THE EFFECTS OF DISCOVERY LEARNING IN A LOWER-DIVISION BIOLOGY COURSE

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This study investigated discovery learning pedagogy and its effects on students' achievement and attitudes toward instruction in a lower-division biology course, entitled Structure and Function of Organisms. Instruction was primarily lecture-based but included four discovery learning activities. Results indicate that students had greater achievement on content learned through discovery methods than lecture-based instruction. Findings regarding students' attitudes toward discovery-based instruction suggest that students enjoyed active, discovery-based problems, believed that discovery helped them gain an understanding of the material and helped them to develop skills that could be used in other courses. The study presented here shows that a moderate amount of discovery learning used in combination with traditional methods of instruction may be an effective means for promoting students' achievement.


Key words: discovery-based instruction

Discovery learning most often refers to pedagogy that exposes students to various situations, questions, or tasks that allow them to "discover" for themselves the intended concepts or material (1). Learning occurs when the learner constructs an understanding of newly discovered information by associating it with prior knowledge in an organized and systematic way. Within this context, discovery learning is defined as student-based exploration of an authentic problem using the processes and tools of the discipline. Discovery learning in its many forms has been recommended as a means for instruction by major science education organizations (4, 13, 14). Research has demonstrated the potential benefits of active/discovery learning over traditional, passive learning (2, 21). Specific benefits of discovery learning include learner involvement yielding more and different ways for the learner to experience the content, student activity, which increases attention to task(s) and creation of an episodic memory that aids reconstruction of knowledge, meaningful learning that involves deeper processing of ideas and confronting misconceptions, and higher-level learning, so that science is viewed as a dynamic process, not simply a static set of facts (3, 20). The meaningful experiences provided by discovery learning result in students who are motivated, self-directed learners that may be better able to learn and recall information (15, 20).

Discovery learning has long been advocated as a means for science instruction at the elementary and secondary level, but it is just beginning to make inroads into postsecondary settings. Within this context, it is viewed as an effective means for improving student achievement and developing science process skills by directly involving students in the learning...
process, resulting in more meaningful learning, which, in turn, leads to increased motivation and improved student attitudes (2, 20). The research presented here focuses on an instructors’ use of discovery learning strategies in conjunction with traditional, didactic instruction.

This study has important implications for instructors of science, who often report student content acquisition (i.e., covering the content) as their primary goal (5, 7, 10). If the limited use of discovery learning in combination with more traditional practices can improve students’ achievement, science faculty should consider reevaluating their current teaching strategies. The combination of discovery and traditional pedagogy in this study is offered as a means for allowing students to become involved in the inquiry process of science, therefore improving college science instruction while allowing instructors to still “cover the content” in a style with which they are familiar and comfortable.

The purpose, therefore, of this study was to gain an understanding of the aspects and influencing factors of discovery learning that impact student achievement and attitudes within the context of a college level, undergraduate biology course. The course studied consisted of two semester-long (15 wk) sections of sophomore level biology, entitled the Structure and Function of Organisms. Each section was taught by the same instructor, had similar numbers of students (~160 each), and used similar exams. The course was primarily lecture-based interspersed with Socratic-type questioning episodes and taught in a large lecture hall. In addition, four discovery learning activities were used during the semester. The discovery activities (see APPENDIX A) were designed to teach students about the process of science and experimental design, while introducing or reinforcing course content. After undergoing an introductory lecture segment, students spent the remainder of the class, (~15–20 min) working in informal groups of three or four, formulating hypotheses based on lecture material, and designing experiments to test the hypotheses. Data sets based on work published in peer reviewed journals were made available to the groups, which they then had to graph, analyze, and interpret. These analyses then served as the bases from which students made predictions about related topics. The subject matter covered via discovery learning in this course were stomatal control, osmosis, hormonal control of tropism, and transport in red blood cells. The focus of the research presented here was to explore students’ attitudes toward discovery-based instruction and the impact of discovery-based instruction on student achievement.

INSTRUMENTS AND METHODS

Achievement. Achievement was assessed using a comprehensive final exam that included both content and process elements of the discovery activities. The final exam was subdivided into categories based on the types of questions that were asked (see APPENDIX B). The categories were defined as content learned through traditional lecture methods, content learned through discovery methods, discovery (science) process skills, and experimental design questions. Three experts with advance degrees in biology1 determined that the questions contained in the categories were comparable in level of difficulty. Descriptive statistics were determined for each student’s performance in each category and compared using a ANOVA. Regression analysis was performed on adjusted scores to determine whether the categories were indicative of overall final exam performance. Partial correlation coefficients were used to determine which category was the strongest indicator of final exam performance. Lastly, a correlation was performed between the final exam scores and the posttest attitude survey to determine the relationship between the two.

Attitude toward instruction. Students’ attitudes toward discovery instruction were determined using an anonymous, posttest-only survey given at the end of the semester. The survey contained four items describing students’ attitudes toward discovery instruction on a Likert-type scale in addition to student’s prediction of their final grade in the class. Descriptive statistics and frequency distributions were collected. Correlation analyses were performed to determine whether there was a relationship between students’

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1 All three experts were faculty of The University of Texas at Austin. Each expert possessed a Ph.D. in zoology and had at least 15 years of teaching experience with various lower and upper level physiology courses at the collegiate level.
attitudes toward instruction and their predicted final grade in the course.

RESULTS

Achievement. The students’ performance on the final exam was evaluated to determine the effectiveness of the discovery instruction on students’ content acquisition, science process skills, and experimental design capabilities. Corrected means, adjusted for varying point values on the categories, indicate that students performed best on those content questions learned through discovery methods and worst on experimental design questions learned through discovery methods (Table 1).

One-way ANOVA revealed the categories of the final exam were significantly different from one another (Table 2). Post hoc tests using Tukey’s honestly significant difference (at $P = 0.05$) indicated significant differences between the categories, discovery content, and experimental design, suggesting students performed best on content taught by discovery methods.

Linear regression analysis determined that the categories were indicative of final exam score. However, because the categories were part of (i.e., correlated with) the final exam score, partial correlation coefficients were used to determine which category was the strongest indicator of overall final exam performance. More specifically, partial correlation coefficients revealed that content learned through discovery methods was the strongest indicator of overall final exam performance (Table 3).

Attitude toward instruction. A postcourse survey was administered to determine students’ views of discovery learning pedagogy and to determine whether there was any relationship between their attitudes toward instruction and their perceived grade in the course. Students reported that discovery learning helped them learn the material (Table 4). They also believed that they could use the skills they acquired here in other courses and would choose another discovery course if given the opportunity. No significant correlations were found between the survey items and the students’ anticipated final grade in the class.

TABLE 1
Descriptive statistics of students’ achievement on exam categories

<table>
<thead>
<tr>
<th>Final Exam Category</th>
<th>Mean</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Discovery content</td>
<td>80.92</td>
<td>23.62</td>
</tr>
<tr>
<td>Discovery process</td>
<td>79.18</td>
<td>25.06</td>
</tr>
<tr>
<td>Lecture</td>
<td>78.05</td>
<td>21.91</td>
</tr>
<tr>
<td>Experimental design</td>
<td>76.13</td>
<td>20.08</td>
</tr>
<tr>
<td>Overall exam score</td>
<td>75.63</td>
<td>13.26</td>
</tr>
</tbody>
</table>

$n = 344$ students.

TABLE 2
Results of one-way ANOVA on exam categories

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>Sum of Squares</th>
<th>Mean of Squares</th>
<th>$F$</th>
<th>$F$ prob.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between groups</td>
<td>3</td>
<td>4,141.83</td>
<td>1,380.61</td>
<td>2.67</td>
<td>0.05</td>
</tr>
<tr>
<td>Within groups</td>
<td>1,364</td>
<td>705,599.58</td>
<td>517.50</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>709,741.40</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

DF, degrees of freedom.

TABLE 3
Partial correlation coefficients for exam categories

<table>
<thead>
<tr>
<th>Predictor</th>
<th>Partial Correlation Coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>Discovery content</td>
<td>0.42</td>
</tr>
<tr>
<td>Lecture content</td>
<td>0.39</td>
</tr>
<tr>
<td>Experimental design</td>
<td>0.18</td>
</tr>
<tr>
<td>Discovery process</td>
<td>0.17</td>
</tr>
</tbody>
</table>

TABLE 4
Postclass survey. Anonymous report of students’ views of discovery learning

<table>
<thead>
<tr>
<th>Survey Items</th>
<th>Mean</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1) I found the inclusion of active learning in this course helped me to understand the material better.</td>
<td>4.38</td>
<td>0.87</td>
</tr>
<tr>
<td>(2) I liked the opportunity to work open-ended problems instead of cookbook problems.</td>
<td>3.85</td>
<td>0.89</td>
</tr>
<tr>
<td>(3) I believe I can use the problem solving skills we learned in class in other situations.</td>
<td>4.00</td>
<td>0.90</td>
</tr>
<tr>
<td>(4) I would choose an active-learning course over a straight lecture course in the future.</td>
<td>4.08</td>
<td>0.91</td>
</tr>
</tbody>
</table>

Scale: 1 = strongly disagree, 5 = strongly agree. $n = 344$ students.
DISCUSSION

Achievement. The majority of the course was taught by traditional lecture methods, so it stands to reason, given that the questions within the different categories of the final exam were equally difficult, that students would perform best on questions that dealt with content presented through lecture. However, this was not the case. The results of this study indicate that students exhibited greater achievement on content-based questions learned by discovery and questions demanding the use of discovery process skills than on questions based solely on content learned through lecture. These findings support the hypothesis that student involvement in discovery learning would result in higher achievement in science content knowledge. These findings are especially important given the inconsistent findings within the research literature (e.g., compare Refs. 6 and 9).

One reason why discovery learning may improve student achievement is because instead of only lower level recall of factual information, it promotes higher-level thinking skills (e.g., application, analysis, synthesis, and evaluation). This higher-level thinking may have led to better student understanding of the discovery-based content and may explain the higher scores on the discovery content portion of the exam (vs. content learned through didactic means). This is further substantiated by the finding that performance on discovery-based content questions and lecture-based content within the final exam are most predictive of final exam score.

Other possible explanations for the increased achievement are that discovery learning increases student attention to task(s) at hand and creates an episodic memory that aids in reconstruction of knowledge. Student involvement in the discovery learning process (i.e., attention to task) “forces” them to struggle with the content and processes of science at the moment of instruction. This immediacy causes students to try to understand material and reconcile any cognitive dissonance in the classroom, at the moment of instruction, and not at a later date. Discovery learning promotes an episodic memory in which information is associated with specific events. Students can use recollections of the discovery activity itself to reconstruct the knowledge gained through the activity. Discovery activities used in this course may have contributed to the increase in student achievement based on these premises.

Perhaps the greatest effect of discovery learning is that it provides students with meaningful experiences, promoting meaningful learning. Researchers assert that meaningful experiences result in students who are motivated, self-directed learners that may be better able to learn and recall information (15, 20). With discovery, students learn in authentic contexts that can lead to curiosity and positive attitudes (20). In addition, discovery learning promotes meaningful learning. By involving the learner, discovery learning gives him/her more and different ways to experience the content, making it more meaningful and resulting in better recall of information (20). Discovery activities place content into context, which may have given students in this study the meaning they needed to make appropriate connections and therefore account for the increase in student achievement.

However, we must also acknowledge the most obvious, parsimonious explanation of the increased achievement scores, students’ “time on task.” More specifically, students may have scored better on discovery content material because, in addition to receiving a lecture on the information and possibly studying it outside of class, students performed activities using that information. The discovery activities provided students with opportunities to read, write, apply, listen, discuss, and reflect on the content and processes of the topics they were studying. It is well documented that writing, discussing, and sharing ideas, solving problems, and applying knowledge increases the tendency of students to retain knowledge (10, 17, 22). However, this alternative hypothesis does not discredit discovery learning but strengthens it. Pedagogies that allow students to focus attention on the critical tasks at hand, think about the content, and apply science content skills, resulting in increased content knowledge, should be the basis of every course. Discovery learning is one such pedagogy that, when used modestly in conjunction with traditional didactic instruction, increases student achievement.

Surprisingly, students in this study received the lowest scores on questions pertaining to experimental
design, on which the discovery activities were based. Although students participated in the discovery process, perhaps they did not recognize the designing of experiments as important relative to the outcomes or content learned through the experiments. As a result, students may not have devoted time to studying experimental design, instead focusing on content. Although at this point, we can only speculate as to the reason why students scored well on those exam questions pertaining to discovery content and science process but paradoxically failed to perform well on questions pertaining to experimental design. Further study is required to clarify this seeming contradiction.

Attitude toward instruction. This study also hypothesized that students would come to appreciate discovery learning and value it as an effective means for enhancing their learning. In support of the hypotheses, data suggest that students in this course liked the active, discovery-based problems, believed that discovery helped them gain an understanding of the material presented in this class, and, through discovery activities, developed skills that could be used in other courses. The improved understanding of material and decided course approval reported by students mirrors the results of earlier analyses (3, 6, 18).

Success, in terms of students’ appreciation of discovery learning may be due in large part to the melding of discovery activities and lecture. Researchers report that courses dominated by discovery and active-learning strategies can lead to poor student attitudes (16, 19). In the course studied here, discovery activities were used sparingly throughout the semester. The limited number of activities used in combination with traditional lecture-based instruction may have been a contributing factor to students’ approval of discovery learning.

Students’ positive views of discovery learning are of particular importance given the context of this study. Discovery learning activities were performed successfully in a large lecture hall without sacrificing the amount of content covered, a common criticism of active instruction such as discovery learning (3). To be successful in a large class, activities must be highly structured (11). That these activities were structured and embedded within lecture may account for their success. Students expect faculty to lecture, so lecture cannot be totally abandoned in favor of a strictly activities-based course unless the activities are gradually implemented over time and students recognize the activities as an integral part of the learning process (12, 16). In the context of this course, students enjoyed and valued participating in the discovery learning activities that gave them experience with processes of science.

CONCLUSION

As evidenced by several national and regional efforts, colleges are striving to improve teaching and learning. Part of this effort involves striving toward goals identified by national science reform efforts (e.g., American Association for the Advancement of Science, Science for All Americans) that include understanding the scientific method and developing scientific habits of mind. For many instructors, departments, and campuses, active discovery learning is viewed as an effective means for implementing science process into a curricula that has traditionally emphasized recall of factual information. The study presented here shows that a moderate amount of discovery learning used in combination with traditional methods of instruction may be an effective means for promoting students’ achievement. Furthermore, when used conservatively students appreciate the value of discovery learning.

APPENDIX A

Discovery Learning Example

In this discovery activity concerning stomatal control, students divide up into informal groups to work on designing an experiment that teaches and reinforces science process skills. Students are given prior information on experimental design and stomatal anatomy and control via lecture and handouts. The activities are graded as part of an “in-class” exercise and calculated into the students’ final grade. At the end of the activity, random groups are asked to present their experiment to the rest of the class. The following is from the discovery activity regarding stomatal control.

Directions For the Group Activity

Parts A-C: follow underlined directions on your group answer sheet.

Part A. What aspect of stomatal control do you wish to investigate? Decide on your independent variable (some event in the hypothesized pathway) and which dependent variable, either stomatal
aperture or rate of stomatal conductance (same as transpiration rate) you wish to investigate.

Answer 1–6 on the group answer sheet. Then, get a data set that is appropriate to your proposed measurement. The data sets on the pink sheets are taken from published research articles.

Part B. Graph your data on the form provided. Place the independent variable (test variable) on the horizontal axis and the dependent variable on the vertical axis. Label the axes of the graph. Graph data points using points (•) or circles (○).

Answer 7–8 on the group answer sheet.

Part C. What you have is a set of measurements that indicates whether or not a relationship exists between your independent and dependent variables. This is one set of observations, but you need to perform an experiment in order to test the mechanism of stomatal control.

Perform an imaginary experiment. What would be the effect of a specific manipulation on guard cell function? Choose an experimental manipulation, such as A–E below, and predict how your curve would differ if the manipulation were done at about the midpoint of your graph.

Sample substances to add in your manipulation:

A) toxin that blocks the proton pump protein
B) toxin that blocks the K⁺-transport channel
C) toxin that inhibits ATP hydrolysis
D) a plant "stress hormone" that closes the stomata
E) some other specific toxin that does what?

On your graph: indicate with an arrow along the x-axis the point at which you make the manipulation. Predict the results by graphing hypothetical values of the dependent variable as "X" points on the graph.

Answer 9–11 on the group answer sheet.

In-Class Exercise

Print names in your group:

Part A.
1) State a testable hypothesis (relationship, association)
2) State the null hypothesis
3) What will be your test variable? (the independent variable)
4) What will you measure (what is the dependent variable)
5) Name at least THREE variables to control in your investigation.
6) What is your prediction of the graphical relationship between your test variable and the dependent variable (measures of the stomatal aperture or conductance)?

Part B (on graph paper).
7) Are your data consistent with your null hypothesis or do they permit you to reject it?
8) Explain the relationship in your graph in terms of what’s happening with the guard cells and stomatal function.

Part C.
9) What manipulation did you choose? (beginning of manipulation indicated by arrow)
10) What is your prediction of the effect of the manipulation on your dependent variable?
11) Explain your predicted results in terms of stomatal function.

APPENDIX B

Content-Based Questions Taught by Lecture

1. Explain how negative feedback will work in ONE of these two systems. Include the effect of the hormone, the target organ, and how the secretion of the hormone gets turned off in negative feedback.

a) release of the hormone secretin
b) release of the hormone CCK (cholecystokinin).

2. The mammalian kidney displays the relationship between structure and function in several ways. Choose one of the major nephron functions, filtration (A), secretion (B), or reabsorption (C), and answer the following:

a) state this function.
b) describe how the shape of the nephron is related to this specific function.
c) describe how the membrane properties of the nephron are related to this specific function.

3. Water moves across membranes by osmosis. (Answer a-c about osmosis).

a) Name a specific plant or animal tissue or structure whose function relies on extensive transport of water.
b) Explain what the cells do to cause osmosis in that particular system and where water moves.
c) How does osmosis in this tissue help the entire organism to function?

Content-Based Questions Taught by Discovery

1. For ONE of the following types of cells (A, B, or C), name three aspects of specific structure (organelles, membrane proteins, shape, etc.) the cells have and for each structure, tell how it is related to the functions important in that specialized type of cell.
A) transport epithelium in animal kidney.

B) guard cells in plant leaf.

C) lymphocyte cells in human blood and lymph

2. Water moves across membranes by osmosis. Choose ONE of these plant structures whose function depends on osmosis: root hair (A); leaf guard cell (B); phloem cell (C)

   a) Explain what the cells do to cause osmosis in that particular system and where water will move.

   b) How does osmosis in these cells help the entire plant to function?

Discovery Process-Based Question

1. This is the oxygen-binding curve for the typical hemoglobin (graph is provided).

   a) As blood arrives into capillaries next to the lung alveoli where $PO_2 = 100$ mmHg, what percentage of hemoglobin in the red blood cells would be bound with $O_2$?

b) When blood arrives at cells where $PO_2 = 40$ mmHg, would hemoglobin be likely to give up (unbind) oxygen or pick up oxygen?

c) If this curve were shifted to the left, would the hemoglobin be more likely or less likely to pick up (bind to) oxygen from its environment?

Experimental Design-Based Question

1. A physiologist is interested in knowing the effect of certain drugs and their interactions on heartbeat rates. Her lab setup allows her to infuse substances into the circulatory system of rats while continuously monitoring their heart rate. Think of an experiment for her to test hypotheses about the effects of Drug A and Drug B. Answer the following three questions about this experiment.

   a) What is the dependent variable in this experiment?

   b) Name a control variable to be held constant for all tests.

   c) Diagram or list how you would utilize the 60 rats in the experiment, for example, five rats given Drug A, five rats given Drug A+C, etc. (you don’t need to write out the entire experimental procedure).

REFERENCES


