Guided Inquiry and Social Collaboration in an Online Classroom

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Abstract: The topic of inquiry is explored in an online freshman level introductory biology course for non-majors. The research took place in a distance learning program at a small community college in the Southeast. Students in the course were required to complete an extended guided inquiry in their homes and to communicate about their work by way of the class discussion board. Extensive social collaboration among the members of the class is documented. The students' work is analyzed qualitatively in terms of their research questions, hypotheses and process skills. A consideration of how the students evaluated the scientific validity of their own work is included.

Keywords: Online biology instruction, web-based teaching, inquiry, distance learning

Introduction

As a pedagogical practice *inquiry science* first came to prominence in American schools in the 1960s. The concept of teaching science by way of experimentation was certainly not a new one. Yet, the overall philosophy behind inquiry-based science instruction began to be systematically paid attention to in a way that was unrivaled at the time (Shymansky, Hedges & Woodworth, 1990; NRC, 2000). The philosophy is quite simple. Students will have a deeper understanding of how science works and how scientists do their jobs if they engage in some of the same *process skills* as professional scientists (Roth, 1995; Enger & Yager, 1998; Martin, Jean-Sigur & Schmidt, 2005). This, it has been widely argued, will foster a deeper level of scientific literacy at all levels of education (AAAS, 1993; NRC, 1996; NRC 2000; Sibert & McInthos, 2001). For example, students may be better equipped to evaluate scientific claims that come to them through the popular media if they have had actual experiences with scientific inquiry. In other words, they may become a more critical consumer of scientific information.

Inquiry based science instruction encompasses a wide range of levels. The experiences that most closely match the work of an actual scientist are known as *open inquiry* (Roth, 1995; NRC, 2000). There are those that argue that "it isn't inquiry" unless it is entirely, or nearly entirely, student directed. Proponents of such open inquiry believe that, in order for a student to fully experience the process of doing science, they must decide their own questions, methods, procedures, etc. This form of inquiry is certainly worthwhile and valuable. Yet, other forms of inquiry exist as well. Certainly even the staunchest of inquiry purists are not naive enough to believe that scientists always direct their own thinking. Many well paid, well respected professional scientists are often told by the people who sign their paychecks what they should research, and often how and when.

A lot of labels have been offered in the literature to describe those forms of inquiry that are not entirely open. In many cases, for example, a teacher may provide a research question to his students. Also, a set of materials may be provided and the question or direction of the research left to the discretion of students. Bell, Smetana & Binns (2005) have recently suggested that the widely used term *structured inquiry* should be reserved for situations in which students are provided with both a question and a method, while *guided inquiry* should be applied to those situations in which only a research question is supplied. Other writers use these same terms, as well as many additional ones, in slightly different ways.

In adult science education, there is also an emphasis on inquiry and a call to help college science students develop an understanding of how science works (Sibert & McInthos, 2001). As anyone who is involved in college level science instruction knows, there has also been an explosion in science courses offered by way of distance learning formats, particularly internet-based ones (Collins, 2000;

Kriger, 2001; Skinner & Hoback, 2004). Some involve library and/or internet research. As noted by Bell, et al. (2005) such research clearly does not represent genuine scientific inquiry. Many college textbook publishers have pursued "virtual labs." Sadly, many of the pre-packaged course cartridges and curricula for online biology instruction feature ostentatious computer simulations that offer students practically no opportunity, if any, to experience real science. Recent research has called the effectiveness of many such programs into question when matched against the current reform movements that intend for students to experience real science as part of their overall preparation to become scientifically literate (NRC, 2002; Sibert & McInthos, 2001; Brickman, Ketter & Pereira, 2005). The most terse and noteworthy argument against heavy use of such simulations may have been summed up by La Velle (2002): "*It just isn't real.*"

This paper explores the challenge of inquiry in online biology instruction. The author has been a community college biology instructor for more than 12 years. Several months ago, he designed and delivered his first online biology course for non-majors. The goal was to provide quality instruction that matched a traditional, seat-based course (Lunsford & Bolton, in press). In the current study, pedagogical processes and student outcomes involving a guided inquiry activity that the students completed at home were analyzed. It is hoped that this paper will assist other reform-minded biology teachers who are involved in, or who are considering, biology instruction by way of a web based delivery system.

Methods

Thirteen students enrolled in a freshman level biology course for non-majors comprise the research participant population. The class was offered by a small community college in the southeastern United States. Enrollment at the college typically averages about 2,000 students. The college continues to experience growth in terms of its distance education offerings. At the time of this study, the only science course offered in an online format at the school had been a chemistry class. Students came to campus to complete lab. The freshman level biology class that is the subject of this writing offered lecture and lab in a distance learning format. With the exception of one lab activity (microscopy) completed with an off-campus laboratory mentor, and two summative examinations taken with a test proctor, the entire course was completed online. Topics in the course included nature of science, cell biology, ecology, genetics, evolution, metabolism, chemistry and others typically teachers opt for "lab activities" that exclusively encountered in an introductory college biology course. Students completed a total of 15 laboratory activities. One of the labs, a guided inquiry involving metabolic activities of the common yeast, *Saccharomyces cerevisiae,* is the subject of this paper. Data sources include the class discussion board responses and laboratory reports of all 13 students. Data were analyzed in terms of the social collaboration among the students and teacher as well as the ways in which the students posed research questions, developed hypotheses and made conclusions. All participants provided informed consent.

To initiate the guided inquiry all students were asked to do some background reading in their textbook about metabolism, particularly focusing on cellular respiration in both aerobic and anaerobic situations. As an extension of their reading, they were asked to locate text or internet information about metabolism in the organism commonly known as "baker's yeast" or "brewer's yeast," *S. cerevisiae.* Practically every biology teacher has seen, at one time or another, the classic experimental set-up for collecting carbon dioxide from a yeast culture shown in Figure 1.

Figure 1: A simple apparatus made of a bottle, balloon and tape used to capture carbon dioxide for quantification during the guided inquiry. Photo by Brian Guercio.

The author felt that this simple but easily inquiry that students could set up at home while interacting by way of the class web page. Students were shown an image similar to Figure 1 to initiate the activity and to acquaint them with the set-up to collect carbon dioxide. They were also provided with written starter instructions.

> In this activity, your dependent variable will always be the measured height and/or diameter of the balloon. Decide on possible independent variables (experimental variables or treatments). Possibilities include, but are not limited to, type of food, amount of food, color of culture bottle, temperature of culture, etc.

As part of their grade for the activity, each student was asked to provide a list of at least five potential research questions on the class discussion board. Further, they were asked to respond to at least two of their classmates' postings. Once the research questions and posts were completed, participants were asked to select a question and write a hypothesis. Additional postings by the class and teacher helped students to hone the hypotheses. In turn, potential methods were posted in the same fashion. Finally, students were asked to run at least one experimental trial and briefly summarize the results. Additional class discussion about each student's results was pursued as described above. Discussion board entries accounted for 40% of each student's grade for the lab. Finally, students were asked to write a detailed research report, formatted like a professional research paper, about their inquiry. This report rounded out the remaining 60% of each student's evaluation.

The student's research questions were categorized into three groups based on the work of Scardamalia & Bereiter (1991; 1992) and Roth & Bowen, (1993). While these researchers dealt mostly with middle-school aged students, their system of categorizing science questions asked by students can be valuable at any level of education. In summary, students may ask (1) basic information questions that are most efficiently answered by way of text and/or library research, (2) wonderment questions that feature a level of curiosity beyond what is readily accessible by text-based (or internet-based) research or (3) covariation questions that are most similar to those asked by practicing scientists. Such questions most often link two variables, the manipulated and the measured.

Next, students' hypotheses were evaluated in terms of scientific soundness (i.e. were they specific, testable and empirically based). Finally, all quantifiable activity could form the basis for a guided students' conclusions were evaluated in terms of if and how well they were based on evidence, and whether and how the students dealt with replication and sample size issues in their conclusions.

To illustrate social interactions among the students and teacher (the author), two students were randomly selected from among the group. Their discussion board entries and research papers were utilized as a source of illustrative quotations in the analysis.

Results

Over the course of 14 days, 260 discussion board entries were produced by the participants and the instructor. The instructor tried, whenever possible, to let the students assist one another with development and improvement of their questions, methods, etc. He would often ask guiding questions and/or explicitly tell students to implement the next step in their inquiry process (ex. accept their hypothesis and ask them to propose a method). He made an effort to structure his questions and comments in a way that would, hopefully, assist the participants in evaluation of the work of their peers.

The participants collectively generated 64 potential research questions. Of these, 61 were detailed enough to be categorized by the author as covariation questions. The remaining three were counted as wonderment questions. Randomly selected examples of questions posed by the participants, as well as related discussion board responses are shown in Tables 1 and 2.

With regard to hypotheses the participants stated, two were judged incomplete by the author. Kevin (all names are pseudonyms) failed to explicitly state a hypothesis but gave enough information for the hypothesis to be inferred (see Table 3). The resulting discussion also led to an exploration of the notion of "operational definitions" and "sample size" in the context of their importance in science. In the second case, the student (Ellen) was not detailed enough in her hypothesis to allow the reader to imagine an experimental design. She hypothesized that "since apple juice is used in fermentation and cider, I believe that it will have a faster metabolic rate than other juices when yeast is added." This hypothesis does not specify which "other juices" would be tested or mention a control. Yet, Ellen sought out help from the teacher on this point. Additional class discussions helped this student to modify this hypothesis to produce a clear, testable statement. See Table 4.

Table 1. Anita's Potential Research Questions and Class Discussion

Anita's questions: (note: all names are pseudonyms) 1. Would the metabolic activity rate be different using a powdered sugar than using regular granule sugar? 2. What effects would adding fruit, such as a raisin have on the metabolism? 3. Would the metabolic activity rate be different using purified bottle water versus tap water? 4. Would the metabolic activity rate be different using juice from concentrate versus freshly squeezed juice? (ex: orange juice) 5. Would water temperature affect the metabolic activity rate? Royce to Anita: I would try to narrow the fruit down to a certain kind of fruit, because some fruits are high acidity [sic] and others are not and that would make a huge difference in the outcome of your experiment. Joe to group: Why not try a set of different fruits? Lillian to Anita: I think your #4 was an interesting question. Using concentrate juice vs. fresh squeezed juice. [sic] Would you use concentrated juice without added sugar, or would you use the regular concentrate where the manufactures add sugar? Anita to Lillian: Good question Lillian. I think I would use the concentrate where the sugar is added because then both the bottles to compare would have sugar (though maybe different amounts), and the test would better compare fresh versus concentrate rather than dealing with the sugar effect. Does that make sense? Teacher to Anita: …another great set of questions from Anita. Please move to step 2; try to select one question and design a hypothesis.

All other hypotheses written by the participants varied widely in quality. However, they were all clearly stated and testable. The two students randomly selected to represent typical examples (Janette and Anita) based their hypotheses from their list of questions (Tables 1 and 2). The discussions of their hypotheses are replicated in Table 5. Table 6 provides a summary of each student's inquiry in terms of the question they pursued, how they dealt with replication and sample size, and how each student summarized the outcome of their inquiry. It should be noted that, despite recommendations from their peers and from the teacher, students engaged in this activity were free to construct their experimental design as they chose.

Table 2. Janette's Potential Research Questions and Class Discusssion

Janette's questions: [sic] 1. In random types of food sources, does time of fermentation (30 minutes versus 2 hours) effect the metabolic activity rate? 2. Will the metabolic activity be effected differently in different temperatures (room temperature, refrigerator, warm oven or freezer)? 3. Does the amount of sugar in a [a commercial gelatin desert] effect the metabolic activity rate differently than sugar free [commercial gelatin desert]? 4. Does the sodium content in salty peanuts versus salt free peanuts effect the metabolic activity rate? 5. Does the color of the container used effect the metabolic activity rate differently than a clear container. Ellen to Janette: I think the [gelatin desert] and the peanuts are very creative. Would you have to crush the peanut to maybe get a better test than a whole peanut? Teacher to Janette: Any of these would be very interesting. You've come up with some unusual (but neat) questions. Please try to select 1, go to step 2 and come up with a good hypothesis. Thanks.

Table 3. Excerpts of a Discussion between Kevin and the Class about Hypothesis and Operational Definitions.

Kevin's Questions: [sic]

1. Will there be a difference in the metabolic activity rate in regular juice versus sugar free juice?
2. Does light or darkness effect the metabolic activity rate?
3. Will the metabolic activity rate be different depending on the brand of yeast chosen?
4. Does the amount of the food source used versus the amount of yeast used effect the metabolic activity rate?
5. Does temperature effect the rate of metabolic activity?

Teacher to Kevin:
Please refine your question and state a detailed hypothesis with operational definitions. In other words, leave nothing open to the imagination. For example, when you say "temperature" or "darkness" what does that mean?

Kevin to Teacher:
The variable is actually light. What I have done is take the same color bottles with the same amount of yeast added to each. I have placed one under a constant light, source, one in complete darkness, and one which is exposed to light and darkness.

Ellen to Kevin:

I like the light and darkness effect. One bottle always in the dark at all times, one in light. Say 4 hours a day, 8 hours a day. I am not sure how many bottles you may want to test.

Teacher to class:

Ellen, your comments to Kevin bring up a very important issue or two. One issue is sample size and replication. As we've studied in Unit I, the larger the sample size the better. When it comes to inductive logic and making generalizations, the more samples we have (and the more times we've repeated an experiment) the better and more scientifically sound our arguments become. Of course there is no correct answer to how many bottles. Two is better than one; three is better than two. Also, everyone be sure to think about the issue of control in your future experimental set ups.

Kevin to class:
I thought I'd mention that all of the bottles are in the house so they are always exposed to the same exact temperatures.

Table 4. Ellen's Request for Help with Her Hypothesis and the Resulting Discussion

Ellen's Hypothesis:
Since apple juice is used in fermentation and cider, I believe that it will have a faster metabolic rate than other juices when yeast is added.

Ellen to teacher:
What do you think I could use as a control in this group professor? I don't know what to do.

Teacher to class:
…[based on Ellen's post] here are some questions I'd like **<u>everyone</u>** to consider. Please consider the following. (1) Ellen thinks apple juice + yeast will produce more carbon dioxide (or the same amount more quickly) than will both grape juice + yeast and orange juice + yeast. (2) Obviously, Ellen will compare the grape/yeast and orange/yeast against the apple/yeast. (3) What could she compare the apple/yeast against for a control to be more sure that addition of yeast made the difference?

Lillian to class:
To see if the yeast made any difference to the apple juice she could just do apple juice without any added yeast in one bottle, but because her hypothesis is comparing the apple juice to other juices, then would her control not be the apple juice/yeast mixture and the comparison to the other juices?

Teacher to class:
Good thinking [Lillian]! I would like to see both of these controls. If there is a difference in the apple juice/no yeast and the apple juice/yeast, then I think she could better compare the apple juice with the other juices.

Table 5. Class Discussion of Anita and Janette's hypotheses

Anita's hypothesis: The bottle with the lemons would produce the most metabolic activity, followed by the one with the raisins and the "plain" one would produce the least activity. My control would be the plain bottle because I would be testing the "food" items against it. Teacher to Anita: This sounds good but I'd like to clarify about the control you've proposed. I understand that you'll not add fruit to it but will you add yeast? Please let me know as you describe your method in Step 3. Be very specific about amounts, time, etc in your procedure. Anita to teacher: …what I propose is to put yeast, water, sugar, all of equal measures into the containers, but only add raisins to one and lemons to the other. Teacher to Anita: Sounds good! I think you can go ahead to step 4, keeping in mind a "time" for the experiment to be declared complete.	**Janette's hypothesis:** I believe that the metabolic activity will be different in the different temperatures. I predict that the activity rate will be slowed down to a near stop in the freezer and the activity rate will speed up in the heated oven. The controls will be the size of the containers, the amount of yeast and water in the container and the amount of time exposed to each temperature. Joe to Janette: Sounds like a good plan. I'm not sure how well the balloon and plastic bottles will do in the oven. Teacher to Janette: Joe's comments may be something to think about. Also, I think your control should be the room temperature environment. Please go ahead with your method, carefully describing what you'll do.

Table 6. Comparison of All Students' (n = 13) Experimental Setup and Conclusions

NAME OF STUDENT	Research Question: "___ CO_2 production by yeast?"	# of replicates (sample size)	# of trials	Student's Comments on Outcome & Hypothesis	Noteworthy student comments or actions if applicable
Anita	Will adding fruit to sugar water mixture increase	1 per 2 treatments and control	1	"…partially disproved..." [fruit added increased but neither fruit performed better]	"This experiment could be repeated to verify results. I am not certain any gas did escape."
Ellen	Will apple, grape or orange juice influence	1 per 3 treatments & 3 controls	1	"…disproved…"	Says one juice must have had more sugar than predicted
Helen	Will saltine (containing less sugar) or snack crackers (containing more sugar) increase	2 per 2 treatments but had no control	2	"I think this experiment proved…"	Increased amount of food & yeast in second trial.

Table 6 continued.

Janette	Do extreme temperatures effect	1 per 3 treatments & control	2	"…supported my..."	
Jeanne	How does water temperature affect	1 per 2 treatments & control	1	No explicit statement from student about hypothesis	"I observed that the warmer the water temperature the greater the reaction in the yeast fermentation."
Joe	How does light affect	1 per 3 treatments & control	2	"the second trial did support…"	Says balloons in first trial may have been damaged when setting up experiment so thicker ones were used in second trial.
June	How do various temperatures influence	2 per 3 treatments & control	1	"I found that [treatment 1] has the best effect…makes the metabolism rate increase rapidly."	
Kevin	Does light intensity influence	1 per 2 treatments & control	3	"I was not able to verify…because I was unable to successfully conduct the experiment."	The instructor believes that this student used too low a water temperature during the first 2 trials and then confused Celsius/Fahrenheit scales during the third trial and used boiling water.
Lillian	Will table sugar, brown sugar or an artificial sweetener affect	2 per 3 treatments & control	1	"The results of my procedure did not give a clear conclusion."	Student recommended repeating with a longer experimental trial
Mary	Does food coloring, especially dark colors, increase	1 per 1 treatment & control for trial 1; 1 per 4 treatments & control for trial 2	2 but arguably, each was a different experiment.	"my…did not fail."	
Rosa	Will fresh or shelf-life expired yeast influence	1 per 1 treatment & control	3	"…trial supported…Does lead me to believe that…was correct."	"However, outside variables such as room temperature and human error in measurement were not taken into consideration."

Table 6 continued.					
Royce	Will carbonated water cause increased	1 per 2 treatments & control for trial 1; changed control for trial 2	2	"…did not prove…" [first trial] "…have proven…" [second trial]	"[based on advice from the class] I added a control to my [second trial]; adding of a bottle of carbonated water without the yeast to see if it worked strictly off of the CO_2 or if yeast help accelerate the production of CO_2. With the second experiment I also changed the size of the bottles."
Wenona	Does agitation of culture increase	3 per 1 treatment & control	1	"…results did not support…"	"If the cultures had been agitated for a longer period of time, giving the yeast a chance to mix with the sugar source, then I believe that the results would have been a little different. Reproducing the experiment and incorporating a longer agitation time could test this further. "

Discussion

It is clear that use of the discussion board on the class web site can provide substantive dialogue among the class members. This paper reproduces only a few of the 260 discussion board entries from the activity (See Tables 1 – 5). Yet, this small sample demonstrates that the class collaborated heavily about their on going inquiries. They evaluated ideas and made suggestions to one another throughout the process. This notion of "science talk" as it has sometimes been called is regarded as typical in actual scientific practice. Reformists and researchers alike contend that such discussion of problems, results and difficulties encountered during inquiry in classrooms are an integral part of the overall experience of "real science" (Roth, 1995; NRC, 1996; NRC, 2000). Regarding college level biology instruction in distance learning formats specifically, Colling (1997) noted the need for heavy social interaction in order to make the experience successful. So, students who pursue inquiry in online courses have no need to work in a vacuum. With careful planning, social collaboration can be readily fostered in such environments.

There was a high level of covariation questions posed by the participants. Both Scardamalia & Bereiter, (1991; 1992) and Roth & Bowen, (1993) report that these types of questions are rarely generated by science students and that they are much more typical of the sorts of questions asked by practicing scientists. The high incidence of covariation questions from participants in this study may best be explained by the fact that students were given an explicit dependent variable ahead of time and were asked to brainstorm things they could manipulate (independent variables) to change this measured variable. This practice may, of course, displease open inquiry purists but it seems to be highly appropriate in the context of a guided inquiry. The online discussion board can be as effective as a traditional classroom discussion in allowing teachers and peers to critique wonderment questions and lead students to pose a "cause and effect" covariation question instead.

As noted in the Results, above, only two hypotheses made by the participants were judged as scientifically unsound. In Ellen's case (see Table 4), she simply was not detailed enough to readily allow an experiment to spring directly from the hypothesis. She also asked for help with a control. The teacher and a classmate were able to help Ellen reason through the process to form a more detailed experimental plan. In the case of Kevin (Table 3), the instructor was only able to assume an implied hypothesis from Kevin's limited discussion board postings. In hindsight, this was not a good practice. Kevin had tremendous difficulty with his experiment (See Table 6). He made very few of the required discussion board posts following the one reproduced in Table 3. In an actual classroom situation the teacher may have been able to monitor the implementation of his experiment more closely and help him past the difficulties he had. To alleviate problems such as these in an online setting, teachers may think about requiring more detailed posts about methodology or asking students to submit digital images of their experiment in progress. However, as in Kevin's case, if the student does not participate in these requirements, then they may fall through the cracks. Even in a traditional classroom setting, a teacher cannot force students into full participation during any activity.

As shown in Table 6, there was a wide range of success in how students dealt with the issues of control, replication and evaluation of experimental outcomes. Only one student, Helen, had no control for her inquiry. Students were explicitly taught the concept of experimental control prior to the beginning of the activity and the class dealt with the concept in the discussion board multiple times (see Table 4 for one example). Perhaps explicitly requiring students to describe the control in their experimental proposal could have alleviated this difficulty. Students showed a range of attentiveness to sample size and replication (Table 6). Jeanne, Ellen and Anita were very weak in this area. Not only did their experimental designs fail to include a sample size beyond one, they only did their experiments one time. Rosa had a sample size of one but did perform three trials with a consistent outcome.

With regard to evaluation of their hypotheses, based on their data, four of the students (ex: Royce and Helen) inappropriately used words like "proved" and "disproved" when speaking of their hypothesis and experimental outcomes. Lillian's statement that "The results of my procedure did not give a clear conclusion" was probably the most accurate of all. Students seemed too eager to draw definitive, black and white conclusions from their limited work. As noted by Lunsford (2002) interpretation of scientific data is a high-level cognitive skill with which students in a traditional classroom setting often have substantial difficulty. The author was encouraged to read words like "supported" in lieu of "proved" in some students' research reports. Also, it is of note that a few of the students identified problems with their experimental designs and/or noted the need for replication. Comments from Lillian, Rosa, Wenona and Helen (Table 6), for example, suggest that at least some students gained a more clear understanding of how science actually works.

Conclusion

Today the average adult clearly has a distorted view of how scientists do their work and how scientific knowledge is generated or constructed. Major reform recommendations put forth in the 1990s (AAAS, 1993; NRC, 1996) will hopefully change this view in the coming years. With the extension of calls to participate in socially based scientific inquiry for adult learners (Sibert, & McInthos, 2001), more attention has been paid to how college biology courses are delivered. Inquiry is a fun way to learn but it is a hard skill to master. Just as in regular classroom settings, students enrolled in online biology courses should have opportunities to design and carry out experiments and to talk about them critically. Distance learning students have the potential to participate in, and learn from, scientific inquiry like their traditional counterparts. In the absence of advanced equipment found in most biology labs, inquiries generated by online students may not be as sophisticated as those of traditional students. Yet they still can experience real science, even while working in their kitchens. Biology teachers may act as mentors by way of the classroom discussion board in an online setting, just as they do in person in a regular classroom. Again, the outcome may not be as sophisticated; yet, the mentoring is genuine. The results of this research clearly show that rich socially-based participation in scientific inquiry is possible in the modern age of online instruction. Teachers in these situations will experience the same sorts of successes, frustrations and failures as they do in a traditional classroom setting.

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