental Health Sciences, grant no. 1R1ES018406.

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