The Benefits of Using Authentic Inquiry Within Biotechnology Education

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Abstract

A broad continuum exists to describe the structure of inquiry lessons (Hanegan, Friden, & Nelson, 2009). Most teachers have heard inquiry described from a range of simple questioning to completely student-designed scientific studies (Chinn & Malhotra, 2002). Biotechnology education often uses a variety of inquiries from cookbook laboratory investigations to authentic inquiries. We examined how authentic inquiry, in the form of student-designed original scientific research projects, impacted learning. In this paper we also describe how students expressed that authentic inquiry in biotechnology education enhanced their understanding. (This paper is a summary of Hanegan & Bigler, 2009)

Advanced biotechnology is the driving force behind innovation in agriculture, drug manufacturing, health services, and sustainable ecology. These industries are rapidly increasing more than twice the average for all industries globally. Zeller (1994) explains that this increase has placed a demand on pre-college teachers to improve biotechnology education to allow students to engage in the increasing workforce needed for new innovations. Additionally, strong recommendations by the National Research Council (NRC) encourage teachers to employ inquiry teaching to increase scientific literacy (NRC, 1996; National Science Teachers Association [NSTA], 2003). Given the societal demands and recurring recommendations, we would expect to see an increase of the integration of biotechnology and inquiry teaching at all levels of education.

However, in a preliminary study we found that biotechnology is most often taught only in advanced biology courses rather than the mainstream courses that most students are required to complete. We also discerned that of 42 biotechnology teachers surveyed, not one teacher incorporated inquiry in their curriculum (Mansius & Hanegan, 2008). Most teachers stated that the equipment did not allow for "authentic" scientific investigations with students. A study conducted by Saye (1997) also stated that students preferred using technology to support teacher-centered instruction.

Although authentic inquiries provide the best learning opportunities, cookbook labs are most often employed in the classroom (Crawford, 2000). Historically, Dewey (1964) exclaimed, "science has too often been taught as an accumulation of ready-made material with which students are to be made familiar, not enough as a method of thinking, an attitude of mind, after the pattern of which mental habits are to be transformed" (p. 183). We also believe that students should have opportunities to engage in authentic investigations by planning, conducting, redesigning, and resolving their own original scientific studies to draw conclusions within their mandated biology courses.

In order to document learning advantages using authentic inquiries in biotechnology, we conducted this study in hopes that more biology teachers would be encouraged to employ authentic inquiry strategies. Students in this study explored numerous ideas to develop their own scientific research questions in biology using biotechnology equipment and corresponding processes such as DNA extraction, PCR, and bioinformatics. The students were pre-service biology education students interested in the process of learning in biology. All participants had minimal knowledge of biotechnology or its uses in industry.

Definitions Used in This Study

Authentic inquiry: Student-driven activity that resembles scientific processes while solving original creative works.
Biotechnology: Limited to gel electrophoresis, polymerase chain reaction (PCR), DNA sequencing, and bioinformatic software.
Intended learning: Procedural and application knowledge of gel electrophoresis, polymerase chain reaction (PCR), DNA sequencing, and bioinformatic software.
Unexpected learning: Extraneous knowledge not taught directly but gained as a result of authentic inquiry participation.

Study Overview and Data Collection

We invited 5 female pre-service teaching students to participate in this study (known as Alpha, Beta, Gamma, Kappa, and Omega). The researcher did not know any of the student participants prior to the study. Students were asked to complete a series of interviews and two laboratory investigations. The final laboratory investigation was an authentic inquiry activity designed by each student. To avoid possible contamination, the students were asked not to discuss their participation with anyone. The students who participated in this study were never engaged as a group.

We collected data, including video and voice recorded data, from individual students participating in this study for 5 months through weekly face-to-face contact. We also collected emails and phone communications between the researcher and the students.

We collected the data in five phases. Phase I was a baseline interview to determine the initial knowledge level of each student. Phase II was an independent student laboratory experience mimicking the typical cookbook lab most often used in high school settings. Phase III was an interim interview to determine knowledge gains by the students after the cookbook lab. Phase IV was an authentic investigation conducted by the student determined by their own personal interests. Phase V was a final interview to determine the students' final knowledge gains.

Interviews included three basic questions: 1) What do you know about gel electrophoresis? 2) What do you know about PCR? and 3) What do you know about DNA sequencing? All the data was transcribed, categorized, and coded using qualitative software tools. We categorized and tallied the students' responses as either explaining 1) purpose, 2) procedure, 3) application, or 4) understanding. We defined these categories as follows: purpose (identification or factual statement regarding the technology), procedure (statements regarding steps of the protocols for the equipment), application (statements regarding specific identification of what the equipment was used for), and understanding (explanation or elaborations on why, or how, the technology could be used). We then sorted the coded data to determine patterns of information expressed by all the participants.

Findings

The common pattern we found when we combined all the participants' responses was that authentic inquiry increased student knowledge. Data revealed that students' participation in the authentic inquiry activity of the study, Phase IV, resulted in 1) deepened intended learning and 2) occurrence of unexpected learning.

Tallies or frequencies (*f*) of comments by categories indicated that all five participants increased their knowledge as indicated from a comparison between baseline, *b* (*bf* = 70) and final interviews (*aif* = 212) conducted after their participation in the authentic inquiry activity, *ai*. The greatest gains were found in all areas of procedural knowledge *(bf =21; aif =101)*, followed by the areas of understanding of PCR (*bf* = 0; *aif* = 13) and understanding of gel electrophoresis (*bf* = 6; *aif* = 12). While students showed a significant increase in procedural knowledge about DNA sequencing (*aif = 21)*, they did not indicate an increased knowledge of understanding about DNA sequencing (*aif* = 5). This finding indicated most of the students were better able to express the procedures of gel electrophoresis and PCR equipment usage after the cookbook lab without a significant difference in understanding. However, after the authentic inquiry activity they deepened their understanding of their procedural knowledge.

We also examined the quality of the responses the students provided. Students provided more factual statements after the cookbook lab, Phase II. However, the students expressed more in-depth understanding in their interviews after the authentic inquiry activity, Phase IV. The following comments by Kappa, Omega, and Beta describe this progression of knowledge.

Kappa Described her Increase in Knowledge About PCR:

Baseline interview. "It's a process used to make a whole bunch of copies of a segment of DNA."

Interview following cookbook lab. "PCR is a process where a DNA sample that's too small is going to be put into different machines, and there is a certain protocol that's made for each kind of gene you want replicated."

Interview following authentic inquiry activity. "It's used to make copies of DNA, to amplify many, many copies of a certain segment of DNA usually. Primers are used to locate exactly on the template strand, [the DNA extracted], where to begin the amplification. You use catalysts to speed up the reactions, and temperatures at specific times during the amplification for the right environment. And this is repeated many, many times. Just to make more copies!"

B*etween the first lab and the second lab*. "When I first started I just felt like I was following steps . . . [after the second lab] . . . I felt more confident in what I was doing and why I was doing the steps that I was doing. I knew exactly why I was putting the primers in, what they did, and what the taq was used for. I knew I had to set a certain number of cycles, and why they had to be a different temperature and different durations."

Omega and Beta Described Their Increased Cognitive Engagement as a Result of the Authentic Inquiry Activity:

Omega. "Doing the protocol on my own, coming up with my own question, figuring out how I wanted to answer it, and how I could answer it, caused me to think and to figure it out. I was actually having to learn things and understand them because I was actually doing it: someone wasn't just giving it to me. I had to think of the logic behind that and try to figure out why it was in that order, and what were the different steps we were supposed to accomplish. It was interesting. I learned a lot from making the protocol and just having the experiment on my shoulders. I was responsible for my own learning."

Beta. "After designing my own protocol, I had to really understand what was going on to write it. As I was writing it and thinking about things with the gene that I was working with, I think that helped me understand so much more of what I was doing and why I was doing it opposed to just reading a protocol or procedure and just going through it and being like, 'ok, here is the product' . . . I knew what I was working towards ultimately."

Conclusions

The significance of this study was that the majority of participant learning occurred during the authentic inquiry activity. The frequencies of the comments recorded showed an increase in overall knowledge, and 4 out of 5 students directly reported that they learned most during the authentic inquiry activity. Furthermore, students also reported that they understood more about the nature of science. Students commented on how scientists learn as they discover new knowledge, must articulate their new knowledge so others are able to understand, and that they often need to seek the advice of other scientists as they develop a scientific investigation.

While our study found that students might gain knowledge by doing cookbook labs, the learning is often disconnected and incomplete. All participants commented on the lack of motivation or reason to learn, and the inability to make greater connections during the cookbook lab. Students did not originally realize the differences until they were engaged in an authentic inquiry activity. Our study strongly suggests that students need to conduct authentic inquiry activities for deeper understanding of biotechnology processes and world-wide applications.

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