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The Development and Evaluation of Lecture Tutorials for Introductory Soil Science

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ABSTRACT

The wide-array of concepts from the natural sciences that must be mastered to succeed in an introductory soil science course presents a significant challenge to students. This study was conducted to determine if students' conceptual development regarding topics in introductory soil science could be improved by using lecture tutorials. Lecture tutorials are activities that students complete following a lecture. They guide the students to critically analyze their understanding of a concept presented in the lecture. Eight lecture tutorials were written and evaluated using pre/post quizzes and surveys in two courses (an environmental science program course and a general studies course). The pre/post quiz results indicate that there was significant improvement in students' conceptual understanding for three of the lecture tutorials, which covered the topics of texture ($p = 0.006$), bulk density ($p = 0.026$), and Liebig's law ($p < 0.001$). Survey results showed that students also felt that they understood these topics better after completing the lecture tutorials. There was no interaction between improvement in quiz scores and course type. However, the student ratings from the environmental science program course were significantly higher for most survey questions when compared to the general studies course. The continued development and evaluation of lecture tutorials to address a broader range of topics within soil science is recommended.

Core Ideas

- Lecture tutorials significantly improved students' performance on quizzes for certain topics.
- Lecture tutorials were effective in courses for majors and non-majors.
- Student ratings of lecture tutorials were higher in the course for environmental science majors.
- Hands-on lecture tutorials were rated as most "fun" by environmental science students.

Soil scientists have a critical role to play in solving some of the most pressing global problems, including climate change and world food production (Hartemink and McBratney, 2008). A basic understanding of soil science is important in many related fields of study (e.g., environmental science, agriculture, public health, civil engineering, and landscape architecture), as well as the day-to-day lives of the general public. With a basic knowledge of soils, even non-scientists can become wiser homeowners and more informed environmental stewards. Although there are many reasons for undergraduates to study soil science, it is a challenging subject due to the complex nature of soils.

Enrollment in soil science courses has experienced a declining trend in recent years (Hartemink et al., 2008). This trend is troubling when we consider that well-trained soil scientists have an important role to play within the scientific community (Hartemink and McBratney, 2008). Past research on learning styles in a Soil and Water Management course suggests that the majority of students in this type of course are multi-modal or kinesthetic learners (Eudoxie, 2011). Based on the diversity of learning styles in a typical soils class, it is important to provide students with a wide variety of learning tools that will work for different learning styles. Lecture tutorials are a tool that may help students conquer difficult concepts in introductory soil science so that they feel empowered to pursue further studies in the field.

Lecture tutorials have been shown to have many benefits in other introductory science courses, including astronomy (Prather et al., 2004; Brogt, 2007) and geology (Kortz et al., 2008). Most instructors teach primarily through lectures in which students play a passive role. However, students learn most effectively through active cognitive engagement. The intent of lecture tutorials is to provide a bridge between these two extremes by pairing lectures with short activities. Lecture tutorials guide students to confront misconceptions, increase student relatedness (e.g., sense of belonging and social closeness), and help students to overcome anxieties about science (Prather et al., 2004; Brogt, 2007; Kortz et al., 2008).

Despite their effectiveness in other fields of scientific study, no lecture tutorials have been published for use in introductory soil science. The purpose of this study is to evaluate the effectiveness of a new set of lecture tutorials developed to improve students' conceptual development in soil science.

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Abbreviations: ENVL, environmental science program; GNM, general studies requirement.

MATERIALS AND METHODS

Eight lecture tutorials were developed covering topics within soil physics (specific surface area, texture, and bulk density), soil mineralogy (clay minerals, weathering), and soil fertility (carbon cycle, C/N ratio, and Liebig's Law). The lecture tutorials use leading questions to guide students' conceptual development, diagram/image interpretation activities, and hypothetical debate questions in which students must choose to agree with one of two statements (Kortz et al., 2008). Three of the lecture tutorials developed for this study also included a hands-on learning component. The hands-on lecture tutorials use simple objects to illustrate the concept: blocks for specific surface area, Styrofoam balls and toothpicks to build models for clay minerals, and paper cups for Liebig's Law (Fig. 1).

The lecture tutorials were evaluated by pre/post quizzes and surveys in two courses: one general studies (GNM) and one environmental science program (ENVL) course. Participation in the study was on a voluntary basis for extra credit. The courses differed in their total enrollment, as well as the class standing and majors of the students. The GNM course was taught in the spring of 2015 with an enrollment of 34 students, 32 of whom participated in the study. The students in this class were 13% freshman, 34% sophomores, 44% juniors, and 9% seniors. The top four majors were: business (34%), environmental science (19%), social and behavior sciences (19%), and undeclared (13%). The ENVL course was taught in the fall of 2014 (12 student enrolled, 10 participating in the study) and again in the fall of 2015 (13 students enrolled, 13 participating in the study). The students in these classes were 87% seniors and 13% juniors, mostly majoring in environmental science (74%), with some majoring in geology (9%), public health (9%), and other subjects (9%). Two of the lecture tutorials (chemical weathering and clay minerals) were used only in the ENVL course because these topics were beyond the scope of the GNM course.

Students completed the lecture tutorials in small groups after a short lecture. The group sizes were 4 to 5 students in the GNM course and 2 to 3 students in the ENVL course. All groups were assigned by the instructor. In the GNM course, the groups were arranged so that each included students from a variety of majors. After completing the lecture tutorial with their group, the students participated in a class discussion to review the lecture tutorial.

A pre-quiz was administered after the lecture, but before the lecture tutorial. A post-quiz was given after the lecture tutorial and discussion were completed. The pre/post quizzes consisted of three to four multiple-choice questions. The quiz questions were written to test conceptual understanding of the topic covered, but used different scenarios and examples from the lecture tutorials. Two versions of each quiz were written with different questions. Half the students in each class took Version 1 as the pre-quiz and Version 2 as the post-quiz, while the other half took Version 2 as the pre-quiz and Version 1 as the post-quiz. This study design is intended to account for any unintentional differences in the difficulty of the two quiz versions. An ANOVA test of the quiz scores was used to determine the effect of quiz (pre vs. post) and course type (ENVL vs. GNM), as well as the interaction between these two variables.

A survey consisting of Likert-scale ratings of five statements about the lecture tutorial was administered anonymously after the post-quiz was completed (Table 1). An ANOVA test was used to determine if student ratings varied significantly between different lecture tutorial topics, between the two courses, as well as if there were any interaction between these two variables.

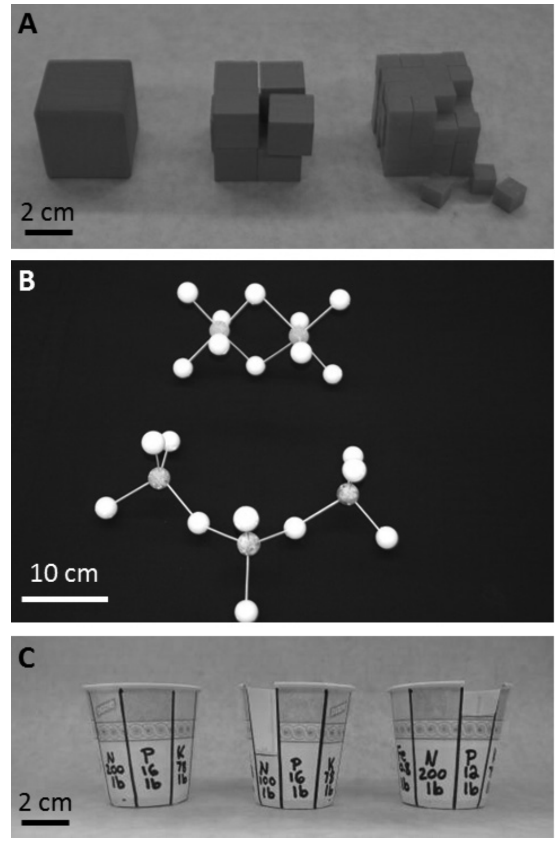


Fig. 1. Photographs of materials utilized in the hands-on lecture tutorials, including blocks used for the specific surface area lecture tutorial (A), toothpicks and Styrofoam balls for the clay minerals lecture tutorial (B), and paper cups used in the Liebig's Law lecture tutorial (C).

Table 1. Survey questions utilized in the study (based on Barbarick, 2010).

	Question	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
1.	The activity was fun to complete	☐	☐	☐	☐	☐
2.	The activity was too difficult	☐	☐	☐	☐	☐
3.	I understood the concept discussed in lecture today better after completing the activity	☐	☐	☐	☐	☐
4.	I recommend the continued use of the activity in this course	☐	☐	☐	☐	☐
5.	I preferred completing the activity rather than having a longer lecture on the concept	☐	☐	☐	☐	☐

RESULTS AND DISCUSSION

The results of this study indicate improvement in students' conceptual development with the use of certain lecture tutorials. This improvement is supported by the students' quiz scores, as well as their self-assessment conveyed through the survey data. Post-quiz scores were significantly higher than pre-quiz scores for three of the eight lecture tutorials. These were the lecture tutorials that covered the topics of texture ($p = 0.006$), bulk density ($p = 0.026$), and Liebig's Law ($p < 0.001$) (Fig. 2). When comparing the two courses, the students in the ENVL course performed significantly better on the quizzes on specific surface area ($p < 0.001$) and bulk density ($p = 0.023$) when compared with students in the GNM course (Fig. 2). For the other topics, the quiz performance was not significantly different between two courses. There was no significant interaction between course type and quiz improvement for any of the lecture tutorials. The lecture tutorials on texture,

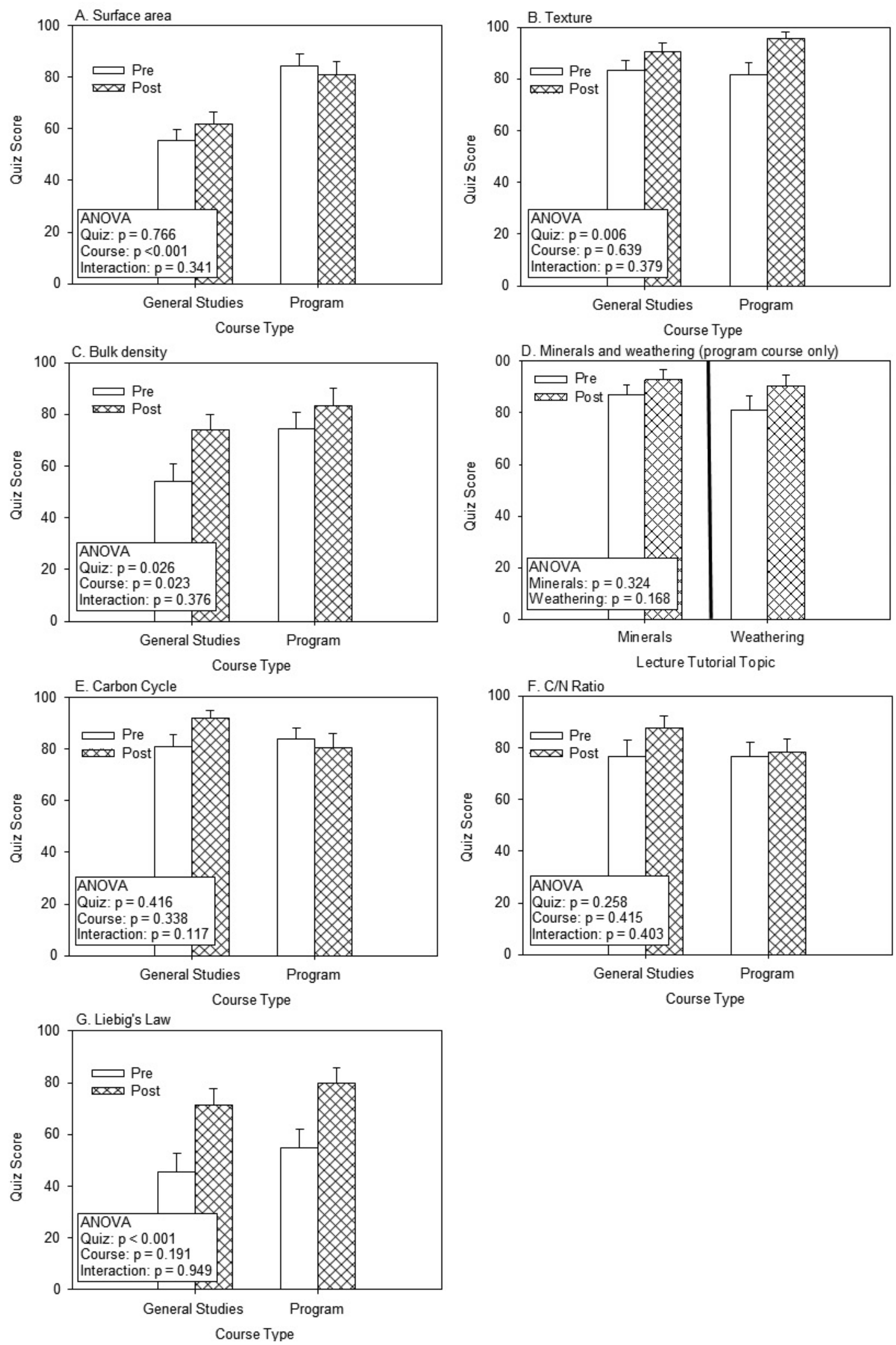


Fig. 2. Results of pre- and post-quizzes administered before and after each lecture tutorial in the general studies and environmental science program courses. Pre-quiz data is represented by solid white bars and post-quiz data is represented with cross-hatched bars. The eight lecture tutorials covered the topics of specific surface area (A), texture (B), bulk density (C), clay minerals (left panel of D), chemical weathering (right panel of D), the carbon cycle (E), C/N ratios (F), and Liebig's Law (G).

bulk density, and Liebig's Law helped to improve quiz scores equally in the ENVL course (juniors and seniors in science majors) and the GNM course (mixed levels and majors).

In addition to improving quiz scores, the texture and bulk density lecture tutorials also received significantly higher student ratings for the statement that "I understood the concept better after completing the activity" (p = 0.040) (Fig. 3C). For the texture lecture tutorial, the average rating was 4.4 in the ENVL course and 4.3 in the GNM course. The bulk density lecture tutorial received average ratings of 4.6 in the ENVL course and 4.2 in the GNM course. The survey results for the Liebig's Law lecture tutorial were not included in the statistical analysis because the survey was not administered in the GNM course due to time constraints. However, the student ratings in the ENVL course had an average of 4.5, which is similar to the results for the texture and bulk density lecture tutorials. These results, together with the quiz scores, suggest that students both perceived that they understood the concept better and performed better on the quizzes after completing these three lecture tutorials.

There were also significant differences between different lecture tutorials in student rating of whether "The activity was fun to complete" (p = 0.042) (Fig. 3A). However, for this survey question, the students rated the texture lecture tutorial significantly higher and the bulk density lecture tutorial significantly lower than other lecture tutorials. In the ENVL course the ratings were 4.0 for the texture lecture tutorial and 3.8 for the bulk density lecture tutorial. In the GNM course the ratings were 3.7 for the texture lecture tutorial and 3.3 for the bulk density lecture tutorial. Although it was not included in the statistical analysis, the average rating for the Liebig's Law surveys in the ENVL course was 4.2. These results indicate that student's ratings of how fun the lecture tutorials were did not always relate to how much their quiz scores improved. However, for the texture and Liebig's Law lecture tutorials, the students did give the activities high ratings for being fun, in addition to showing improvement in their quiz scores.

A second trend in student ratings of whether lecture tutorials were "fun to complete" can be seen in the data from the ENVL course. The three top-rated lecture

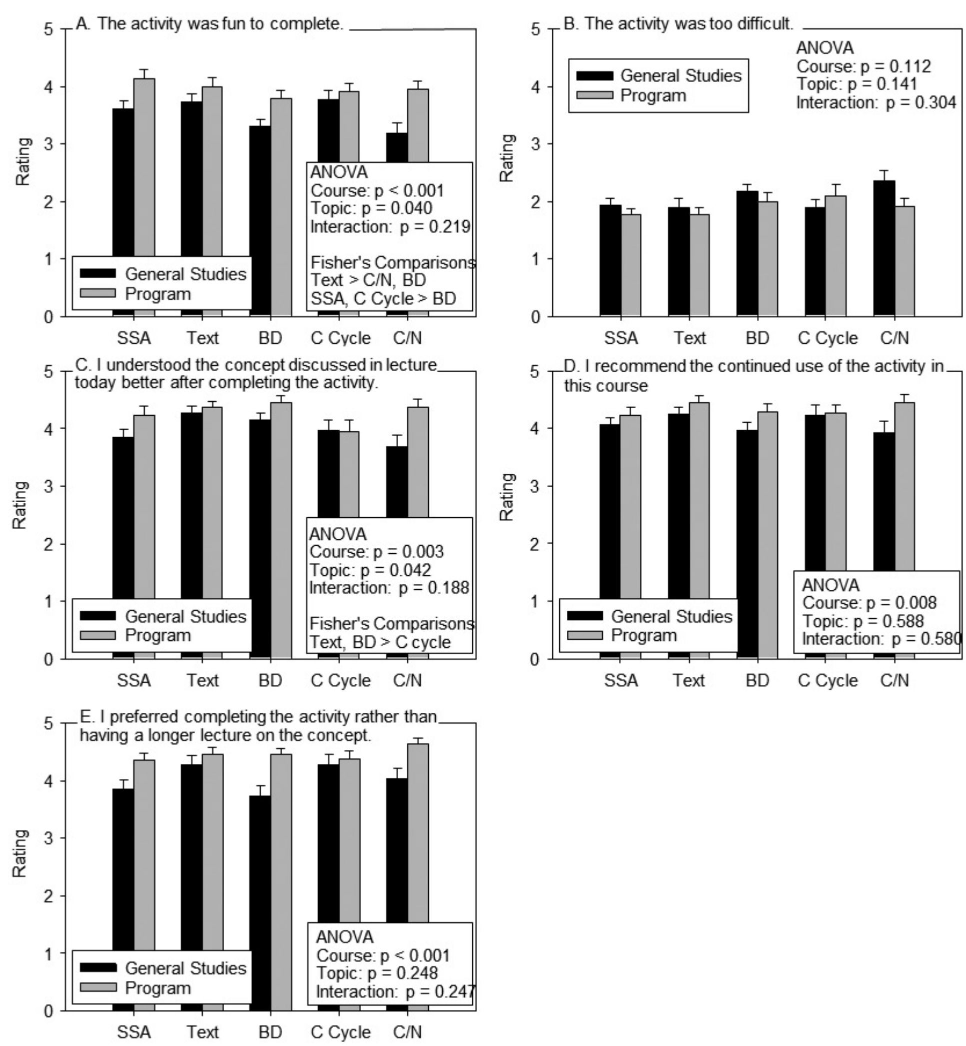
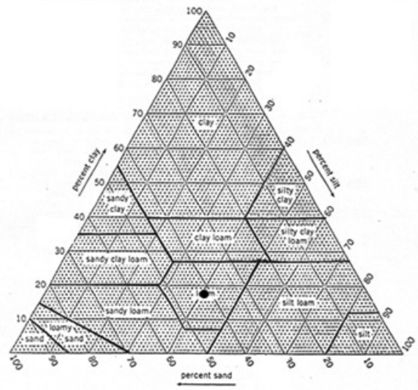


Fig. 3. Student survey data for five of the lecture tutorials (data for the other three lecture tutorials is not presented because it was not collected in both courses). The topics of the lecture tutorials are abbreviated as follows: SSA = specific surface area, text = texture, BD = bulk density, C cycle = carbon cycle, C/N = C/N ratio. Survey data from the general studies course is represented in black and data from the environmental science program course is in gray. Each graph shows the response to a different survey statement: "The activity was fun to complete" (A), "The activity was too difficult" (B), "I understood the concept discussed in lecture today better after completing the activity" (C), "I recommend the continued use of the activity in this course" (D), and "I preferred completing the activity rather than having a longer lecture on the concept" (E). All responses are weighted on a Likert scale (1 = strongly disagree, 2 = disagree, 3 = neutral, 4 = agree, 5 = strongly agree).

What is a loam?

Loam: A mixture of sand, silt, and clay that exhibits equal properties of the three separates.



1. The dot on the texture triangle (above) is in the middle of the "loam" class. Determine % sand, silt, and clay at this point.

   % sand ______

   % silt ______

   % clay ______

2. Examine the textural triangle and complete the following statements.

   a. A soil with as little as _____% clay can be put in the clay textural class.

   b. A soil with as little as _____% sand can be put in the sand textural class.

3. **Student 1:** A loam has equal properties of sand, silt, and clay, so it must have about 33.3% of each.

   Student 2: But certain soil separates can have greater influence even when they are lower in actual amount. So, a soil may be a loam even though the proportions are not equal.

   Who do you agree with? Explain why.

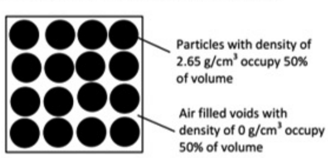
4. According to the textural triangle, a soil with 33.3% sand, 33.3% silt, and 33.3% clay is a ______________.

5. **Smaller / Larger** (circle one) particles have greater influence on soil properties when present even in small amounts because they have a **Higher / Lower** (circle one) surface area per unit volume.

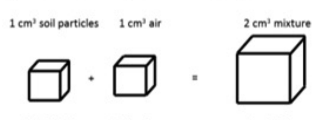
Fig. 4. Worksheet for the texture lecture tutorial.

Bulk Density

1. If soil particles with a density of 2.65 g/cm^3 are packed leaving 50% void space, what is the density of the packed volume (bulk density)?



2. Essentially what we are doing here is combining two materials with different densities. Let's examine the problem from a slightly different perspective.



   a. What is the mass of the soil particles?

   b. What is the mass of the air?

   c. What is the sum of the two masses?

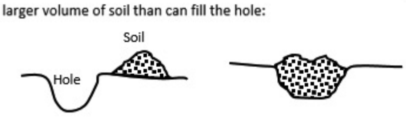
   d. What is the sum of the two volumes?

   e. What is the density of the combined volume? Hint: Use your answers to c and d.

   f. Is the combined density greater or less than the density of the soil particles alone?

   g. Does this agree with your answer from problem 1? If not, you can change your answer to problem 1.

3. Imagine that you dig a hole (to examine the soil) and then fill it back in. Even though you refill the hole with the exact same amount of soil that was removed, you end up with a larger volume of soil than can fill the hole:



   a. Because you filled the hole with the exact same amount of soil that was removed, you know that the volume of the solids has not been altered. So how is it that the volume of the soil increased?

   b. In excavating and refilling the hole, how have you affected the bulk density of the soil? Has it increased, decreased, or remained the same? Explain your answer.

   c. In excavating and refilling the hole, how have you affected the particle density of the soil? Has it increased, decreased, or remained the same? Explain your answer.

4. Explain in your own words the difference between particle density and bulk density.

Fig. 5. Worksheet for the bulk density lecture tutorial.

Class preparation: Assembly of "buckets"

To complete the worksheet each group of students needs three paper cups prepared as follows. Use a maker to divide each cup into eight panels of equal width, which fill the entire circumference of the cup. Label the bottom of the first cup "A", label the second cup "B", and label the third cup "C" and for each cup label and cut the panels as follows:

- Cup A. The eight panels should be labeled as follows: "N 200 lb", "P 16 lb", "K 78 lb", "Ca 39 lb", "Mg 31 lb", "S 12 lb", "Mn 0.2 lb", "Fe 0.8 lb".
- Cup B. The eight panels should be labeled as follows: "N 100 lb" (this panel should also be cut to 1/2 its original height), "P 16 lb", "K 78 lb", "Ca 39 lb", "Mg 31 lb", "S 12 lb", "Mn 0.2 lb", "Fe 0.8 lb".
- Cup C. The eight panels should be labeled as follows: "N 200 lb", "P 12 lb" (this panel should also be cut to 3/4 of its original height), "K 78 lb", "Ca 39 lb", "Mg 31 lb", "S 3 lb" (this panel should also be cut to 1/4 of its original height), "Mn 0.2 lb", "Fe 0.8 lb".

The Leaking Bucket Model for Liebig's Law of the Minimum

Liebig's Law of the Minimum: The essential element that is present in lowest supply relative to crop demand limits yield.

Leaking Bucket Model: The shortest plank of a wooden bucket limits the amount of water held.

Examine the "buckets" provided. Each has a letter on the bottom to bottom, which corresponds to the sections of this worksheet.

Bucket A: This bucket represents a field a field that produces 2 tons/ha of soybeans. The amount of water the bucket can hold is used to represent crop yield.

1. If you increase the length of the plank labeled N, will the bucket hold more water?

Yes or **No**

2. If you add more N to the field that this bucket represents, will the soybean yield increase?

Yes or **No**

3. Examine the numbers on each plank. These represent the amount of each essential element required to maximize yield. What essential element is needed in the greatest amount? What essential element is needed in the lowest amount?

Highest________ Lowest ________

Bucket B: This bucket represents a different field.

1. Two students are discussing which essential element needs to be added in increase crop yield in this field:

Student A: I think that nitrogen needs be added, because the crops have much lower nitrogen than they need. You can see this based on the height of the plank.

Student B: I think that manganese needs to be added. The field has more pounds of nitrogen than any other essential element, the pounds of manganese are the lowest.

Who do you agree with and why?

2. To get the yield back up to 2 tons/ha (like field A), how much nitrogen needs to be added?

5. What will the crop yield be if no fertilizer is added?

Bucket C: This bucket represents another field used to grow soybeans.

1. What will the crop yield be if no fertilizer is added?

2. What will the crop yield be if 4 pounds of phosphorus is added?

3. What will the crop yield be if 9 pounds of sulfur is added?

4. What will the crop yield be if 6 pounds of sulfur is added?

5. Use your responses above to explain why it is a waste of money to fertilize the field with an essential element that is <u>not</u> the most limiting element.

6. Explain Liebig's Law of the Minimum in your own words.

Fig. 6. Class preparation instructions and worksheet for the Liebig's Law lecture tutorial.

tutorials were the clay minerals lecture tutorial (average = 4.4), Liebig's Law (average = 4.2), and specific surface area (average = 4.1). These three activities all included a hands-on component (see Fig. 1). This result suggests that these types of activities appeal to students in a course designed for environmental science majors and provides further support for the prevalence of the kinesthetic learning style among undergraduate soil science students (Eudoxie, 2011). However, only one of these three hands-on lecture tutorials helped the students to significantly improve their quiz scores. Student perceptions of hands-on activities in the GNM course could not be assessed because the clay minerals lecture tutorial was not used in the class and survey data was not collected for the Liebig's Law lecture tutorial. The only hands-on lecture tutorial for which survey data was collected in the GNM class was the tutorial on specific surface area. This lecture tutorial was not rated any higher by students in the GNM course when compared to lecture tutorials without a hands-on component (Fig. 1C).

When comparing the two courses, there were significant differences in student ratings for most survey questions. Ratings for "the activity was fun to complete" were significantly higher for the ENVL course than the GNM course ($p < 0.001$), averaging 3.5 in the GNM course and 4.0 in the ENVL course (Fig. 3A). The ENVL students also agreed more strongly with the statement that "I understood the concept better after completing the activity" when compared with the GNM students ($p = 0.003$) (Fig. 3C). In this case, the ratings averaged 4.0 in the GNM course and 4.3 in the ENVL course. The student ratings for "I recommend the continued use of the activity in this course" were also significantly higher in the ENVL courses ($p = 0.008$) (Fig. 3D). The average ratings for this survey question were 4.1 in the GNM course and 4.3 in the ENVL course. Finally, the ENVL students also felt more strongly that they "preferred completing the activity rather than having a longer lecture on the concept" when compared with the GNM students ($p < 0.001$) (Fig. 3E). For this survey question the average ratings were 4.0 in the GNM course and 4.6 in the ENVL course. The only survey question for which there was no significant difference between the two courses was the students' agreement with the statement that "The activity was too difficult" ($p = 0.112$) (Fig. 3B). For this survey question the student ratings were low for both courses, averaging 2.1 in the GNM course and 1.9 in the ENVL course. These results indicate that even though improvement of quiz scores was similar between the two courses, the lecture tutorials were viewed more positively by students in the ENVL course. More generally, the survey results

support that lecture tutorials are an effective tool for use in an introductory soil science course for environmental science majors.

Lecture tutorials have been used successfully in a large class setting (Kortz et al., 2008). However, due to the nature of the institution at which this study was conducted, class sizes were small (12–34 students). In the small class setting, it is easy to organize a full class discussion to review the lecture tutorial. Furthermore, distributing materials for the hands-on lecture tutorials can be completed quickly, without interrupting the transition between lecture and lecture tutorial. Further study is needed to determine if the lecture tutorials developed here can provide the same benefits to students in a large lecture setting as they do in a small class.

CONCLUSIONS

Three of the lecture tutorials developed in this study helped students to improve their conceptual understanding of the topic, which was demonstrated by a significant improvement in their post-quiz scores. These three lecture tutorials are available as PDF files on the author's website (http://judithkturk.wix.com/soiltutorials) and are also presented in Fig. 4 to 6.

More research is needed on the effectiveness of soil science lecture tutorials in a large lecture setting, especially for lecture tutorials involving a hands-on component. Furthermore, the continued development of lecture tutorials to address a broader range of topics within introductory soil science is suggested. To select topics for the development of future lecture tutorials, a comprehensive study on common misconceptions among soil science students would also be helpful.

There was no significant interaction between pre- and post-quiz improvement and the type of course. The effectiveness of the lecture tutorials at improving conceptual development is similar in courses for science majors and courses for non-science majors. However, student ratings of the lecture tutorial were significantly higher in the course for science majors. This suggests that the lecture tutorials may help science majors develop a positive attitude toward soil science and could perhaps encourage more students to pursue further studies within the field.

ACKNOWLEDGMENTS

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