RESEARCH ON LEARNING

Scaffolded Instruction Improves Student Understanding of the Scientific Method & Experimental Design

ALLISON R. D'COSTA,
MARK A. SCHLUETER

Abstract

Implementation of a guided-inquiry lab in introductory biology classes, along with scaffolded instruction, improved students' understanding of the scientific method, their ability to design an experiment, and their identification of experimental variables. Pre- and postassessments from experimental versus control sections over three semesters showed that most students improved in their understanding of the scientific method and experimental design skills. Students exhibited improvement in their ability to create hypotheses and correctly identify controls and dependent variables. However, students in both groups struggled with the identification of independent variable and controlled variables.

Key Words: *Scientific method; guided inquiry; experimental design.*

For several years, there has been a call to reform the way science is taught (Rutherford & Ahlgren, 1990; National Research Council [NRC], 2003). Current science instruction must include the use of "inductive" instructional methods, such as inquiry-based learning, and opportunities for students to experience the nature of science (NRC, 2000; Lunsford, 2003). Ample literature shows that this type of learning actively engages students through problem solving and critical thinking, as well as improves their academic achievement (Bransford et al., 1999; Prince & Felder, 2007).

Ample literature shows that this type of learning actively engages students through problem solving and critical thinking.

Inquiry is an active-learning process in which students analyze data to answer research questions (Bell et al., 2005; Wilke & Straits, 2005). Because not all inquiry is equal, Herron came up with a model that classifies inquiry into four levels based on how much teacher direction is provided to the students in a science activity, and whether there is already an existing solution to the problem (Herron, 1971). In the first level, called "confirmation/verification," the teacher provides students with the research question and procedure, the students are told how to analyze the data, and the results are known to the teacher and students in advance. In the second level, called "structured" inquiry, the teacher provides students with the research question and procedure, the students are given data and asked to analyze it and formulate an explanation, and although the students don't know the result in advance, the teacher does. "Guided inquiry" is the third level, in which students design their own procedure to answer a question provided by the teacher or selected from a list of questions. They must decide what data they need to collect, analyze the data, formulate and evaluate an explanation, and connect it to scientific knowledge. The results are usually not known and may vary from student to student. In the last level, "open inquiry," the question and procedure are student generated, and the results are not known and may vary from student to student (Herron, 1971; Bell et al., 2005; Kellow, 2007). Scientific inquiry challenges students to ask questions, conduct experiments, gather evidence, and apply the concepts they have learned. Most inquiry requires skills such as designing an experiment, group work, problem solving, data interpretation, oral and written communication, and reading of primary literature (Wilke & Straits, 2005; Coil et al., 2010). Research has shown that acquisition of these skills is the hallmark of an undergraduate science education (Airey & Linder, 2009; Alberts, 2009a, b; Bao et al., 2009; Brickman et al., 2009). It has been suggested that instructors must not assume that all students possess the skills required to conduct inquiry (Wilke & Straits, 2005), and a recent survey showed that even though most college science faculty overwhelmingly support teaching science process skills, they spend less time teaching these skills in lieu of content (Coil et al., 2010).

It is recommended that instructors scaffold the levels of inquiry in order to help students acquire the skills, and begin teaching these skills early in an undergraduate's science education (Coil et al., 2010). Students should not be exposed to open inquiry until they have sufficient experience with the lower levels of inquiry. Gradual progression to the higher levels of inquiry by varying the amount of information given to students, and by giving them more ownership and responsibility of their experiment, will help students gain confidence to conduct their own scientific investigations.

The American Biology Teacher, Vol. 75, No. 1, pages 18–28. ISSN 0002-7685, electronic ISSN 1938-4211.
DOI: 10.1525/abt.2013.75.1.6

While students in our college-level introductory biology courses for majors can list the steps of the scientific method, a majority are uncertain about designing a controlled experiment and fail to understand the impact of the experimental variables on the result of the experiment (Grunwald & Hartman, 2010). It was hypothesized that scaffolded instruction of experimental design would provide students the skills to design their own experiment in a guided-inquiry lab in introductory biology, and that this exercise would give them a better understanding of the scientific method and experimental design.

○ Methods

The hypothesis was tested over three semesters using two sections of introductory biology for majors each semester, with all sections taught by the same professor. Each semester, one section served as the experimental section, with students exposed to an inquiry-based lab, while the other section served as the control, performing traditional labs. Assignment of sections was random. In order to determine whether students had prior knowledge or any misconceptions about the scientific method and experimental design, a pretest comprising 30 multiple-choice questions was administered to both sections (Appendix and Table 1).

We scaffolded the instruction of experimental design in both sections in the first 2 weeks of lab, but included a "guided inquiry" lab in the third week only in the experimental section to give students an opportunity to apply their skills. We wanted to determine whether this extra application of skills while working independently would solidify the students' grasp of experimental design (Table 2; Schlueter & D'Costa, 2013).

Following the pretest, both sections discussed the scientific method and steps toward designing a controlled experiment. Students in the experimental section were given a brief introduction to the bean beetle *Callosobruchus maculatus*, the model organism we chose to use in the inquiry lab. Students observed and learned to recognize the features of the adult beetles and eggs, and practiced handling and viewing them under a dissecting microscope. Next, the students were asked the question, "Do female beetles prefer to lay eggs on their natal bean (bean-type from which they hatched)?" The instructor facilitated a brainstorming session in which the whole class participated in experimental design guided by the instructor. It was decided that female beetles be offered a variety of beans, including their natal bean, to lay eggs on; if there was a preference, the hypothesis was that more eggs would be found on the natal beans than on other beans. A week before, the instructor had set up the experiment as follows. Three females that had hatched out of mung beans (natal bean) were placed along with 3 males in a Petri dish containing 10 black-eyed peas, 10 adzuki, and 10 mung beans. Twelve such Petri dishes were set up. A week was given for the females to mate and lay eggs on the beans. Following the brainstorming, these Petri dishes were handed to the students, who had to count the number of eggs laid on each bean type and determine whether the females preferred the mung (their natal bean) over the rest.

The following week, students (in groups of 4) in the experimental section spent about half of the lab designing their own experiments using bean beetles. Students either picked a question from a list or formulated their own observation-based question (Figure 1), and then developed an original hypothesis. Facilitated by the instructor and a worksheet, students had to design their experiment using materials and equipment readily available in the lab (see Schlueter & D'Costa, 2013). After spending about 45 minutes brainstorming, each student group gave a short presentation to the class on the hypothesis they developed and the experiment they would perform to test the hypothesis. The class and instructor made suggestions to the group on their experimental design and hypothesis. Outside of class, the students met with group members to discuss any changes to their experiment.

During the first 30 minutes of the next lab, students set up their experiments and began to collect data over the next 3–4 weeks. At the end of their experiment and after data analysis, each student group gave a short presentation to the class, discussing their results, whether the data supported or refuted their hypotheses, and any inconsistencies or errors in the experimental design. Then the students wrote a brief lab report, which was submitted to the instructor.

At the end of the semester, students from both experimental and control sections took a posttest, identical to the pretest. Students did not receive their pretest results prior to taking the posttest. Both tests were administered by Scantron and were graded at the end of the semester. A paired one-tailed t-test was used to compare the results of the pretest and posttest.

Table 1. Question categories in the pre- and postassessment.

Question Category	Number of Questions	Question Number on the Assessment Exam
Use of scientific method	3	1, 23, 27
Theory/hypothesis	6	2, 3, 20, 25, 26, 30
Experimental design & sample size	5	14, 21, 22, 28, 29
Independent variable	5	4, 8, 13, 17, 24
Dependent variable	4	7, 9, 16, 18
Controlled variable	3	7, 11, 19
Control	4	5, 10, 12, 15

○ Results

The pre- and posttest for each student were compared, and the percent change was calculated. Table 3 shows the average pretest and posttest scores for each section over the three semesters.

Except for the control section in the second semester, all sections showed some improvement in their ability to apply the scientific method to problems and pick out experimental variables. Scores for students who did not take both the pretest and the posttest were excluded.

A paired one-tailed t-test that compared the pretests and posttests of all the students in the experimental group showed a statistically significant improvement of 7% ($t = 4.856$, $p = 0.0001$) in their ability to apply the scientific method and experimental design. In comparison, the control sections showed an improvement of only 2%, which was not statistically significant ($t = 1.172$, $p = 0.1233$).

Question category analysis was performed using paired one-tailed t-tests. Each question category had three to six questions.

Table 2. Comparison of tasks conducted by experimental and control sections.

3-hr lab	Experimental	Control
Week 1	(1) Pretest (2) Introduction to scientific method, nature of science, basic statistics, steps to designing a controlled experiment, and experimental variables. (3) The instructor facilitated a brainstorming session in which the whole class participated in the design of a controlled experiment.	
	Experimental: examined data from an experiment dealing with egg-laying preferences of bean beetles on different bean types (see Schlueter & D'Costa, 2013)	*Control:* examined data from an experiment regarding peanut growth in different types of soil
	STRUCTURED INQUIRY: At this step of the scaffold, both sections received the experimental question and determined the experimental design, but did not perform the experiment themselves. Students tallied up the raw data, analyzed it, reflected on the results, and made conclusions, including whether the hypothesis that they had developed during the brainstorming session was supported or refuted by the data.	
Week 2	(1) *Corn experiment:* Do water or soil nutrients (fertilizer) affect corn plant growth? Instructor facilitated a brainstorming session about conditions required for corn growth and discussed experimental design. All students examined corn growth in four different soil conditions (*control:* soil + water; *drought:* soil + ¼ water; *fertilizer:* soil + water + fertilizer; and *student's choice:* soil + water + (e.g. excess water or fertilizer, coffee, eggshells added)). The students were given detailed methods on experimental setup and procedures to follow to perform the experiment. They germinated the corn seeds and placed the germinated seeds in 4 different soil conditions. After 4 weeks, the students analyzed the growth of the corn plants, reflected on the results, and made conclusions, including whether the hypothesis that they had developed was supported or refuted by the data. Both sections wrote a detailed lab report.	
	STRUCTURED INQUIRY: At this step of the scaffold, both sections received the experimental question, brainstormed as a class to determine experimental design, received detailed methods on experimental setup, performed the experiment, analyzed the raw data, and made conclusions.	
	Experimental: Brainstorm the design of their own group experiments using bean beetles (1.5 hour)	*Control:* Students dismissed
Week 3	Students set up their experiment (generally in <30 minutes), and began to collect data over the next 3–4 weeks	No guided inquiry activity
	GUIDED INQUIRY: At this step of the scaffold, students chose their own question to investigate, developed their own hypothesis, designed an original experiment, analyzed their results, and made conclusions. There was very little help from the instructor.	
	Both sections worked on standard lab exercises for the course	
Week 4 onward	Students collected data from their beetle experiments over the next 3–4 weeks	No guided inquiry activity
	Both sections worked on standard lab exercises for the course	

Comparisons were made examining pre- and posttest scores for each relevant group of questions from the three experimental sections. In addition, comparisons were made examining pre- and posttest scores for each relevant group of questions from the three control sections (Figure 2).

In the experimental group, question categories with the most improvement were scientific method, with 11% improvement ($t = 3.671$, $p = 0.0334$); hypothesis/theory questions, with 11% improvement ($t = 2.853$, $p = 0.0178$); dependent-variable questions, with 17% improvement ($t = 10.614$, $p = 0.0009$); and control-group questions, with 4% improvement ($t = 3.212$, $p = 0.0424$). No significant improvement was found in questions that dealt with the independent variable ($t = 0.446$, $p = 0.3429$) and controlled variables ($t = 2.115$, $p = 0.0624$), or questions that dealt with sample size and experimental design ($t = 1.054$, $p = 0.1757$) (Figure 2). When combining all the question categories, experimental group students showed a statistically significant improvement of 8% ($t = 4.000$, $p = 0.0071$).

In the control group, the only question categories that showed improvement were the hypothesis/theory questions ($t = 2.188$, $p = 0.0401$) and the dependent-variable questions ($t = 2.898$, $p = 0.0313$). All the other question categories showed no improvement. When combining all the question categories, control-group students showed little improvement (3%), which was not statistically significant ($t = 1.746$, $p = 0.1314$) (Figure 2).

○ Conclusions

Science process skills provide students the foundation to do inquiry. Scaffolded instruction gives students repeated chances to practice a

BEAN BEETLE EXPERIMENT

Goal: To formulate a hypothesis and design an experiment to test your hypothesis.

Today, each lab group will choose one of the following observations and questions to pursue further. Next week, you will perform an experiment designed by you to test the question that you have chosen to investigate. Prior to beginning the experiment next lab, each group will meet outside of class and prepare a 5-minute presentation on their question, hypothesis, and the experiment that was designed by the group.

OBSERVATIONS AND QUESTIONS ABOUT BEAN BEETLES

Males are driven to find females and mate with them. Typically, males find females and begin mating within 15 minutes. Male beetles have been observed attempting to mate with other male beetles.

(1) What senses do males use to find their mates?

(2) Does mating decrease or increase a beetle's life span?

(3) Does the presence of females reduce or increase the number of male-to-male mating attempts?

(4) Does the presence of extra male beetles increase or decrease the time it takes for a male to successfully mate with a female beetle?

It is claimed that adult bean beetles do not need to eat or drink.

(5) Does the presence of food increase the life span of a bean beetle?

(6) Does the presence of light or darkness affect the life span of a bean beetle?

Females show preference to laying eggs on their natal bean (the bean they hatch from).

(7) Does the size of a natal bean affect whether a female will lay an egg on it?

(8) Does the presence of an egg on a bean affect whether a female will lay a second egg on it?

(9) Is seed coat necessary to lay eggs?

(10) What makes the natal bean attractive to the female: its color or shape?

SUPPLIES AVAILABLE

- Virgin male and female beetles.
- Nonvirgin male and female beetles.
- Mung beans (natal bean) with seed coat, mung bean without seed coat, mung beans w/ eggs.
- Other bean types (adzuki beans, black-eyed peas, chickpeas, black beans).
- Water, yeast, fruit-fly media.
- Petri dishes, scissors, microscopes, electronic balances.
- Beetle "storage" areas include (a) cool area, (b) warm area, (c) dark area, and (d) light area.

Figure 1. Guided-inquiry experiment guidelines and resource worksheet.

Table 3. Comparison of pretest and posttest scores for each section and percent change.

Semester	Section	Number of Students	Average Pretest Score	Average Posttest Score	Change	Percent Change
1	Experiment	20	20.6	22.5	1.9	0.06
	Control	19	18.9	19.6	0.7	0.02
2	Experiment	18	21.2	21.8	0.6	0.02
	Control	17	21.4	20.4	−0.9	−0.03
3	Experiment	19	19.6	23.2	3.6	0.12
	Control	18	20.8	22.6	1.8	0.06
Average	Experiment	57	20.5	22.5	2.0	0.07
	Control	54	20.3	20.9	0.6	0.02

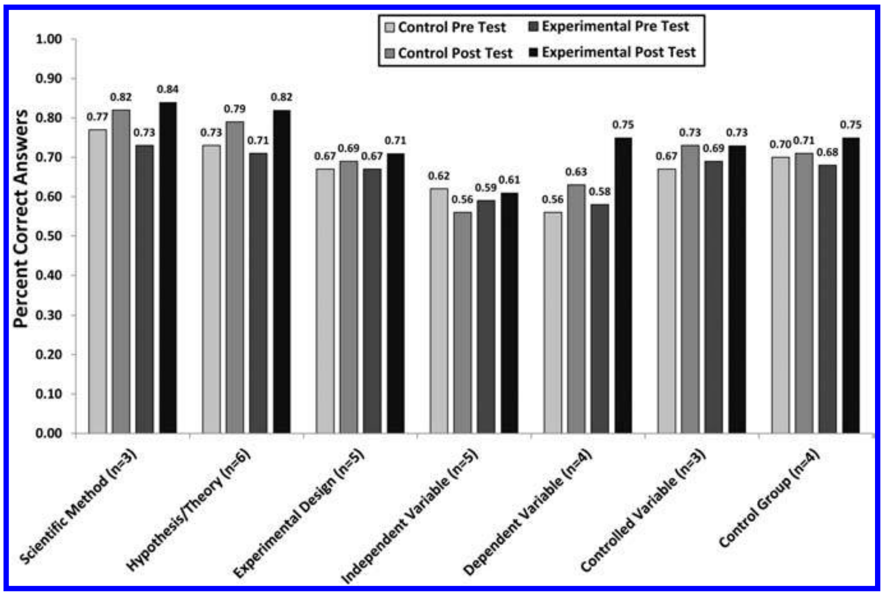


Figure 2. Mean results of specific question categories on the scientific-method assessment test given to freshman biology students over three semesters.

skill with decreasing dependence on the instructor, as they acquire the knowledge and confidence to perform the skill. Our goal was to improve students' skills in applying the scientific method, designing experiments, and picking out experimental variables. We hypothesized that providing 3 weeks of scaffolded instruction in experimental design would improve students' skills in these areas. We conducted our study over three semesters, with a control and experimental section of introductory biology for majors each semester, both taught by the same instructor. Following 2 weeks of structured inquiry labs in both sections, the experimental section was exposed to an additional "guided inquiry" lab in which the students could work independently and apply what they had learned. Pre- and posttest comparisons of experimental versus control sections showed that this additional guided-inquiry lab gave students a better understanding of the scientific method and experimental design. Students in the experimental sections showed a greater improvement (7%) in their ability to apply the scientific method and experimental design over the control sections (2%).

Both sections still struggled to identify the independent and controlled variables in an experiment. Students often confused the control with the controlled variables, and the experimental group with the independent variable. More scaffolding with structured and guided-inquiry labs should alleviate this problem and help students master these skills. One exception was noted: Students in the experimental section improved their ability to identify the dependent variable by 17% (Figure 2). In the future, we plan to greatly increase the number of inquiry-based labs in introductory as well as upper-level courses. We also plan to allow students to repeat their experiments to address any errors and inconsistencies that they find.

Data also suggested that over the three semesters, the instructor had improved his teaching of the scientific method to the students. Students in the third semester in both experimental and control sections showed the greatest improvement (Table 3). Specifically, in the first semester, the experimental section improved by 6%, compared with 12% improvement found in the third semester. Likewise, students in the control section showed a 2% improvement in the first semester, compared with a 6% improvement in the third semester.

By conducting this educational research experiment, we have realized that instructors cannot assume that all students enter college with the science process skills needed for inquiry. Instructors must devote the time to provide explicit and scaffolded instruction of these skills and must begin teaching these skills early in an undergraduate's science education. Here, we have provided one such example of how scaffolding inquiry labs help students acquire skills. Instructors must act as facilitators and give students the time to brainstorm and think for themselves. Very often instructors can't wait to give students the answer, and this does not help in inquiry-based learning. Instructors should also ensure that students do not go off track as they work independently. Conducting these labs required quite a bit of prep on the part of the instructors. This included growing and maintaining the beetles, collecting virgins, and making sure there were sufficient beetles and virgins available in time for the weeks they were needed.

Student evaluations indicated that students enjoyed designing and having control over their own experiments. They found the inquiry-based labs to be more interesting and engaging and preferred these investigative lab experiences to the more structured traditional labs. However, they did not like the prolonged 3–4 weeks of data collection time it took to monitor the beetles; they preferred instant results. These inquiry labs got students interested in doing research. Two students asked to do independent research with beetles over the next 6 months. One student wanted to determine whether adult beetles could survive in the absence of food and water, and the other investigated the effect of temperature on a beetle's life span. Both students presented their research at a local scientific meeting.

Our work has clearly shown that scaffolding inquiry labs helped students acquire skills and got a few of them interested in conducting research. We plan to offer students many more opportunities to do inquiry. Even though these labs can add to an instructor's workload, it is very satisfying to know that this method works. Instructors need not reinvent the wheel when designing inquiry labs – sometimes it just takes presenting a traditional lab in a different way by having students perform the lab before the concept is taught, or by asking students to come up with their own procedures (Bell, 2005).

○ Acknowledgments

We thank Drs. Lawrence Blumer and Christopher Beck for inspiring us through their National Science Foundation–sponsored Bean Beetle Curriculum Development Workshop. We also thank Sarah Schlueter for her assistance in preparing the manuscript.

References

Airey, J. & Linder, C. (2009). A disciplinary discourse perspective on university science learning: achieving fluency in a critical constellation of modes. *Journal of Research in Science Teaching*, *46*, 27–49.

Alberts, B. (2009a). Making a science of education. *Science*, *323*, 15.

Alberts, B. (2009b). Restoring science to science education. *Issues in Science and Technology*, *25*, 77–80.

Bao, L., Cai, T., Koenig, K., Fang, K., Han, J., Wang, J. & others. (2009). Learning and scientific reasoning. *Science*, *323*, 586–587.

Bell, R.L., Smetana, L. & Binns, I. (2005). Simplifying inquiry instruction: assessing the inquiry level of classroom activities. *Science Teacher*, *72*, 30–33.

Bransford, J., Brown, A.L. & Cocking, R.R., Eds. (1999). *How People Learn: Brain, Mind, Experience, and School.* Washington, D.C.: National Academy Press.

Brickman, P., Gormally, C., Armstrong, N. & Hallar, B. (2009). Effects of inquiry-based learning on students' science literacy skills and confidence. *International Journal for the Scholarship of Teaching and Learning*, *3*, 1–22.

Coil, D., Wenderoth, M.P., Cunningham, M. & Dirks, C. (2010). Teaching the process of science: faculty perceptions and an effective methodology. *CBE Life Sciences Education*, *9*, 524–535.

Grunwald, S. & Hartman, A. (2010). A case-based approach improves science students' experimental variable identification skills. *Journal of College Science Teaching*, *39*, 28–33.

Herron, M.D. (1971). The nature of scientific inquiry. *School Review*, *79*, 171–212.

Kellow, J.-M. (2007). Herron's model. [Online.] Available at http://www.inquiringmind.co.nz/Herron_Model.htm.

Lunsford, E. (2003). Inquiry in the community college biology lab. *Journal of College Science Teaching*, *32*, 232–235.

National Research Council. (2000). *Inquiry and the National Science Education Standards: A Guide for Teaching and Learning.* Washington, D.C.: National Academy Press.

National Research Council. (2003). *BIO 2010: Transforming Undergraduate Education for Future Research Biologists.* Washington, D.C.: National Academy Press.

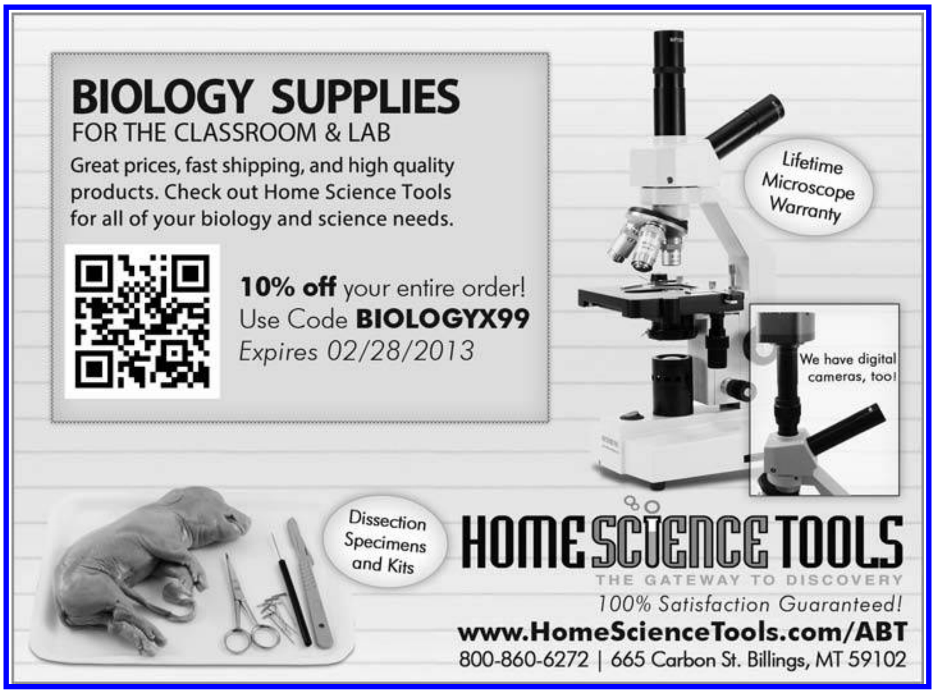
Prince, M. & Felder, R. (2007). The many faces of inductive teaching and learning. *Journal of College Science Teaching*, *36*, 14–20.

Rutherford, F.J. & Ahlgren, A. (1990). *Science for All Americans.* New York, NY: Oxford University Press.

Schlueter M.A. & D'Costa, A.R. (2013). Guided Inquiry Lab using Bean Beetles for Teaching the Scientific Method and Experimental Design. *American Biology Teacher, 75* (*in press*).

Wilke, R.R. & Straits, W.J. (2005). Practical advice for teaching inquiry-based science process skills in the biological sciences. *American Biology Teacher*, *67*, 534–540.

ALLISON R. D'COSTA is an Assistant Professor of Biology at Georgia Gwinnett College, 1000 University Center Lane, Lawrenceville, GA 30043; e-mail: adcosta@ggc.edu. MARK A. SCHLUETER is a Professor of Biology, also at Georgia Gwinnett College; e-mail: mschluet@ggc.edu.



Appendix. Pre- and Posttest to Assess the Understanding of the Scientific Method and Experimental Design. Text in bold is the correct answer.

1. Put the parts of the scientific method in the correct order:
   (I) Design an experiment
   (II) Formulate a hypothesis
   (III) Analyze data, make conclusions
   (IV) Determine whether hypothesis is supported or refuted
   (V) Do background research and ask questions
   (VI) Make an observation

   (a) I, III, II, IV, V, VI
   (b) V, VI, I, III, II, VI
   (c) VI, V, II, I, III, IV
   (d) II, VI, V, I, III, IV

2. A hypothesis
   (a) is a random guess.
   (b) is a theory.
   (c) must be testable.
   (d) must always be proven true.

A rice farmer has determined that his rice yield has declined since last year. He feels that the sparrows are eating the ripe rice grains. To test his hunch, he stakes a fine net above half the rice field, while keeping the other half of the field open. Answer questions (3–7).

3. Which would be a reasonable hypothesis for the farmer's experiment?
   (a) The presence of the net will not keep the sparrows away.
   (b) The presence of the net will keep the sparrows away and increase the yield of rice.
   (c) The presence of the net will lower the levels of sunlight and decrease the yield of rice.
   (d) The presence of the net will do nothing to increase the yield of rice.

4. What is the independent variable in the farmer's experiment?
   (a) The sparrows
   (b) The net
   (c) The rice field covered with the net
   (d) The rice field not covered with the net

5. What is the control group in the farmer's experiment?
   (a) The sparrows
   (b) The net
   (c) The rice field covered with the net
   (d) The rice field not covered with the net

6. What would be a dependent variable in the farmer's experiment?
   (a) The amount of sunlight passing through the net
   (b) The number of sparrows caught in the net
   (c) The amount of weeds growing in the fields
   (d) The yield of rice

7. What is a controlled variable in the farmer's experiment?
   - (a) The amount of sunlight
   - (b) The type of rice being grown
   - (c) Amount of water
   - **(d) All of the above**
   - (e) None of the above

8. A well-designed experiment must test __________ independent variable(s) at a time.
   - (a) zero
   - **(b) one**
   - (c) two
   - (d) several

A clinical trial for a new drug for colon cancer, "Colonix," was giving very positive results in the treatment of colon cancer in the "experimental" versus "control" group. Each group was composed of 50 people. Answer questions (9–11).

9. What could be a dependent variable in this experiment?
   - **(a) The number of tumors**
   - (b) The number of times a day "Colonix" was administered
   - (c) The amount of weight lost by each group
   - (d) The side-effects of the drug

10. The people in the "experimental" group were administered "Colonix" once a day, while the people in the "control" group were administered
    - (a) "Colonix" once a day.
    - (b) "Colonix" twice a day.
    - **(c) a placebo once a day.**
    - (d) aspirin once a day.

11. "Colonix" was so successful that the experimenters decided to publish their results in a scientific journal. The reviewers for the journal found that the "experimental" group was mostly composed of people in their twenties, while the "control" group was mostly composed of middle-aged people. The reviewers decided that the study was not valid and could not be accepted for publication because:
    - (a) "Colonix" should not be given to young people.
    - (b) There were too few people in each group.
    - (c) "Colonix" should have been given to the middle-aged group instead of the group in their twenties.
    - **(d) The groups were not age-matched.**

12. A "control" lacks the __________ variable.
    - **(a) independent**
    - (b) dependent
    - (c) controlled
    - (d) none of the above

13. A student decides to set up an experiment to see if a new fertilizer affects the growth of roses. He sets up 10 rose pots. Five of the pots will receive a small amount of fertilizer in the soil and will be placed in the sun. The other five pots will not receive fertilizer and will be placed in the shade. All 10 pots will receive the same amount of water, the same type and height of rose plants, and the same type and amount of soil. He grows the roses for 2 months and charts the growth every 2 days. What is wrong with this experiment?
    - (a) The number of pots in each group is too few.
    - **(b) Both groups of pots should be placed in the sun.**

(c) He needs to add more fertilizer.

(d) Roses take more than 2 months to grow.

14. A group of students wants to determine whether mealworms prefer light or dark. Which is the best experimental design?

(a) Take 3 mealworms, place one on cardboard, one on paper, and the third one on foil. Determine the distance crawled by each mealworm in the presence and absence of light on each surface.

(b) Take 3 mealworms, place all of them on paper. Determine the distance crawled by each mealworm in the presence and absence of light.

(c) Take 12 mealworms, place them side-by-side on cardboard, and determine whether each mealworm moves either toward or away from the light.

(d) Take 12 mealworms, place them side-by-side on cardboard, and determine the distance crawled by each mealworm in the presence and absence of light.

15. A student wanted to determine what would happen to starch production (measured by an iodine test) in leaves of a plant that did not receive light. He used one plant, but covered several leaves with foil to block the sun, while leaving several leaves uncovered. What is the control in this experiment?

(a) Foil

(b) Leaves covered with foil

(c) Leaves not covered with foil

(d) Amount of starch produced

16. The factor that is observed/measured/counted in an experiment is called

(a) the control.

(b) the controlled variable.

(c) the independent variable.

(d) the dependent variable.

A student decides to determine the length of time it takes for milk left out of the fridge to spoil. He buys 1% milk from a supermarket, fills two 100-mL glass beakers with 50 mL of milk, and places one beaker in the fridge and one beaker on his kitchen counter. Answer questions (17–19).

17. What is the independent variable?

(a) Milk

(b) Milk in the fridge

(c) Time milk is left out of the fridge

(d) Milk on the kitchen counter

18. What is the dependent variable?

(a) The smell of the milk

(b) The taste of the milk

(c) The texture of the milk

(d) All of the above

(e) None of the above

19. A controlled variable in this experiment is

(a) the smell of the milk.

(b) the amount of milk in each beaker.

(c) the temperature at which both beakers are kept.

(d) the taste of the milk.

20. What is FALSE about a theory?
   (a) It is a general set of principles that explains some aspect of nature.
   (b) It can never be proven false.
   (c) It is supported by large amounts of evidence.
   (d) All of the above

21. A market-researcher wants to compare the amount of usage of iPods in adults versus teenagers. The best way would be for him to
   (a) form two groups, one comprising 10 adults and the other comprising 10 teenagers, and ask each group how much time they spend on their phones.
   (b) ask his wife and teenage son how many hours they spend listening to their iPods.
   (c) form two groups, one comprising 100 adults and the other comprising 100 teenagers, and ask each group how much time they spend on their iPods.
   (d) form two groups, one comprising 10 adults and the other comprising 10 teenagers, and ask each group how much time they spend on their iPods.

22. Which of the following would test whether girls or boys were smarter?
   (a) Form two groups, each comprising 100 age-matched girls and boys, and test them on various subjects and levels.
   (b) Form two groups, each comprising 100 age-matched girls and boys, and ask them one question.
   (c) Give a 10-year-old girl and a 10-year-old boy a biology test and see who scores best.
   (d) Form two groups, each comprising 100 age-matched middle school girls and boys, and ask them college-level questions.

23. A high school student is looking for a topic for the school's upcoming science fair. Which of the questions below would NOT be a good idea for him to pursue?
   (a) Is the weed-killer "Weed-be-gone" effective?
   (b) Are people who eat candy happier?
   (c) Does drinking carbonated sodas cause tooth decay?
   (d) Is Bermuda grass more drought-resistant than other types of grass?

24. An exercise-science researcher wants to determine whether consuming proteins *or* carbohydrates within 45 minutes after a workout increases insulin levels in the blood. He forms two age-matched groups and feeds one group some protein and carbohydrates plus 8 oz. water after their workout, while giving the other group only 8 oz. water. He then draws blood from his subjects to determine their insulin levels. What is wrong with his experimental design?
   (a) He is using two independent variables in his experiment.
   (b) He will not be able to tell whether the protein or the carbohydrate increased insulin levels.
   (c) He needs to also test one group with only carbohydrates, another with only protein.
   (d) All of the above
   (e) None of the above

25. Which of the following best describes a null hypothesis?
   (a) A hypothesis that gives data that cannot be measured
   (b) A hypothesis that states there is no difference between two groups
   (c) A hypothesis that can be proven to be true
   (d) A hypothesis that is false

26. If your hypothesis is not supported by the data,
   (a) your experimental design is incorrect.
   (b) your experiment is a failure.

(c) you should ignore the data and repeat the experiment.

(d) None of the above

27. A student is assigned to conduct a research project on two types of trees. Which of the following projects would not be applicable to the scientific method?

(a) Oak trees are taller than Magnolia trees.

(b) Oak trees have more flowers than Magnolia trees.

(c) Oak trees shed more leaves than Magnolia trees.

(d) Oak trees are prettier than Magnolia trees.

28. What experimental design would best test which type of mouthwash would kill the most bacteria: an alcohol-based mouthwash versus antibacterial mouthwash?

(a) Have 10 bacterial plates plated with alcohol-based mouthwash, 10 bacterial plates plated with antibacterial-based mouthwash, and 10 bacterial plates without mouthwash. Plate bacteria on all plates and compare growth.

(b) Have 10 bacterial plates plated with alcohol-based mouthwash and 10 bacterial plates plated with antibacterial-based mouthwash. Plate bacteria on all plates and compare growth.

(c) Have 10 bacterial plates plated with antibacterial-based mouthwash and 10 bacterial plates plated without mouthwash. Plate bacteria on all plates and compare growth.

(d) Have 10 bacterial plates plated with alcohol-based mouthwash and 10 bacterial plates plated without mouthwash. Plate bacteria on all plates and compare growth.

29. What experimental design would you use to test whether rubber horseshoes are better than metal ones in regard to racehorse speed?

(a) Run 10 horses with rubber shoes on a dry track versus 10 horses with metal shoes on a wet track.

(b) Run 10 horses with rubber shoes on a wet track versus 10 horses with metal shoes on a wet track.

(c) Run 10 horses with rubber shoes on a wet track versus 10 horses of the same breed and age with metal shoes on a wet track.

(d) Run 10 horses with rubber shoes on a dry track versus 10 horses of the same breed and age with metal shoes on a wet track.

30. If the results of the experiment you perform do not turn out as you predicted,

(a) you need to redo the experiment until you get the expected results.

(b) your hypothesis was incorrect.

(c) you did not follow the scientific method.

(d) your experimental design is incorrect.