Improving Higher-Order Thinking and Knowledge Retention in Environmental Science Teaching

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We instituted interdepartmental pedagogical and curricular reform across a series of introductory environmental science courses, integrating more field experiences, data analysis, and synthesis. Using quantitative and qualitative methods, we found that the students who took the series of modified courses showed greater improvement in answering more cognitively challenging questions than did the students who experienced an earlier version of the courses. The students attributed their understanding to the fieldwork. In a second year, we used only the new materials but compared students who took two of the courses with a gap between them with students who took these courses consecutively. The students who experienced the gap performed better on questions that tested understanding at the highest cognitive level. Therefore, the scaffolded curriculum with inquiry-based field labs, thematic content, and spacing between courses improved knowledge retention and higher-order thinking.

Keywords: course sequencing, field laboratories, inquiry-based learning, scaffolding, education

Understanding and addressing environmental problems requires undergraduates to acquire both a depth of understanding of environmental science and a broad suite of skills, including higher-order thinking skills. Adopting approaches and practices that increase understanding, retention, and skills has been seen as crucial for lower-division science student success (Tobias 1990). Growing evidence indicates that supplementing labs and lectures with field-based research experiences and an approach that models the scientific process leads to increased learning and knowledge retention (Handelsman et al. 2004). Students view opportunities to apply themselves to assignments for which they synthesize and integrate material learned in class as powerful learning experiences (Kuh 1995). Additional innovative approaches and practices that are focused on reforming the undergraduate science curriculum include using overarching and thematic content ideas, designing specific in- and out-of-classroom activities to engage students actively, encouraging metacognition, and engaging students in research experiences (Froyd 2008). For example, lower-division undergraduate students at the University of Michigan who engaged in research experiences had increased retention rates in their majors and were significantly more likely to attend graduate or professional school (Board on Science Education 2011).

Exit interviews and other internal assessments revealed that Portland State University (PSU) environmental studies and science majors suffered from low motivation in math and statistics. We therefore set out to revise three core introductory courses for both of our majors (environmental studies and environmental science) with the goal of increasing the retention of knowledge and improving higher-order thinking. We attempted to integrate statistics and math in the new labs using theme-based local environmental inquiry-based projects and local data sets. We deliberately scaffolded knowledge about climate change and the loss of biodiversity in urbanized watersheds and inquiry skills across the three courses, hypothesizing that the material would increase the students' retention of knowledge and enhance their higher-order thinking skills, including the understanding of environmental impacts from multiple factors, through inquiry-based learning and the use of modeling. We developed the new curricular materials to be useful for the faculty of any undergraduate institution.

Knowledge, which here refers to understanding about particular scientific phenomenon, is more likely to be retained through college courses if the student has prolonged contact with the topic, such as a frequent use of knowledge after the course (Custers 2010) and the spacing of learning (deWinstanley and Bjork 2002). *Learning*, which here refers to academic and cognitive gain, is enhanced when it occurs under varied conditions, such as in the laboratory and in the field (Halpern and Hakel 2003). Providing multiple occasions for students to learn different aspects of central,

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thematic content may provide multiple retrieval cues for those concepts and retrieval practice and may ensure that the knowledge is better integrated and retained (Sobel 2004).

Knowledge is also enhanced when information is represented in both visual and auditory formats (Halpern and Hakel 2003). Asking students to create conceptual models, for which the students process and arrange the information that they have learned in a visual format, helps them actively integrate information. Asking students to revise their models over time allows them to integrate new knowledge (Gobert and Buckley 2000); asking them to reflect on what they have learned through the use of modeling provides an opportunity for metacognition and allows the subsequent change of the students' understanding of concepts (Blank 2000). Students also learn new material more effectively in courses that include active, inquiry-based learning (Wood and Gentile 2003). Newer insights into learning suggest that courses should provide opportunities for self-directed inquiry to ensure that knowledge is truly understood (Donovan and Bransford 2005). Participation in science research projects develops skills for higher-order complex thinking (Webb 1999). Combining student-constructed conceptual models and inquiry projects could provide the students with insights into their own scientific reasoning and could enhance their learning experience (Dresner 2013).

Scaffolding involves layered learning, such that the students learn basic information and skills, and are enabled to learn more complex information and skills over time (Dabbagh 2003). It can be used to advance the students' learning about crucial concepts—known as *gateway* or *threshold* concepts—or to focus their understanding about complex and problematic concepts, such as climate change (Meyer and Land 2005). Learning these threshold and problematic concepts may improve cognitive gain about the broader subject (Clark 2000), may help improve the students' confidence in their ability to learn new science skills and concepts (Handelsman et al. 2004), and may engage their prior knowledge in a constructive manner. Intrinsic motivation is improved when students perceive learning tasks to be presented at an acceptable difficulty level (Fox and Hackerman 2003). Engaging prior knowledge is thought to help increase student confidence (Hallikari et al. 2008). In addition, the spacing of courses in a series with deliberate scaffolding might affect student learning by providing a pause that either enhances or detracts from the further integration of knowledge (deWinstanley and Bjork 2002).

We developed a three-course sequence with a deliberate scaffolding of content and skills across courses at PSU for lower-division undergraduate majors in environmental science and environmental studies. Within each course, we involved the students in field trips to local forested sites to collect comparative data and in lab exercises to learn techniques of experimental design and data analysis. We also used conceptual and quantitative modeling within each course to improve the students' ability to understand the consequences and indirect effects of biodiversity loss due to urbanization and climate change. We sought to understand the overall, yearlong effect from the combination of course-specific activities.

We focused our project evaluation on two main topics: whether scaffolding materials with thematic content focused on climate change and approaches such as inquiry-based labs yielded an increased retention of knowledge and increased higher-order thinking and whether taking the courses consecutively or with a gap increased the retention of knowledge. In the first year, we also examined what factors might contribute to differences in knowledge gained through the year. By the second year, we were convinced that the new materials and approaches were better and used them for all of our courses. We had an opportunity to compare the effect of taking the systems and the problem-solving courses consecutively with the effect of taking these two courses with a 3-month break between them, assuming that the students taking a consecutive sequence would outperform those with the gap, because they would not have had as much time to forget the material.

Designing the courses

Three faculty members in the Environmental Science and Management Department and one in the Geography Department designed the labs and collaboratively articulated the courses. The three courses, which are intended to span one academic year, were "Introduction to environmental systems" (which we abbreviate as "Systems"), "Introduction to physical geography" ("Geography"), and "Environmental problem solving" ("Problem solving"). During the first course, "Systems," the students learned field investigation skills and implemented team research projects in which they measured and analyzed species diversity in undisturbed forested areas and in urbanized forests. We also used qualitative modeling to visualize ecological interactions as they relate to global climate change. During the second course, "Geography," the students studied the major drivers of climate and how variation in temperatures and precipitation produce different spatial patterns of water availability and biota. They conducted field investigations of differences in water temperature in forested and urban streams. In the third course, "Problem solving," the students studied patterns of phenology (periodic patterns of plant and animal cycles sensitive to climate change) and how change in climate shifts these patterns. Assignments such as qualitative modeling and the associated metacognitive assignments provided a synthesis of sequencewide content knowledge. Similarly, the information learned across the three courses was needed for students to make informed decisions about which questions to ask, experimental design, and the interpretation of results in the laboratory assignments in the third course. These assignments, such as the phenology and carbon-sequestration inquiries, built on earlier laboratory and lecture materials in all three courses and provided opportunities for the students to synthesize content across the courses. They used more-advanced statistics to analyze plant

Table 1. Example applications of teaching approaches and their applications in labs.	
Teaching approaches	**Application in labs**
Inquiry-based learning	Course 1: term research project comparing urban and rural forested sites, course 2: geography field labs, course 3: phenology labs
Scaffolding of knowledge and skills	Phenology and water quality labs were introduced in the first course and developed further in the later courses; ecological effects of climate change theme in lecture and labs for all three courses; began with qualitative modeling then introduced quantitative modeling; began with graphing and calculating means; then moved on to *t*-tests and regression
Local data sets and forest- and climate-themed labs	The use of local forest vegetation, temperature, and water quality data sets, including student-collected data
Modeling	Qualitative modeling paired with reflective essays to illustrate basic ecological concepts and reflection, quantitative modeling combined with qualitative modeling (e.g., labs in which students measure and model carbon storage of urban trees)

phenology patterns over time and used quantitative modeling to model carbon sequestration in forests (see table 1; the laboratory materials for the test-group courses are available at *www.ecology-climate.org*).

Evaluating student learning

Subjects were voluntarily recruited from those students taking these majors-only courses during the 2 years of our study. The students were placed in the experimental or control group on the basis of their schedules; we could not assign students to groups randomly. We acknowledge that this may have presented some self-selection bias, but an analysis of the differences between pretest scores indicated no appreciable difference between the groups at the start (see below). We tracked which students took which courses. The evaluation, designed and coordinated by external evaluators, employed a mixed-method design that included quasiexperimental assessments of students.

In the first study, the experimental group ($n = 15$ students) took the sequence of three revised courses with the scaffolded concepts and skills designed into their labs. A control group of students ($n = 15$) took the original versions of the three courses, versions that lacked deliberate scaffolding, most of the fieldwork, and much of the climate-change content. There were more students in both types of courses, but only 15 from each track took all three designated courses.

All students took a retention of knowledge test (RKT) consisting of questions designed to test three out of four different levels of knowledge (Webb 2005). The test included four questions at level 1, which was the recall of facts and concepts (e.g., a multiple-choice prompt such as "Species diversity is best measured by…"); six questions for level 2, applying information to routine problems with two or more steps (e.g., "What are two different, important ecological problems that result from earlier spring budburst?"); and four questions at level 3, applying knowledge to more complex decisionmaking problems (e.g., "Describe three short-term and three longer-term effects of clear-cutting on species diversity and water supply"). Level 4 questions and prompts, which require complex reasoning, experimental design, and extended time periods (e.g., "Conduct an investigation on the topic of local climate change and the urban forest, from specifying a problem, designing and carrying out an experiment, to analyzing its data and forming conclusions") were beyond the scope of this relatively short test. The reflective use of modeling can illustrate higher-order thinking skills, so these essay assignments were included in each course of the sequence as an instructional and assessment tool in this study. The test was administered to all of the students early in the fall term, at the start of the "Systems" course, and again at the end of the last of the three sequenced courses ("Problem solving"). Focus groups were held with representatives from the experimental group at the end of the academic year. Essay assignments concerning qualitative modeling were given to all groups, and essay assignments concerning prior experiences and career aspirations were given to the experimental group. We had uneven participation in our control group and could not match their pre- and post-RKT scores.

During the second year, we conducted a second study that was focused on the spacing of the environmental courses ("Systems" and "Problem solving"). The new labs and other materials were used in all sections of the courses. However, because of PSU's flexible system for student registration for required courses, nearly all of the students who took the two environmental courses in the second year had already taken a different version of the "Geography" course. Therefore, it was not included in the second study. The students took the "Systems" course in the fall, and they all took the pretest. The experimental (or spaced) group took the "Problem solving" course in the spring with one term in between (9 months total); the control (or consecutive) group took the "Problem solving" course in the winter (6 months total). Both groups took the posttest at the end of the "Problem solving" course. We compared the students between the two groups (15 students each). More students took each course, but only 15 each took the two courses at the planned intervals.

For both studies, we tested for both the retention of knowledge over time and the acquisition of higher-order (level-3) thinking skills. To examine whether the students in the experimental group retained more knowledge than did those in the control group in the first study, we analyzed how end-of-the-year cognitive-level-1 and -level-2 responses differed between the groups; in the second study, we examined how that information had been remembered and integrated even by the end of the spring term. To examine higher-order thinking, we examined cognitive-level-3 questions. We could track only a total of 30 students over each academic year (15 in each treatment group per year) because of the difficulty in keeping students in a cohort over the year.

The students in the experimental group were engaged in research projects in the urban forest. These student research projects were not comparable between the control and experimental courses, so we could not use research skill progress as a comparative measure. Instead, we used increases in higher-order cognitive skills as a proxy for research skills (Webb 1999).

During the "Systems" course, the first course of the sequence, the students designed conceptual models of variables in their research projects early in the term and then again at the end of the term and wrote reflective essays about their models. They also wrote an essay about their motivations to major in the environmental field so that we could better understand the role of their prior experiences in natural environments and whether they attributed their earlier experiences to their choice of major. Metacognitive essay questions posed during this first course asked the students to describe how and why their comprehension might have changed over the term (n = 23 students). During the "Problem solving" course, the students used both conceptual and quantitative models (e.g., system dynamics). These essays were analyzed using a rubric to find supporting evidence for student learning.

At the end of the first study, 21 students from the experimental group (15 students who took the sequence as prescribed and 6 who did not take the middle course in the sequence, "Geography") participated in focus group discussions about the value of taking courses in the sequence and the elements within the courses that contributed to their understanding. The moderator for the focus groups, the graduate research assistant for the 2-year study, posed a series of questions to the group and also allowed for spontaneous comments. The students' comments were analyzed by two graduate students, using a rubric; their scores were calibrated to assure that they followed the rubric in a similar manner.

Using the SPSS Amos statistics package (Microsoft, Redmond, Washington), the data were examined for a normal distribution (using the Shapiro–Wilk test) and an equality of variance (Levene's statistic), transformed as necessary to meet the assumptions of the statistical tests. The data from the first study were normally distributed and had equal variance, but the data from the second study were neither normally distributed nor of equal variation. To determine whether there was a difference between the student posttest scores in the first study (the experimental group and the control group for levels 1–3), we used an analysis of variance (ANOVA). Posttest-only single-sample t-tests were used to determine which cognitive level was responsible. We also examined the higher-order thinking skills questions (level 3) by analyzing the differences in posttest scores between groups. To determine whether the spacing of the courses affected retention and depth of knowledge, we compared the change in test scores from students taking the courses consecutively with those taking them spaced with the Wilcoxon signed-rank test.

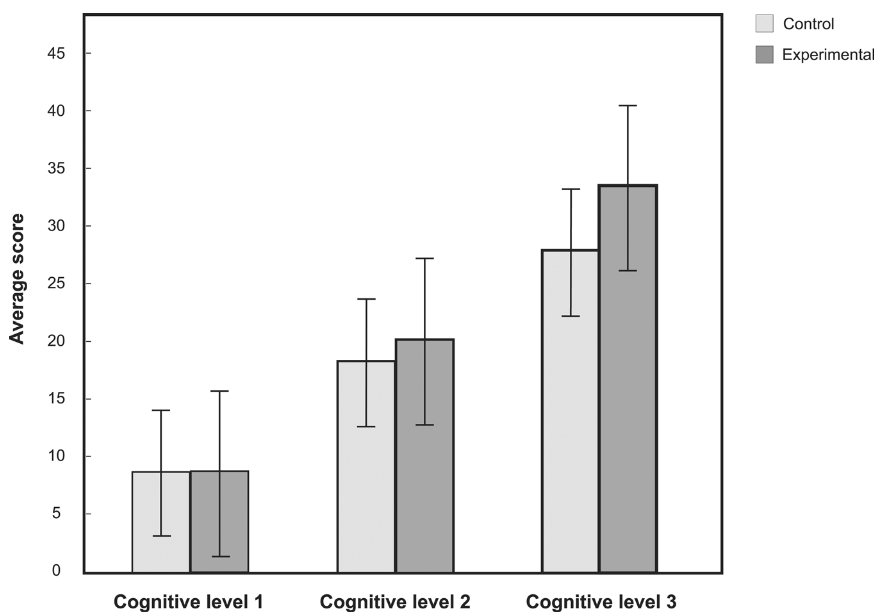

Figure 1. Average scores of student posttests for the experimental (sequence modified material) and control (older material, not sequenced) groups. The error bars represent the standard error.

Welch independent two-sample t-tests were run to compare pretest scores between the experimental and control groups for the first study in order to confirm the equality of the students. The pretest means were similar across groups, differing by only one point for each cognitive level. There was no significant difference in scores between the experimental and control groups for each cognitive level (level 1, $t(28) = 0.632$, $p = .531$; level 2, $t(28) = 0.74$, $p = .464$; level 3, $t(28) = 0.425$, $p = .674$).

In the first study, the students using the revised materials showed significantly higher overall posttest scores than those of the students using the original materials ($F(1,28) = 148.56$, $p < .0001$; figure 1). Post hoc tests revealed that this difference was due to the ability of the experimental-group students to respond to more challenging questions. The students from the group with new materials scored higher on cognitive-level-2 questions than did the students using the original materials ($t(28) = -9.07$, $p = .038$; experimental-group mean = 13.5, standard error [SE] = 0.98; control-group mean =12.8, SE = 0.98). Significant differences between the groups on level-3 questions ($t(28) = -3.765$, $p = .001$; experimental-group mean = 37, SE = 1.593; control-group mean = 32, SE = 1.593) indicated that the new material helped improve the students' higher-order thinking skills. In contrast, the groups did not differ significantly for level-1 questions ($t(28) = 2.629$, $p = .114$; experimental-group mean = 3.4, control-group mean = 3.8).

The focus group responses provided evidence that the students found fieldwork to be important in their learning. When they were asked whether the thematic approach to local forest ecology and field trips in several of the courses succeeded in improving their understanding of the ecological impacts of global climate change, all of the students responded affirmatively. Field-related activities were mentioned during the discussion by 19 of the 21 participants in the focus groups (see table 2).

Evidence from the student comments indicated that the students felt more confident with the material partly because of its deliberate sequencing. Overall, 11 of the 21 participants indicated that they were more confident because of the sequence of courses (e.g.,"I learned about how ecology actually works"). They also mentioned the value of integration of the content of the courses, essay assignments, the focus on climate change, phenology, lab work, lectures, and learning how to read scientific papers.

The students' qualitative modeling essays provided additional evidence that the fieldwork elements of courses helped change their comprehension. Fifteen of the 23 essays contained details indicating that the students placed a value on the fieldwork aspect of the course. In particular, several students noted how the content was applied out in the field (e.g., "Seeing what you learned happening right outside was powerful"). Seven of 23 students, when they were asked how modeling activities helped them, noted that the modeling activities themselves helped them achieve a better understanding (e.g., "Modeling helped me focus on specific interactions").

In one conceptual model (figure 2), a student chose to illustrate his understanding of the process of human disturbance's altering forest plant composition (creating environments with more deciduous and less coniferous trees) that favored the spread of invasive plant species. The student stated in his accompanying description that creating the model had given him a better understanding of the data collected during the course's research component.

In the second study, the students in both groups improved their scores, according to a comparison of pre- with post-test scores within each group; the groups showed similar improvement in their cognitive-level-1 scores (figure 3; Wilcoxon signed-rank test, $W(28) = -8$, $p = .386$). The students who took the courses over 9 months improved more than the consecutive group students on cognitive-level-2 questions (post- and pretest scores for the level-2 questions, $W(28) = -71$, $p = .0069$), which indicates a greater retention of information. A Welch independent two-sample t-test comparing the post- and pretest scores for cognitive-level-3 questions showed large differences between the groups ($t(28) = -1.66$, $p = .054$; spaced group mean = 5.78, SE =1.25; consecutive group mean = −4.71, SE = 0.99).

The value of an intentionally planned integrated curriculum

The comments by the experimental-group students in the focus groups, combined with their greater increase in mean scores, lends support to the idea that knowledge retention and the depth of understanding increase with the integrated teaching methods that we used, such as deliberate sequencing and multiple modes of retrieval. Although the number of students in each group was small, we detected differences in scores in the first study between the group with scaffolded, modified materials and the control group and, in the second study, between the spaced and consecutive course sequencing. During the first study, the students in the course with

Table 2. Year-1 focus group student questions (n = 23) with sample positive responses.

Question	Sample response	Number of responses
What were the most effective elements of the series of classes?	"[Field trips] were the best part of the series. I do feel I have some job skills that I would even be able to put on a resume. Why can't we do more of that in college—build our resumes with skills instead of information we will forget or could always look up?"	16
Did the thematic approach using local urban forests make the information more relevant?	"Yes, I have lived here in Portland for a while, so it was cool to relate my previous knowledge and places I am connected to." "Yes, all three courses brought those things together and made the information more relevant to me. I hadn't ever thought about the place I live in this way before."	8
Did the sequencing of the courses make sense to you, allow you to build on your prior knowledge?	"The sequence really helped me understand climatic variations. [I] needed background that we got in the other courses." "I liked the integration between the three courses. All courses had repeated material, so they all built on each other, especially in relation to phenology and urbanization impacts."	12

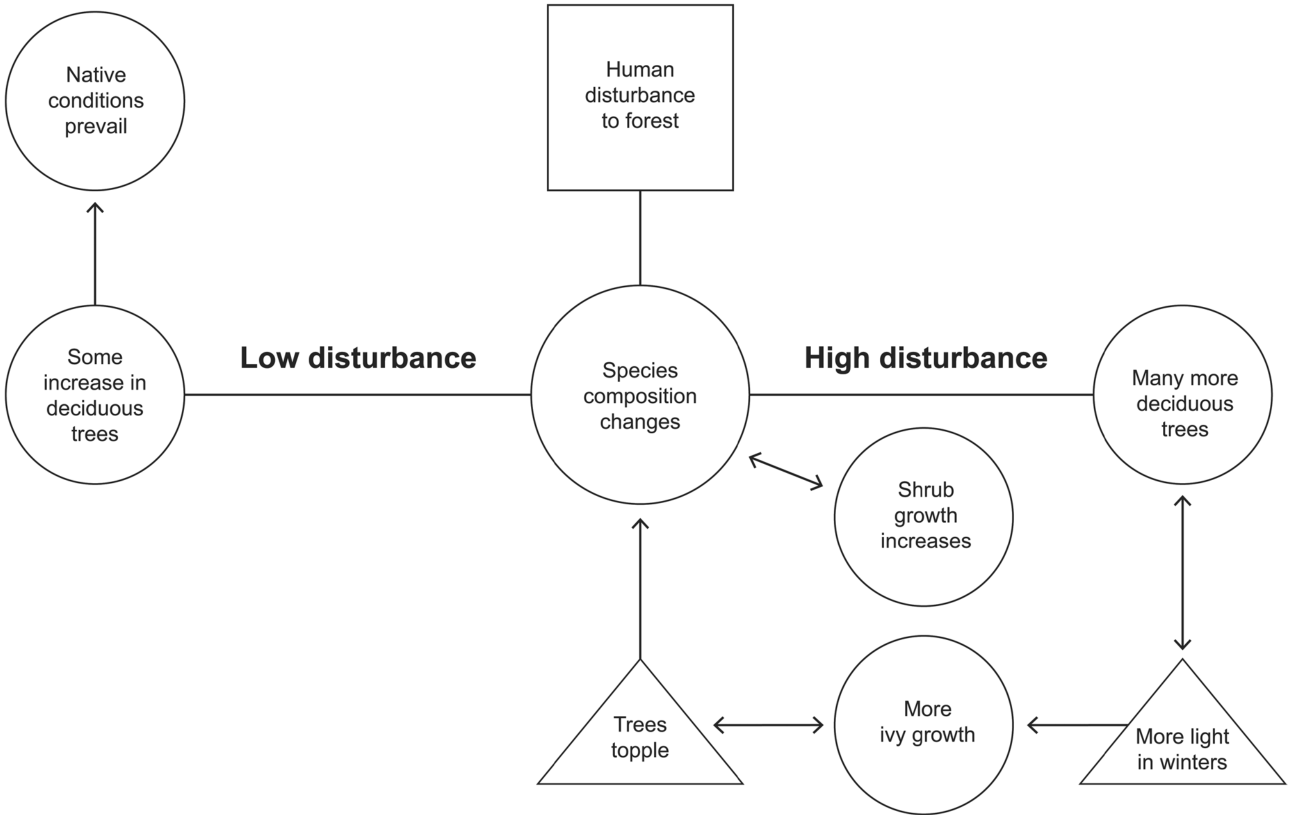

Figure 2. A student conceptual model of the ecological components derived from his research study of the urban forest. The student diagrammed the particular variables that were affected by human disturbance of the forest, particularly the change from conifer- to deciduous-dominated overstory and particular interactions resulting in a predominance of invasive ground cover. Positive interactions are indicated with an arrow, positive feedback loops are shown with a double-headed arrow. The circles indicate biotic elements; the triangles indicate abiotic elements.

revised materials and approaches learned the material with a climate change theme through a deliberate scaffolding of concepts, through labs and lectures, and through a series of field trips to collect data pertaining to the urban forest. The students who experienced the new labs had higher posttest scores for the two higher cognitive levels than did the students who had not. The engagement of the students in the linked curricula appeared to help those students retain information over the course of an academic year. Our results from the second year showed higher scores for the students taking the two environmental courses over the year than for the students taking them over a shorter time span. We saw significant differences for higher-order thinking skills over the 2 years of the study, specifically in cognitive levels 2 and 3.

In both studies, the students' scores on the questions aimed at cognitive level 1, which measured information retained through recall and routine learning, were slightly higher for the control groups. The older version of the courses and the lack of spacing before the posttest might have made it easier for the students to learn and recall the material by routine learning. In both studies, the students in the experimental groups had significantly higher posttest scores for cognitive level 2 (applying learning to a task or more-routine problem) and for cognitive level 3 (requiring the application of what was learned to more-complex problems). The experimental-group students clearly experienced a greater degree of coverage of the material and may have learned knowledge more applicable to problem solving–oriented questions.

To achieve higher-order thinking skills, students need to be engaged in specific higher-order thinking tasks, such as analysis, synthesis, and evaluation of the material (Halpern and Hakel 2003). To promote the long-term retention of information, to motivate students toward further learning, and to allow students to apply information in new settings, it is important to provide field trips and other varied learning environments (McKeachie et al. 1986) and prolonged contact with the material with opportunities for spacing. In the first study, the students in the experimental group clearly experienced a greater depth of coverage of material. In the second study, the students who experienced a gap between the courses might have benefited from additional practice in skills and similar material in the other courses in the program that they might have taken during the gap term.

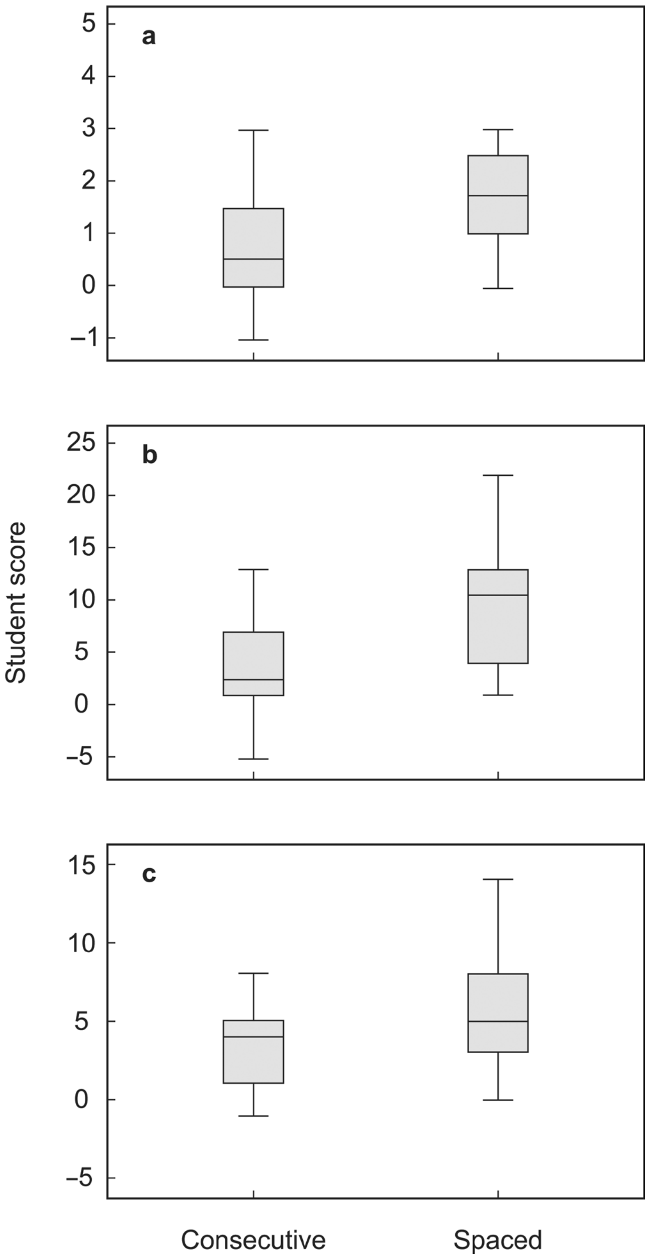

Figure 3. Median (horizontal bar) and quartile scores for cognitive-level-1 (a), -2 (b), and -3 (c) questions in the second study's experimental group (with spaced learning) and control group (with consecutive learning). The scores for all of the students' cognitive-level-1–3 questions were summed (composite scores), and the pretest scores were subtracted from the posttest scores to create a score that represented growth. The error bars represent the range of 90% of the composite scores.

Students who choose to major in environmental science or environmental studies may benefit from having field-based instruction early in their undergraduate education. Environmental studies majors at Western Washington University showed greater identification with natural places than did other majors (Myers 1997). When asked to describe in an essay their motivations for majoring in the environmental field, the students in our experimental group most often cited having had significant experiences in natural wild places. Another reason was a concern for the destruction of natural places. By giving them opportunities to work in urban forests and streams over several terms and to engage in research projects in which they learned firsthand about variation and losses in species diversity and declines in water quality due to urban effects at a local scale, we may have thereby provided them with experiences that engaged their prior knowledge and matched their expectation that they would learn to help solve environmental problems.

In a similar study of high school students, Miri and colleagues (2007) found that the experimental groups experiencing an enhanced curriculum showed a statistically significant improvement in critical thinking skills, self-confidence, and maturity when compared with the control groups. They recommended purposeful engagement in higher-order thinking strategies through relevant real-world problems and inquiry-oriented experiments.

By focusing on climate change and urbanization, using local data sets, and involving the students in inquiry-based research projects pertaining to urban forest and streams, we were able to touch on the previously mentioned key ecological systems in a way that was both current and locally relevant. The success of the new set of labs may be attributed to place-based learning (Payne and Wattchow 2008). Place-based learning was a factor that helped undergraduates better synthesize Earth and environmental science concepts and that helped attract underrepresented groups to science (Semken and Freeman 2008). The success of our new labs may also be due to the opportunities that they afforded the students to participate in authentic research through the collection of phenology data that contributed to a national data collection effort, as well as to conduct their own original investigations. Authentic research, an active approach to learning, uses the key features of science inquiry and scientific teaching and may help increase students' confidence in their abilities to do and understand science and may lead them to scientific careers (Seymour et al. 2004).

Planned curriculum in which theories and ideas are reintroduced and further developed over time may provide a more solid structure for students in which they can apply their learning in a manner facilitating higher-level cognitive function. Our analysis suggests that the completion and spacing of courses had an effect on the students' transfer, retrieval, and application of integrated environmental science knowledge. The effect of the 3-month spacing was not significant for lower-level cognitive items, such as recall, but became more pronounced for higher cognitive levels—those requiring the students to compare, relate, interpret, predict, and apply strategic thinking. The students who took the series of courses over a longer time frame may have integrated what they had learned across terms better, whether because they had more time to let the ideas sink in;

because they really had to pay attention to the material after the gap, rather than thinking of it as familiar and glossing over it; or because they had other relevant courses in the meantime that reinforced key ideas. Over time, the students reorganized their ideas and the connections between ideas. Spaced learning may elicit higher general performance on simple and complex concepts, because the passage of time may allow better integration of new knowledge (Vlach and Sandhofer 2012).

Some factors that affect our conclusions include a small sample size and differences among instructors for the reference courses. These factors present limitations to our overall experimental design and conclusions. We encountered problems running this experiment because our student culture is dependent on flexibility in scheduling. Many students did not stay in the experimental group or control group during the first study, which limited our ability to match pretests and posttests as was intended. Our low numbers in each group may challenge the validity of our results. Nonetheless, they are consistent with the literature and highlight the need for additional research.

Conclusions

The sequence and spacing of a series of courses with a deliberate scaffolding of concepts and skills and with strong field components had an impact on students' higher-order thinking skills. During the first year, we saw overall positive results from the students taking a coherent sequence of courses when they were compared with the students taking an older version of the courses, in which the material was not deliberately sequenced or place based. During the second year, we studied the spacing effect, using two of the new courses. We saw that the students taking the new series of courses over a 9-month period, with a 3-month gap, had a greater ability to apply environmental science content to solve more-complex problems than did the students taking the courses consecutively over 6 months. Therefore, our results suggest increased learning for college science students from the combination of scaffolded knowledge, repeated visits to field sites, and the use of local data sets and modeling, combined with metacognitive reflection and a 3-month pause between related courses. The new instructional materials are now a core part of our undergraduate majors courses, and we expect that students' learning will continue to improve in the future.

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