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Assessing Students' Understanding of the Scientific Process

Amy Marion

New Mexico State University, Department of Biology, Las Cruces NM 88003 USA
(**amarion@nmsu.edu**)

The primary goal of the introductory biology laboratory courses at NMSU is to assist students as they develop a critical understanding of the scientific process. A multi-year study is being conducted to determine the effectiveness of inquiry-based lab exercises in achieving this goal. Preliminary data analyses indicate success in teaching some aspects of the scientific process in one introductory biology laboratory course.

Keywords: Scientific process, student assessment

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Introduction

At New Mexico State University, our introductory biology labs utilize inquiry-based laboratory exercises to teach the scientific process. As often as possible, our students are active participants in the formation of hypotheses and the design of experiments. The primary method of student assessment in these courses is through weekly lab reports. The effectiveness of this course structure has been evaluated using an assessment tool to track students' understanding of the scientific process throughout the semester. It was hypothesized that the use of inquiry-based laboratory exercises is an effective method for teaching the scientific process, and predicted that students' scores on these periodic assessments would improve throughout the length of the semester.

The study has been conducted for at least five semesters in all three of our introductory biology laboratory courses. The courses include BIOL 101L *Human Biology Laboratory* (non-science majors), BIOL 111L *Natural History of Life* (1st semester biology for majors), and BIOL 211L *Cellular & Organismal Biology* (2nd semester course for majors). It should be noted that BIOL 111L is not a prerequisite course for BIOL 211L. In addition, the student body in each of these courses is substantially different. Students in BIOL 111L are from a wide variety of majors with almost 60% of the students from majors other than life science, while the BIOL 211L course is composed of approximately 50% pre-nursing and allied health students and only approximately 25% life science majors. The focus of this presentation is on the BIOL 211L course with some comparison to the results in the BIOL 111L course.

Notes for the Instructor

Methods

The assessment tool consisted of a one-page description of a research experiment from the primary literature, followed by six multiple choice questions about the experiment, each question focusing on a different skill necessary for effective use of the scientific process. An example of one assessment tool is provided as Appendix 1 of this document. The scientific process skills evaluated included (1) hypothesis formation, (2) predicting experimental results, (3) experimental design, (4) drawing a conclusion from experimental data, (5) identifying any assumptions embedded in the experiment, and (6) identifying the implications of the experimental conclusion. The students were not notified about when these assessments would occur during the semester and therefore could not study for them. It was assumed that a student's active participation in laboratory exercises and submission of laboratory reports would provide the necessary preparation for correctly answering the questions on the assessment tool.

Four different assessment tools (A, B, C, and D) were used and administered throughout the semester at four different times (Weeks 2, 6, 10, and 14). Each assessment tool was provided to different lab sections at different weeks of the semester. This eliminated any bias that could be created by the relative difficulty of a particular assessment tool. An example of the schedule of assessments is shown in Table 1.

Table 1. Distribution of assessments throughout the semester.

Section #	Week 2 Jan 30-Feb 1	Week 6 Feb 27-Mar 1	Week 10 Apr 3-5	Week 14 May 1-3
1	C	D	A	B
2	C	D	A	B
3	C	D	A	B
4	D	A	B	C
5	D	A	B	C
6	D	A	B	C
7	A	B	C	D
8	A	B	C	D
9	A	B	C	D
10	B	C	D	A
11	B	C	D	A
12	B	C	D	A
13	B	C	D	A

Results

For the purpose of the analyses shown here, the students' scores have been converted to the percent of correct responses. For some of these analyses (Figs. 1 and 3) the data includes only those students who completed all four assessments throughout the semester. One-way paired t tests were used to evaluate significant differences in mean scores.

The average score on the assessments through two semesters of BIOL 111L and five semesters of BIOL 211L (Fig. 1) indicates significantly different mean scores in week 2 versus week 14 only for BIOL 211L students ($p < 0.05$).

Student performance on each scientific process skill (Fig. 2)shows significant differences in student scores only for their understanding of hypothesis formation ($p < 0.005$), predicted results ($p < 0.025$), and the experimental conclusion ($p < 0.05$).

Figure 3 is a comparison of assessment scores for BIOL 211L students based on whether they have previously taken BIOL 111L. There are significant differences in the week 2 and week 14 mean scores for all students, students who have taken BIOL 111L, and students who took BIOL 111L in the semester immediately previous to taking BIOL 211L ($p < 0.01$ in all cases).

In all figures, dotted lines indicate data with significantly different mean values as determined by 1-tailed paired t tests. Solid lines indicate data with no significant difference in the mean values from week 2 to week 14.

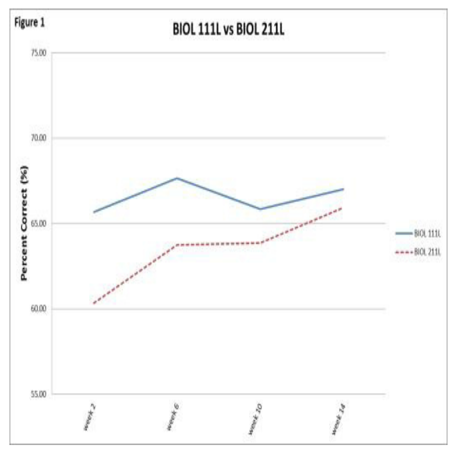

Figure 1. Average score on the assessments through two semesters of BIOL 111L and five semesters of BIOL 211L.

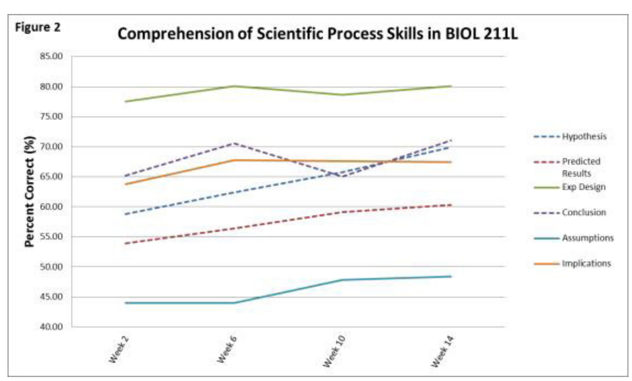

Figure 2. Student performance on each scientific process skill in BIOL 211L.

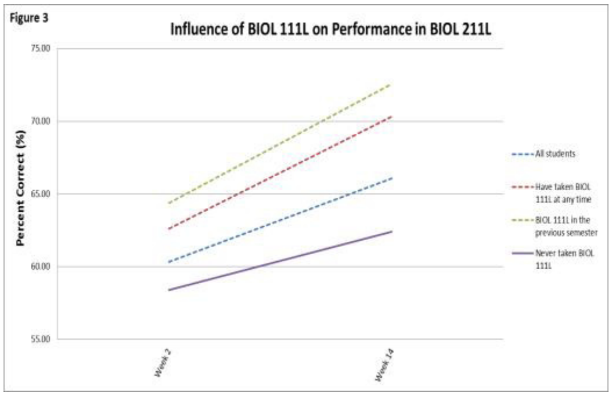

Figure 3. Comparison of assessment scores for BIOL 211L students based on whether they have previously taken BIOL 111L.

Discussion

The data evaluated here indicate that the NMSU introductory biology courses are successful in teaching some, but not all, aspects of the scientific process. The BIOL 111L students begin the semester with a stronger understanding of the scientific process than BIOL 211L students, but do not show a significant gain in their understanding of these concepts as the semester progresses (Fig. 1). However, BIOL 111L is not a prerequisite course for BIOL 211L. The majority of BIOL 211L students (53.8%) have not completed BIOL 111L and, therefore, are more similar to the BIOL 111L students in taking their first laboratory science course. The difference in BIOL 111L and 211L student performances in week 2 may be the result of different levels of difficulty of the assessment tools used in each course. The structures of the BIOL 111 and 211L courses are somewhat distinct as well. The lab exercises used in BIOL 211L are more experimental and the weekly lab reports are more comprehensive. The significant gain in knowledge seen only in BIOL 211L might be the result of these differences in course structure or may reflect the disparity in the characteristics of the student populations of each course. While students do not show a significant increase in their understanding of scientific process while they are taking BIOL 111L (Fig. 1), having previously taken BIOL 111L clearly has a positive influence on performance in BIOL 211L (Fig. 3).

BIOL 211L students show significant gains in their understanding of hypothesis formation, predicting experimental results, and drawing conclusions (Fig 2). These skills are conceptually similar. If students comprehend the subtle difference between a hypothesis and the predicted result of an experiment, drawing a conclusion from the experimental data seems to easily follow. Conversely, the skills of recognizing the assumptions embedded in an experiment and extrapolating to the implications of the experiment are conceptually more challenging. These are skills that we seem to always struggle with to help students master. The BIOL 211L students have a stronger understanding of experimental design from the beginning of the semester which may prevent any significant gain in knowledge of this skill during an introductory course.

This study has generated a very large data set that has only begun to be analyzed. A more thorough investigation will be required if the factors contributing to student understanding (or lack of understanding) of scientific process can be identified. These initial analyses imply that the BIOL 111L students may benefit from a course structure more similar to the BIOL 211L course. In addition, the pedagogy of the 211L course should take into consideration the needs of the students who have not taken BIOL 111L and should further emphasize the skills of identifying experimental assumptions and implications.

Materials

I have used Scantron forms (“bubble sheets”) for student responses on these assessments. To reduce the expense of supplying Scantron forms to hundreds of students per semester, each student can use the same Scantron form for all four assessments. The first assessment of the semester (Week 2) uses question numbers 1-6 on the Scantron; Week 5 uses question numbers 15-20, etc. I also employ a laboratory section code on the Scantron forms that facilitates the data analysis. Each laboratory section has a designated bubble to fill in on their Scantron. For example, all students in lab section one fill in question #7 letter A; section two fills in question #7 letter B; etc. This allows easy organization of the large quantities of data that are generated with each assessment.

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About the Author

Amy Marion earned her BS in Biology at Marywood University in Scranton, PA and her PhD in Botany at the University of Vermont. Since 2001 she has served as the Laboratory Coordinator in the Biology Department at NMSU, focusing on introductory laboratory courses for majors and non-majors.

Mission, Review Process & Disclaimer

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Appendix

Assessment A Used in BIOL 211L in Spring 2013

Type 2 diabetes is one of the most prevalent diseases in the United States today. Currently, there is no cure for diabetes. Patients must work to manage the symptoms of the disease as best they can to prevent the complications that can arise from long term high blood sugar levels. The cost of long-term disease management is high, financially and otherwise. Therefore, in addition to seeking a cure, physicians and scientists are also searching for ways to prevent diabetes. Often they look to lifestyle changes such as diet and exercise for possible ways to prevent patients from developing Type 2 diabetes.

A team of researchers, led by Dr. Simin Liu at Harvard Medical School, conducted a long-term study aimed at identifying ways to prevent Type 2 diabetes (Liu, et al., 2004). Their study focused on the effect of diet, specifically the intake of fruits and vegetables, on the risk of developing diabetes. Fruits and vegetables contain a variety of beneficial nutrients and plant chemicals believed to prevent certain diseases. In addition, different types of fruits and vegetables may differ in the beneficial nutrients they contain. Dr. Liu's team proposed that a diet high in fruits and vegetables could prevent the incidence of Type 2 diabetes. They studied almost 40,000 female health professionals over a 10 year period. These women volunteered to complete a questionnaire about their diet at the beginning of the study period. The questionnaire contained 131 questions about the type, quantity, and frequency of the foods they ate, as well as questions about their general health. None of the women had Type 2 diabetes at the beginning of the study. Over the 10 year period, the women were asked to report if they had been diagnosed with Type 2 diabetes. The research team then analyzed the data to compare the health and diet habits of women who developed diabetes to those who did not develop the disease within the period of the study.

The researchers calculated that the study participants consumed an average 2.2 servings per day of all types of fruits, and an average 3.9 servings per day of all types of vegetables. The researchers also divided the fruits and vegetables into different categories such as citrus fruit, dark yellow vegetables (carrots, yellow squash), green leafy vegetables (spinach, lettuce), and starchy vegetables (potatoes). Over the 10 year study period, 1,614 study participants developed Type 2 diabetes. The data indicated that there was an inverse relationship between the intakes of total fruits and vegetables, citrus fruits, dark yellow vegetables, green leafy vegetables, and legumes and the relative risk of developing Type 2 diabetes. However, there was a positive relationship between the intake of potatoes and the risk of developing Type 2 diabetes. The information provided on the questionnaire allowed the researchers to assess known risk factors for diabetes in each participant's health history. These known risk factors include such things as exercise, history of high blood pressure, history of high cholesterol, family history of diabetes, and Basal Metabolic Index (BMI), a measure of whether a person is overweight. After taking these diabetes risk factors into consideration, the research team found no statistically significant reduction in the risk of developing diabetes with increased intake of total fruits and vegetables or intake of any subcategory of fruits or vegetables. Because being overweight greatly increases the risk of developing Type 2 diabetes, the research team separated the study participants into those with a BMI below 25 kg/m^2 (classified as underweight or of normal weight) and those with a BMI above 25 kg/m^2 (classified as overweight or obese). There was no relationship between fruit and vegetable intake and Type 2 diabetes in participants with a BMI value below 25 kg/m^2. Among participants classified as overweight or obese (BMI > 25 kg/m^2) there was an inverse relationship between intake of dark yellow vegetables and green leafy vegetables and the risk of developing Type 2 diabetes.

1. When did you most recently take BIOL 111GL Natural History of Life Laboratory?

   A. Fall 2012 B. Summer 2012 C. Spring 2012
   D. Fall 2011 E. Summer 2011 F. Spring 2011
   G. Before Spring 20101 H. I have not taken BIOL 111GL Laboratory

2. The experiment of Liu, et al. hypothesized that

   A. women with a BMI below 25 kg/m^2 have a reduced risk of developing Type 2 diabetes
   B. women in the health professions generally eat more fruits and vegetables
   C. a high intake of fruits and vegetables leads to a BMI value above 25 kg/m^2
   D. Type 2 diabetes can be prevented by eating more daily servings of fruits and vegetables

3. The experiment predicts that

   A. there will be an inverse relationship between low fruit and vegetable intake and Type 2 diabetes
   B. women who eat more fruits and vegetables will have a lower incidence of Type 2 diabetes
   C. women who eat more daily servings of potatoes will have a higher risk of Type 2 diabetes
   D. a higher intake of dark yellow vegetables places women at higher risk of developing Type 2 diabetes

4. During the analysis of data, the researchers separated fruits and vegetables into different categories because

   A. the serving sizes vary for different types of fruits and vegetables
   B. some people eat a very limited variety of fruits or vegetables
   C. they hypothesized that green leafy vegetables would be most beneficial in preventing Type 2 diabetes
   D. fruits and vegetables differ in the nutrients and beneficial plant chemicals they contain

5. Liu et al. concluded that

   A. eating more daily servings of all fruits and vegetables prevents Type 2 diabetes
   B. eating more servings of green leafy vegetables may help prevent Type 2 diabetes in overweight women
   C. higher intake of fruits and vegetables is beneficial because it lowers BMI values
   D. high daily intake of fruits is more important than high daily intake of vegetables

6. The design of this experiment assumes that

   A. higher daily intakes of fruits and vegetables is positively correlated with Type 2 diabetes
   B. the eating patterns of the study participants did not change over the period of the study
   C. the symptoms of Type 2 diabetes can be controlled by eating more fruits and vegetables
   D. non-diabetic women eat healthier than diabetic women

7. One implication of this study is that

   A. overweight women may reduce their risk of developing Type 2 diabetes by eating more dark yellow and leafy green vegetables
   B. after taking diabetes risk factors into consideration, there is no significant benefit to eating more fruits and vegetables as a way to prevent Type 2 diabetes
   C. women who have Type 2 diabetes would benefit from eating more salads
   D. low fruit and vegetable intake leads to the development of Type 2 diabetes

Literature Cited

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