MOVING FROM Didactic to Inquiry-Based Instruction IN A SCIENCE LABORATORY

THOMAS LORD TERRI ORKWISZEWSKI

As I walked past a science room at the onset of class recently, I heard the professor say:

> *All right, class, open your lab books and turn to page 32. I doubt many of you read through today's investigation so take a few minutes to look over what you'll be doing while I prepare the reagents you'll use during the lab.*

The teacher turned his back to the class and transferred several milliliters of stock solution into two or three reagent bottles while the majority of the class members talked quietly among themselves at their seats (but few of them read the lab). After several minutes, the teacher regained the attention of the class and told the students to work with a lab partner as they performed the lab. The teacher also instructed the students to individually answer all lab questions embedded in the experiment by the end of class. At this point most of the students left their seats and headed to the materials table in the back of the room. As they gathered around the congested table, they attempted to find the items needed to perform the investigation. Eventually, they returned to their seats at their lab table with the materials they thought they needed. It was at this point that one of them in each group began to read the step-by-step procedure (skipping the pages holding introductory paragraphs). In the meantime, the teacher took his position in the front of the room and waited for the students to ask what they were supposed to do.

This "cookbook" method of lab instruction is common in our schools and colleges. As in the non-lab portion of the class, students read or wait to be told exactly how they are to perform the lab. So prevalent is this form of instruction that participants know what to skip and what they should memorize. For example, students know that most instructors will write relevant information for the test on the board or overhead. In a lab, students generally direct their attention to the highlighted words in the lab's descriptive paragraphs for the important vocabulary. Despite assigning students a written lab report, very little is learned by rephrasing the written procedure and plugging results into the prepared written lab questions.

THOMAS LORD is Professor in the Department of Biology, Indiana University of Pennsylvania, Indiana, PA; e-mail: trlord@iup.edu. TERRI ORKWISZEWSKI is a graduate student in the Department of Biology, Indiana University of Pennsylvania, Indiana, PA; e-mail: choochoo02@earthlink.net.

Observing students in an inquiry lab is startling different. Instead of students following descriptive paragraphs during the lab, they are provided a series of challenging questions they attempt to answer through an investigation they design. Biology students may be asked to design an experiment that demonstrates molecular movement through a membrane or to find observable variations between plant and animal cells by scanning a variety of tissue specimens. Inquiry learning instills higher understanding than simply following step-by-step instructions on a series of lab book pages. In inquiry-based classrooms, students discuss what procedures will and will not lead them to a valid conclusion; they acknowledge variables that will interfere with their outcome's validity, and learn the importance of maintaining a control sequence to compare to their results (Marbach-Ad & Sokolove, 2000).

Numerous studies in recent years support replacing cookbook procedures with student initiative activities (Weaver, 1998; Hart et al., 2000). Healy (2000) suggests the pedantic teaching methods utilized two decades ago are no longer effective in creating long-term learning in students. While it is unclear why this has occurred, it has been suggested that the rapidly evolving technologies in education have created students who demand instantaneous feedback and involvement. Class members are no longer content to sit passively through a lecture or laboratory activity; rather today's students need to be engulfed in it. Students who don't become involved in the lesson mentally tune out what is going on and passively await the end of class with their brains turned off. Lord (1999) describes this as "the couch potato phenomena."

Involving students in inquiry is much more difficult than simply providing activities for them to do in the classroom. While active learning suggests students are physically participating in the lesson, inquiry learning requires that they are also mentally participating in it (Enger & Yager, 2001). In fact, academic theorists agree it is more the mental participation than the physical participation that is the important ingredient to enduring understanding (Wiggins & McTighe, 1998). Students need to consciously consider the events they are exploring; students also need to actively examine what they possess and predict the ramifications of intervening with the action.

While previous studies have shown that inquiry teaching can have a positive impact on learning (Blank, 2000;

Marbach-Ad & Sokolove, 2000), comparing college student performance taught by two different instructional methods in a science laboratory has not been done. This study compared introductory biology students taught lab through step-by-step directions with those taught through inquiry questions.

Methods

One hundred college students enrolled in non-majors introductory biology classes at Indiana University of Pennsylvania were asked to participate in a study. Each contributor filled out a questionnaire with his/her college major, year of graduation, SAT scores in science and mathematics, and the number of science and math courses he/she completed in high school and college. An analysis of the questionnaire found no difference in backgrounds of students in the control and experimental groups. The participants were also given a Science Attitude Survey (Moore, 1996) and an Integrated Processing Skills test (Okey & Dillashaw, 1995) at the onset of the fall 2001 semester. The Science Attitude Survey is composed of 40 questions that seek participants' responses (on a 1 to 5 Licker Scale) to such statements as: "Researchers should not criticize other researchers' works" or "Scientists have to study too much in school." The Integrated Procession Skills test is a 36-question, multiple-choice test designed to measure a student's understanding of scientific thinking. Representative questions include: "Several students shined a flashlight on a wall, and then moved toward and away from the spot made by the light. Which of the following is true about the image size as the students moved?"

Students attended class together in the same lecture hall each week but were scheduled into one of four separate laboratory sections. Both researchers taught three of the labs while only one of the researchers was involved in the fourth with another professor. While all of the sections performed the same topics within the lab during the week, only two of the groups followed the printed instructions in the students' laboratory manual. These participants were named the Control Group. The other two sections followed inquiry-based activities prepared by their instructors and were named the Experimental Group. Both the Control and the Experimental sections were videotaped during the lab; these tapes were appraised at the end of each week to assure that the purity of the method was maintained.

All the participants heard a short presentation on inquiry teaching/learning, and all took part in an inquiry-based activity during the first large-group session of the semester. Furthermore, although all the students utilized the same materials and attempted to meet the same objectives in the 22 labs in the course (Figure 1), the investigative procedures of the Experimental and Control groups were quite different.

Figure 1. Student Labs in the Introductory Biology Course.

The labs below listed were taught either through inquiry or step-by-step directions:

1. Taxonomy
2. Population Biology I
3. Population Biology II
4. Diversity and Trophic Levels
5. Stream Ecology
6. Microscope and Cells
7. Osmosis
8. Fermentation
9. Variation
10. Inheritance I
11. Inheritance II
12. Classification
13. Evolution
14. Natural Selection
15. Fetal Pig Anatomy I
16. Fetal Pig Anatomy II
17. Human Circulation
18. Effects of Temperature on Respiration
19. Human Nervous System
20. Animal Behavior
21. Animal Development
22. Plant Structure and Function

The Control Group

Participants in this section followed several pages of written directions in their laboratory manual and answered a number of related procedure-generated questions as their lab report. Students worked in groups during the labs but each participant was required to hand in a completed lab report each week. An example investigation in the lab instructed students to record the weight of several raw eggs (each with its shell removed) that had been submerged in a series of solutions containing different concentrations of sucrose. After first reviewing osmosis with a full page of reading, each team was told to weigh an egg (provided by the instructor) at 20-minute intervals. The lab directions instructed the students precisely what they were to do:

> *Subtract the initial weight value of your egg (weight at time 0 minutes) from each of your subsequent readings to obtain the relative weight changes of your egg over time.*

When they finished, a member of each group recorded the results in a table outlined in the lab book. Next, tables from each group were merged into a common chart drawn on the chalkboard in the front of the room by the instructor. Students were asked which solutions listed on the board were hypertonic, isotonic, and hypotonic. Following the student responses, the instructor encouraged participants to graph their results for weight vs. time and weight vs. concentration from their information (a readily-prepared template of the two graphs was provided). Finally, students were asked to answer a few questions about their findings.

If students maintained their interest in the procedure for the two-hour lab period, it could have lead to a reasonably high level of understanding. However, due to the slow pace (weighing eggs at 20-minute intervals) and the strictly-directed procedure, most students tuned out midway through the activity and methodically followed the directions in the conclusion.

The Experimental Group

The procedure followed by the Inquiry Group for this investigation was quite different. Instead of reviewing osmosis with a page-long narrative, followed by cookbook procedures and plug-in data tables, the Experimental Group was separated into small, cooperative learning teams and prompted to list 10 examples of osmosis in everyday life. After a brief interlude, the instructor randomly selected a member of each group to describe one of his/her team's examples. This generally resulted in a dozen daily instances of osmosis (i.e., from plant turgor to contact lenses). Next, the instructor showed the class a hen's egg and asked how the egg could be used to demonstrate osmosis. As the groups began to discuss the challenge, the professor circulated around the class and assisted teams having difficulty. If a group needed help, the instructor would show students an egg that had been de-shelled (by an overnight immersion in vinegar) and ask them to think of the raw egg without the shell. After viewing the de-shelled egg, students generally noticed the cell's membrane and began discussing how materials moved through it.

Table 1. *t*-test Comparison of quiz score totals between Control and Experimental populations.

Group	N	Mean Score	Standard Deviation	Standard Error	*t* score
Experimental	48	89.7	12.7	2.3	3.78*
Control	48	84.8	15.4	2.0	
*p<0.05					

Table 2. ANOVA for science attitude and processing skills in Experimental population.

		N	Mean	S.D.	S.E.	F
First Semester						
Attitude	Pre	96	62.2	5.12	1.6	3.9*
	Post	88	67.8	6.43	2.4	
Processing Skills	Pre	96	20.5	3.2	2.2	2.4
	Post	88	22.8	3.6	2.5	
Second Semester						
Attitude	Pre	95	66.4	4.72	1.2	4.8*
	Post	83	72.6	5.40	1.4	
Processing Skills	Pre	95	23.7	3.2	2.2	4.5*
	Post	83	28.8	3.62.5		
*p<0.05						

Table 3. Chi-square comparison of student responses in the Experimental and Control Groups.

Group	N	Positive Responses	Negative Responses	X2
Experimental Group	48	37	11	7.04*
Control Group	48	31	17	2.04
*p>0.05				

At this point, all the groups were active in designing their own experiments to demonstrate osmolarity. Student teams were not told what procedure to follow; however, they were encouraged to review the meaning of hypertonicity, isotonicity, and hypotonicity, and to apply the different concentration gradients to experiments with their egg. They were also instructed to construct a graph that compared the variation in the egg's weight during the time of the experiment.

Following the routine taught on the first day of class, teams first discussed the challenging task, developed a plan to perform the experiment, and divided the job of gathering materials pertinent to its execution. In this example, one student from each group retrieved glassware from the side counter of the room while a second student in each team acquired the chemicals the group needed from an array of ingredients in the back cabinets. A third member of each team procured a de-shelled egg from a bowl placed on the front table by the professor. Gathering at their lab station, students in each team would next begin to arrange their glassware and prepare their solutions. Generally, no group followed the exact same procedure of another and therefore, each group's experiment differed in its design. Yet, by the end of the lab most of the teams would have drawn similar conclusions.

Discussion of Results

In this study, the Experimental and Control Groups followed their perspective formats each week except during the early portion of the lab period. In the first five minutes of each class, students completed a 10-question quiz to evaluate what they learned in the previous week. Students in all sections took the same quiz. At the end of the semester, quiz results from team members in the Control Group were compared to team members in the Experimental Group. The comparison revealed a higher success rate among students in the Experimental Group on most of the weekly quizzes. A *t*-test comparing the total of quiz averages of the Control Group with the total quiz averages of the Experimental Group revealed a significant difference in correct answers for the students using the Inquiry approach (Table 1).

Learning through inquiry challenges students and enhances their attitude and learning in other ways as well. At the conclusion of the semester, members of both groups were retested with the Integrated Processing Skills Test and the Science Attitude Survey with their results being compared to their pre-test effort. While there was no difference in pre- and post-test results with the Control Groups, the comparisons revealed that students in the Experimental population had developed a better attitude about science and were better equipped to think through science problems than students in the Control population (Table 2). Furthermore, class attendance, enthusiasm, and interest in the labs were more evident in the Experimental students each week. Videotaped students revealed more eagerness and motivation in coming to a meaningful solution in the Experimental sessions than the Control sessions.

It is interesting to read the written appraisals taken at the conclusion of the course by students in the two groups. It should be mentioned that Introductory College Biology I and II are taken by students representing all of the college years (freshman through senior) and non-science related majors (i.e., history, philosophy, economics). Noting this, it is laudable that over three quarters (78%) of the comments from participants in the Experimental Group were positive (Table 3). In addition, present-day laws require that all participants agree to take part in a study such as this at its onset. Some of the comments from students reflect this. The positive comments listed below were from the students in the Experimental Group:

> *I never realized how much fun it was to discover science like real scientists do.*
>
> *What a terrific way to learn, why don't all the profs teach this way?*
>
> *I never did well in science in high school and don't like it very much (that's why I've waited so long to take it). But working with friends in a team to do an experiment made science fun, interesting and understandable.*

A few of participants in this group expressed dissatisfaction with inquiry learning. One student commented:

> *The labs in this course were very confusing. We were never told what we were supposed to do and didn't know until the end if what we had decided to do was right.*

Another student stated:

> *No one taking this course is a science major so how can our teacher expect us to make up our own experiments? The labs were a complete waste of time.*

Responses from students taught in a traditional cookbook manner in the Control Group also varied. One student said:

> *The labs in biology were the best part of this course.*

Another stated:

> *I learn much more from doing experiments in lab than sitting in biology lecture.*

A student who did not like the experience wrote:

> *The labs in biology were GROSS, they didn't add anything to what we were doing in class and were a waste of time.*

Conclusion

This study supported the contention that students from inquiry-taught labs learn more biology than students in classes with step-by-step directions, and they enjoy the investigations more than their traditionally-taught classmates. When compared, participants in the Experimental Group scored consistently better on the lab tests than students in the Control Group. The research also revealed that a significantly higher number of participants in the Experimental Group responded favorably about their experience in biology lab than did participants in the Control Group. In addition, the study found that students taught with the inquiry approach acquired enhanced science attitudes and reasoning skills during the year.

All science professors should consider teaching through inquiry challenges. Not only do their students understand the material better than the memorizers, they retain the information for a longer period of time. Inquiry taught students are able to apply what they learn to new situations and more often acquire a personal interest in the science around them than do traditionally-taught students. Finally, inquiry fosters an enthusiasm for the subject that generally does not occur with teacher-centered instruction. Robert Yager (1991), a highly respected educational theorist, recently noted that:

> *... inquiry teaching helps kindle the embers of science in students; if it is done carefully, inquiry will flame a passion for science in the participant for the rest of his life.*

Acknowledgments

This material is based upon work supported by the Indiana University of Pennsylvania's Teacher Education Center for Mathematics, Science and Technology and the Collaborative for Excellence in Teacher Preparation in Pennsylvania, an initiative supported by the National Science Foundation under Grant No. 9986753.

References

Blank, L.M. (2000). A metacognitive learning cycle: A better warranty for student understanding? *Science Education, 84,* 486-503.

Enger, S. & Yager, R. (2001). *Assessing Student Understanding in Science.* Thousand Oaks, CA: Corwin Press.

Hart, C., Mulhall, P., Berry, A., Loughran, J. & Gunstone, R. (2000). What is the purpose of this experiment? Or can students learn something from doing experiments? *Journal in Science Teaching, 37,* 655-675.

Healy, J. E. (2000). Assessment – A new way of thinking about learning. *Journal of College Science Teaching, 29*(6), 415-421.

Lord, T.R. (1999). Are we cultivating couch potatoes in our college science lectures? *Journal for College Science Teachers, 29*(1), 59-62.

Marbach-Ad, G. & Sokolove, P.G. (2000). Can undergraduate biology students learn to ask higher level questions? *Journal of Research in Science Teaching, 37,* 854-870.

Moore, R.W. (1996). *A Scientific Attitude Inventory.* Miami, OH: College of Education, Miami University.

Okey, J.R. & Dillashaw, F.G. (1995). *Test of Integrated Process Skills.* Athens, GA: College of Science Education, University of Georgia.

Weaver, G.C. (1998). Strategies in K-12 science instruction to promote conceptual change. *Science Education, 82,* 455-472.

Wiggins, G.P. & McTighe, J. (1998). *Understanding by Design.* Alexandria, VA: Association for Supervision and Curriculum Development.

Yager, R. (1991). The constructivist learning model: Toward real reform in science education. *The Science Teacher, 58*(6), 53-57.