Interdisciplinary Journal of Problem-Based Learning

Volume 8 | Issue 2 Article 4

Published online: 3-13-2014

Engaging Non-Scientists in STEM Through Problem-Based Learning and Service Learning

Andrew Tawfik
Concordia University Chicago, aatawfik@gmail.com

Rebecca J. Trueman
Algonquin College, truemar@algonquincollege.com

Matthew M. Lorz
Sustainable Environments, LLC, mlorz@hotmail.com

THE INTERDISCIPLINARY JOURNAL OF
PROBLEM-BASED LEARNING

VOICES FROM THE FIELD

Engaging Non-Scientists in STEM through Problem-Based Learning and Service Learning

Andrew A. Tawfik (Concordia University Chicago), Rebecca J. Trueman (Algonquin College), and Matthew M. Lorz (Sustainable Environments, LLC)

This study follows the evolution of a single biology course designed for non-science majors. In its original design, the course used only traditional pedagogical techniques, such as lecture and textbook homework assignments. Over several iterations of the course, the class combined problem-based learning (PBL) and service learning to better support student knowledge. For this study, our goal was for students to learn biology concepts as they engaged in a lake cleanup project within the greater Chicago metropolitan area. Data sources consisted of pretest, posttest, and final exam scores to assess learning. The results suggest the combination of PBL and service learning led to gains in student learning.

Keywords: service learning, STEM, problem-based learning, biology

Introduction

Traditional undergraduate university teaching has often emphasized rigid, one-way communication between faculty and students. That is, faculty would lecture and expect students to absorb the information before showing mastery through multiple choice tests. However, this style of teaching fails to contextualize the subject matter or promote problem-solving skills (Gallagher, 2013). If students are merely passive recipients of information, they often fail to retain and later transfer knowledge in meaningful ways (Jonassen, 2011).

More recently, instructors have implemented various instructional strategies to enhance problem-solving. As such, there are now many studies that empirically verify the effectiveness of problem-based learning (Leary & Walker, 2009; Strobel & van Barneveld, 2009), project based learning (Beddoes, Jesiek, & Borrego, 2010; Grant, 2011) and service learning (Keen & Hall, 2009). The aforementioned instructional strategies engage students in active and contextualized learning, which which enhances the the students' abilities to apply the acquired knowledge (Merrill, 2002). These student-centered approaches also allow students the flexibility to apply their existing skills and strengthen areas of weakness as they work collaboratively with faculty and other students to solve problems (Savery, 2006). When the problems utilized in class are based on authentic problems, researchers argue they better support higher order learning (Hmelo-Silver, 2013; Hung, 2006).

Pedagogical Approaches

This paper presents the challenges and benefits we experienced as we employed alternative teaching approaches when teaching biology to non-science majors. Specifically, the initiative combined various forms of problem-based learning and service learning. Problem-based learning (PBL) was originally developed as an alternative to the didactic, lecture-based forms of learning (Barrows, 1996; Hung, Jonassen, & Liu, 2008). This instructional strategy theorizes that students learn best when knowledge is contextualized and centered around a problem that is relevant to the field of practice. In doing so, learners take responsibility of their learning (self-directed learning) as they investigate ill-structured problems that possess multiple solutions. As individuals are engaged in PBL, theorists argue that students learn the concepts while also learning problem-solving skills requisite for a community of practice (Hmelo-Silver & Eberbach, 2012). The PBL model specifically prescribes the following elements:

1. Student-centered learning,
2. Problem serves as the catalyst for learning,
3. Self-directed learning,
4. Collaborative learning in groups,
5. Group discussions focused around an ill-structured problem, and
6. Instructor serving as the facilitator of student inquiry, rather than the main source of knowledge.

http://dx.doi.org/10.7771/1541-5015.1417

Similarly, service learning was also an attractive pedagogical strategy for our initiative because of its emphasis on community problems germane to ecology and environmental responsibility (McClam, Diambra, Burton, Fuss, & Fudge, 2008). By actively combining the benefits of service learning and PBL, our project promoted an increased understanding of the complexity of social issues relevant to a particular field while allowing the students the opportunity to resolve ill-structured problems. The benefit of service learning projects also went beyond the tangible beautification of a public space. We chose service learning to create a stronger connection between the subject matter and students' communities. In our case, the highly visible nature of these projects presented an opportunity to communicate with the public and potentially enhance responsible environmental citizenship within our students.

The research has documented the potential of service learning in STEM courses. For instance, Gorman (2010) found that students involved in a service learning project to monitor *E. Coli* levels reported various learning benefits. The author observed that students were able to apply their learning to actual problems, but also connect the world around them with the concepts taught in class. Similarly, Larios-Sanz et al. (2011) reported that students who volunteered at an underserved hospital were better able to understand the relevancy of microbiology to their everyday lives. The authors further described how students were able to understand other elements of the ill-structured problem, such as social variables related to inequality and poverty not discussed in class. Cawthorne, Leege, and Congdon (2011) extended that research by looking at students' sense of self-efficacy as they engaged in a service learning project within an environmental biology course. Along with gains in learning, the authors found that students involved in service learning reported greater self-efficacy after they participated in the project. In each case, the service learning provided an authentic problem for students to solve, while also allowing the students a sense of ownership as they worked to benefit the community.

For the purposes of this project, the instructional activity involved immersing students in an urban eutrophic aquatic ecosystem. This lake is part of Prairie Lakes Park (42.03696 N,-87.91142 W), located in Des Plaines, IL. This small lake, situated in a highly urban environment, has an area of ~40,000 m^2 and a maximum depth of 7 m. This setting thus provided an ideal opportunity to link ecology concepts with service learning due to the increased threat of pollution. The lake also provided an ideal context for the ill-structured problems that are central to PBL. For instance, the lake is located under the O'Hare airport flyway and adjacent to a busy interstate. Previous managers had also used Aqua Shade Blue and Jet Black pond dyes, which affected water clarity. As such, students could offer a variety of resolutions to these problems given the complex nature of the ecosystem.

Background

This study explains an initiative to improve science pedagogy for non-science students enrolled in a general-education biology course. The team consisted of the instructional designer (first author), instructor (second author), and subject matter expert (third author). The collaboration between these three individuals helped to outline course objectives, develop necessary materials to scaffold student learning, and determine authentic problems for students to solve.

The course was originally offered as the science requirement of the university core curriculum. However, it became apparent to us that asking the non-science student to retain and understand the introductory science concepts using didactic learning was ineffective. Although we had taught the class since 2007, there was a constant struggle in lectures and labs to engage students in the subject matter and see biological concepts as relevant to their everyday lives. Moreover, class discussions seemed to come to a standstill if the instructor asked the students to describe and resolve biology problems within their environment. Although we felt these types of class discussions were important, the dialogue often ended with students asking if the material would be on the test. In our informal assessment of the situation, students had difficulty if we strayed too far from the familiar, didactic lecture format where students had clear expectations of what they were required to memorize.

By 2008, a course was created entitled "Biology in the World Today," which was design to teach STEM concepts specifically for non-science majors. The course was designed to cover a variety of topics, including how cells work and human genetics. Throughout the semester, the course progressed to more complex topics such as the human body, digestion, restoration, and muscles. As the course progressed further, the instructor tried to help students understand the human impact on the environment. This would invariably lead to discussions about how these concepts could be seen on different, yet related levels. For instance, small scale biology (such as cells, molecules) make way to larger scale biology (genetics of different life forms), and intersect to form the world's ecosystem.

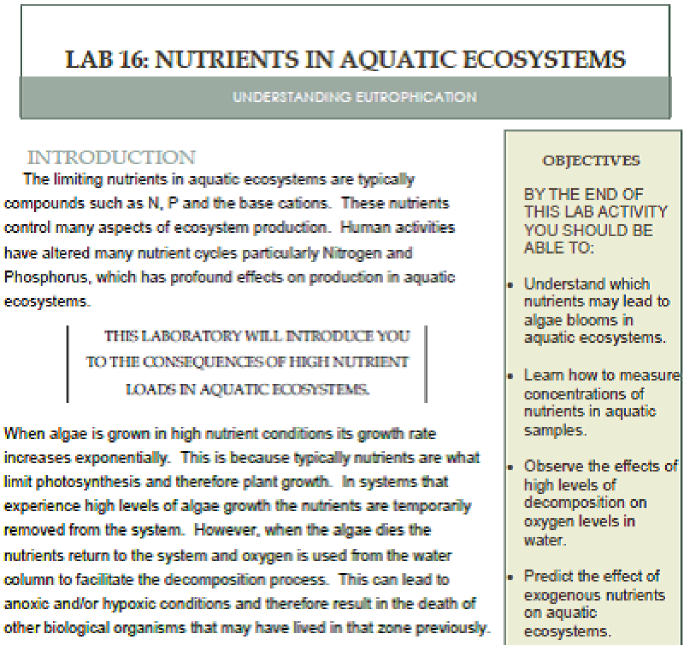
During the first year of this course, we struggled to attain the students' interest and engagement in science through lectures and lab sessions. In 2009, "Biology in the World Today" was taught primarily using a textbook aimed at retention of basic biological principles, but this approach often failed to emphasize problem-solving. For instance, discussions in class and during labs still revolved around the formulaic aspects of biology and definition of terms. When the discussions challenged the students to think about how these concepts could relate to contextualized biology problems, the disconnect between classroom learning and problem-solving became apparent to our team.

In 2010, we started to implement a few inquiry-based laboratory activities, such as discovering cells in food and seed germination inquiries. However, the students were very uncomfortable completing laboratory activities without the guidance of a linear style laboratory instruction set, which prescribed a familiar step-by-step approach. At the same time, we were aware of the eutrophication of local lakes within our community. Using a service learning approach, we then combined students from class with our research in the form of an extra activity to construct an environmental remediation for local lakes. We thought that a service learning approach would be beneficial because it required students to combine the subject matter within the local context for the betterment of the community (Levesque-Bristol, Knapp, & Fisher, 2010). This method also afforded a new opportunity to describe the processes involved in nutrient cycling of aquatic ecosystems.

Over time, the project grew to include other inquiry-based activities (see Table 1). During the Fall 2010 semester, we sought out volunteer students from the "Biology in the World" course to help in the clean-up process for the local lake, but only four students offered to help. In Spring 2011, we offered extra credit for students' participation in the lake cleanup process, at which point twelve students volunteered. As part of the initiative, we informally tracked the success of these twelve students in the course. Over time it seemed that students who helped with lake clean-up efforts were learning in situ when completing the service activity. This gave us confidence to expand the activity to other course sections.

In Fall 2011, we formally incorporated the lake clean-up and remediation activity via service learning into one section of "Biology in the World Today," while omitting it from the other section being taught. The results (shown later) encouraged us to move forward with service learning, such that in Spring 2012 and Fall 2012 service learning was implemented

Figure 1. Cookbook Laboratory Manual.


LAB 16: NUTRIENTS IN AQUATIC ECOSYSTEMS

UNDERSTANDING EUTROPHICATION

INTRODUCTION

The limiting nutrients in aquatic ecosystems are typically compounds such as N, P and the base cations. These nutrients control many aspects of ecosystem production. Human activities have altered many nutrient cycles particularly Nitrogen and Phosphorus, which has profound effects on production in aquatic ecosystems.

THIS LABORATORY WILL INTRODUCE YOU TO THE CONSEQUENCES OF HIGH NUTRIENT LOADS IN AQUATIC ECOSYSTEMS.

When algae is grown in high nutrient conditions its growth rate increases exponentially. This is because typically nutrients are what limit photosynthesis and therefore plant growth. In systems that experience high levels of algae growth the nutrients are temporarily removed from the system. However, when the algae dies the nutrients return to the system and oxygen is used from the water column to facilitate the decomposition process. This can lead to anoxic and/or hypoxic conditions and therefore result in the death of other biological organisms that may have lived in that zone previously.

OBJECTIVES

BY THE END OF THIS LAB ACTIVITY YOU SHOULD BE ABLE TO:

- Understand which nutrients may lead to algae blooms in aquatic ecosystems.
- Learn how to measure concentrations of nutrients in aquatic samples.
- Observe the effects of high levels of decomposition on oxygen levels in water.
- Predict the effect of exogenous nutrients on aquatic ecosystems.

in all sections of "Biology in the World Today" and accounted for 10% of a student's overall course grade. During this time, we also began investigating other teaching tools that would benefit this student population. To properly support the students, we wrote a combination textbook and lab manual that subdivided each unit into short descriptions of the scientific concepts using language a non-scientist could understand. As part of the exercise, each week the students completed a short paper-based exercise that we called a "cookbook laboratory manual" (the type of laboratory activity that has step-by-step instructions; see Figure 1).

Goals

Prior to our course redesign, students heard lectures about nutrient cycling in aquatic ecosystems. In class, students made the connections between nutrient imbalances and the effects on flora and fauna in these nutrient imbalanced systems. As we noted earlier, it was clear from our informal discussion with students that they were unable to transfer that

Table 1. Advancing science pedagogy in non-science students.

Condition Number	Semester	Instructional Strategy	Resources
1	Spring 2011	No service learning	
2	Fall 2011	PBL/Service Learning	
3	Spring 2012–Fall 2012	PBL/Service Learning	Inquiry/ cookbook labs

information during discussions of ill-structured problems. We thus decided to combine the benefits of problem-based learning (PBL) and service learning within the "Biology in the World Today" course.

The goal of the current project was to transition from a lecture-based format to a problem-centered pedagogy. Specifically, we wanted the students to possess the ability to think critically about complex issues and apply biological concepts to real problems. At the outset, we identified the following overarching goals:

1. Allow learners to employ biology in meaningful ways to solve problems,
2. Develop learners that can make informed decisions and think critically about science as responsible citizens of the world, and
3. Promote motivation within learners about biology.

Problem Based Learning

Based on these goals, we developed several questions that functioned as the catalysts of our course redesign. For the PBL portion, the following included:

- How do we make these topics relevant?
- How do we convey the problems that face biology today?
- How do we make the subject matter meaningful through contextualization?
- How do we show the students that the subject matter is not only relevant, but important for our future?
- How do we support meaningful learning and retention?
- How do we go beyond surface level understanding of the material?
- How do we show students the effects of biology in complex contexts with multiple, intersecting variables?
- How do we allow students to understand the connection between the laboratory context and real world analysis?
- How can we allow students to show an understanding and master of laboratory instrumentation?

Service Learning

The service learning questions were similar, yet related. However, these questions tended to emphasize how to directly link the biological concepts with the problems close to our communities. These questions included:

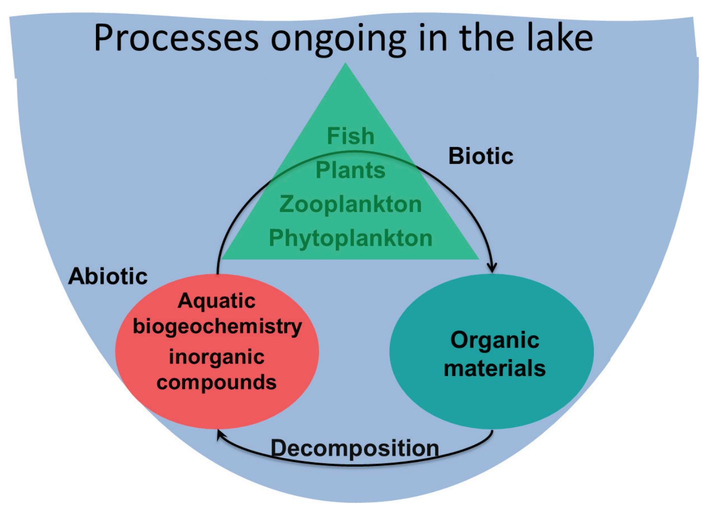
- How do we make these topics fun for students?
- How can we go beyond interest and actually help the environment?
- What can benefit can we add to our local communities and engender a sense of sense of ecology responsibility?

The actual PBL/service learning activity served as a parallel project to the topics presented in class. While performing the lake clean-up, students were asked to consider nutrient cycling within the abiotic to biotic systems (Figure 2). In addition, students were asked to consider how pollutants might cycle in this system. Based on these questions, the following subgoals were identified for the Des Plaines lake restoration project:

1. Complete nutrient analyses
2. Examine the nitrogen and phosphorus concentrations in the lake
3. Examine the flora and fauna in the lake
4. Determine the level of eutrophication
5. Develop management strategies to reduce nutrient availability
6. Construct a timeline for completing the project.

In Phase 1 of the activity, the students were required be at the lake for at least 10 hours over the course of two months. Specifically, students were to identify the problems and generate a remediation plan for the chemical imbalances. The instructor would be there each weekend from 10:00 am to 6:00 pm and work with student teams of three to four students. Students were allowed to form their own groups and were encouraged to engage in collaborative learning. For the project, students were told they could come and go as needed based on how they defined the problem and what they identified as requisite research to construct a remediation plan. Their only requirement was that each had to be there for 10 hours. During this time, the instructor would have discussions with each group and answer questions they identified as being relevant to the cleanup project.

Figure 2. Linkages between the abiotic and biotic environment as explained using organisms to precipitate nutrient exchanges within an aquatic ecosystem.



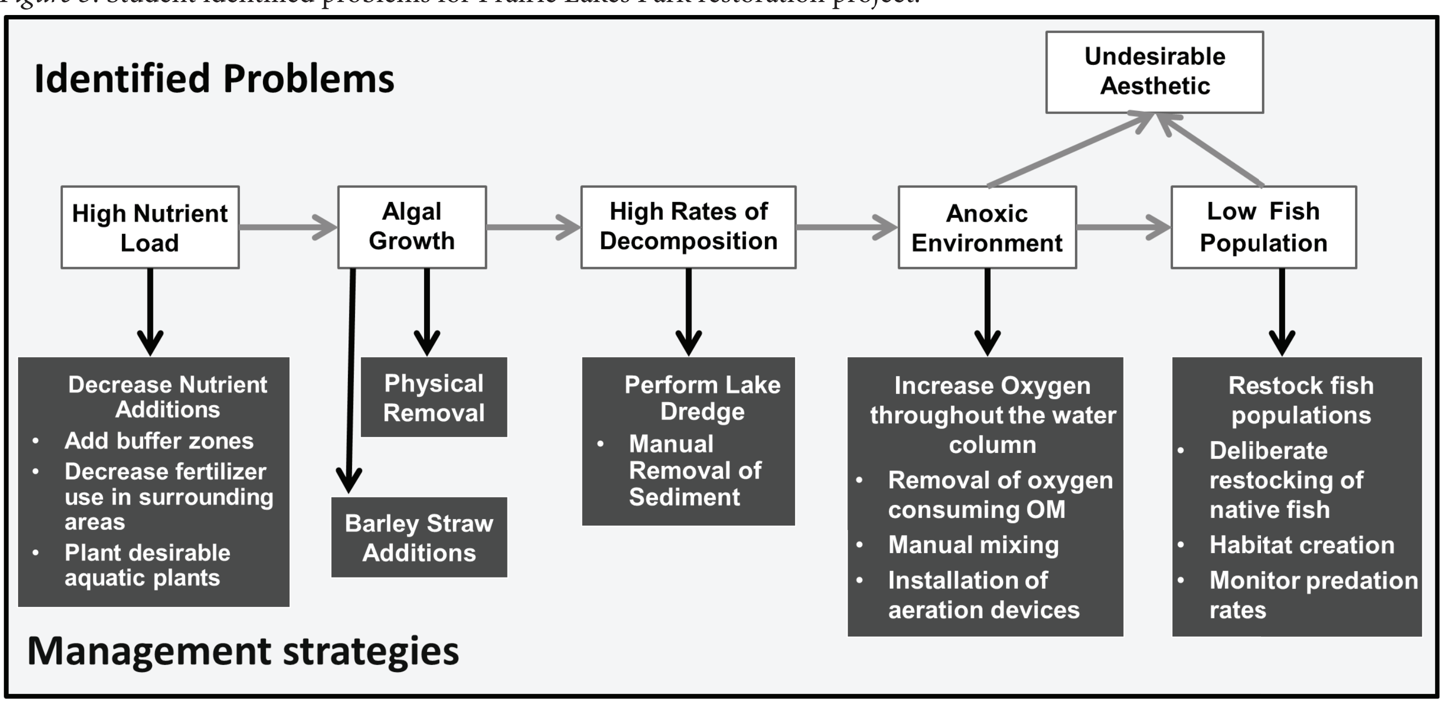
The project modified other elements in the course. For instance, the labs shifted from a formal, in-class setting to a task that resembled an actual field analysis. When students arrived at the lake, they were given Hanna sensors, a handheld device used for field analysis by practitioners. Based on how students defined the problems that plagued the lake, they would use the Hanna sensors to measure nitrates and phosphates. The Hanna readings would then rank the nutrient as a natural or high pollutant. Students would then take this lab experience as data that supported their problem definition and proposed a remediation plan. In-class time was also allotted to discuss the findings of the lake project. Instead of a strict lecture-based approach, time in the face-to-face meetings was used to collectively discuss student findings and relevant topics from the previous weekend (see Figure 3).

While Phase 1 focused primarily on problem definition and solution generation, Phase 2 required students to actually employ their group's ecosystem restoration strategy they had previously outlined. The guidelines required students to articulate their goals, outline their restoration plan, justify their plan, and implement their proposed solutions. We believe that the implementation aspect was particularly important for our experience. In many instances of PBL, students are given hypothetical scenarios to consider (Herrington, Reeves, & Oliver, 2014). As such, students may not be able to take part in the execution of a proposed solution because the activity is often constrained to the classroom. However, service learning allows the students to apply solutions to authentic problems within the community around them.

Very little detail was provided beyond the goals identified above. This open-ended approach was selected for multiple reasons. First, the ecosystem of a lake is a very ill-structured problem, and we wanted to avoid constraints on student problem-solving. We wanted to provide a general structure of what we expected, but allow students to collaboratively define the actual problems with the nutrients; outline the variables that were important as they assessed the site; grapple over the data needed to determine the eutrophication levels; and proffer their own remedy solutions. The approach also allowed the students a more authentic learning experience. As noted previously, we often felt the disconnect between the problems assigned, labs, and actual biology problems. The PBL and service learning combination allowed us to overcome many of these issues.

By immersing students in the complex cycling between inorganic and organic materials, we noticed in our discussions that students began to understand how the biogeochemistry of a system interacts with the biological organisms within a system. As part of the project, students were expected to generate questions such as: "Could plants absorb pollutants? What is the threat to the living organisms as a result of the pollutants?" As such, the service learning combined with PBL afforded the students the opportunity to contextualize and apply their knowledge in new ways related to human issues of clean water, safe food, and community outreach. This also allowed the students an opportunity to gain problem-solving skills related to analogical transfer, self-directed learning, and solution evaluation.

Figure 3. Student identified problems for Prairie Lakes Park restoration project.



The Students

All of the students in "Biology in the World Today" were non-science majors. Each class was usually comprised of the following demographics: 70% white, 18% African American and 13% Hispanic students. Approximately 40% of the students were the first in their family to attend an institution of higher education (Table 2).

The Challenges

While most of the students that completed "Biology in the World Today" would not become scientists, we thought it was important for all students to understand the importance of science for their daily lives. However, general science education classes may present the only opportunity to educate non-science major students on topics that will be vital to the students' future decision-making and environmental responsibility. This inevitably led to challenges throughout this course.

One of the greatest challenges of the course was that few students had familiarity or background with STEM concepts. At the beginning of the class, many students would reiterate to us in informal conversations that they were only enrolled in the class as part of the general education requirement. This sentiment was expressed to us many times by various students. Moreover, many students informed us that they would not do well because they never enjoyed science. As such, it became clear they experienced some initial resistance with the subject matter. Overcoming these negative attitudes in these students was critical to their success within the course.

Because of their expressed aversion to the discipline, it was therefore important for us to instill in the students the importance of a competent understanding of science. In a similar vein, an additional challenge was a lack of background knowledge. Science instruction at the undergraduate level often requires the students to have prior scientific knowledge on which to build upon. Because of the limited nature of the high school classes taken by non-science oriented students, many students entered "Biology in the World Today" with a very limited foundation of scientific knowledge. This severely limited the initial scope of the course because the instructor needed to revisit fundamental concepts in the beginning of class before proceeding to more complicated topics.

Another challenge was the students' resistance to the incorporation of non-traditional pedagogical techniques. Because most students had little or no previous experience with PBL or service learning, they were wary of these instructional strategies and the time commitment. Many students within the class were accustomed of the time commitment involved in traditional didactic classes; however, introduction to the project created uncertainty among the students as to how they would effectively manage their learning. While this period of uncertainty typically diminished as students became immersed in the project, it exacerbated the implementation obstacles in the early stages. Surprisingly, the resistance to aspects of service learning was stronger than the resistance to PBL, primarily because of their dislike of the cleanup process. However, the students' resistance reduced when the students were able to see the tangible results of their service. In fact, once students had spent time at the lake, many volunteered to come back at a future time.

Benefits of Integrating Real-World Problems into a Biology Course

Our experience of engaging students in 'real-world' science appears to be effective with students. As part of our initiative, we tracked final exam grades of students in the courses that had incorporated the lake cleanup activity. Although the final exam was not identical to the pretest and posttest, the assessment was designed to evaluate similar learning objectives such as nutrient analysis, eutrophication levels, and lake flora, among others. To assess validity, all tests were compared with the learning objectives for the semester. As an additional measure of validity, all tests were reviewed by an additional subject matter expert who had worked with an

Table 2. Student demographic information for the "Biology in the World Today" courses.

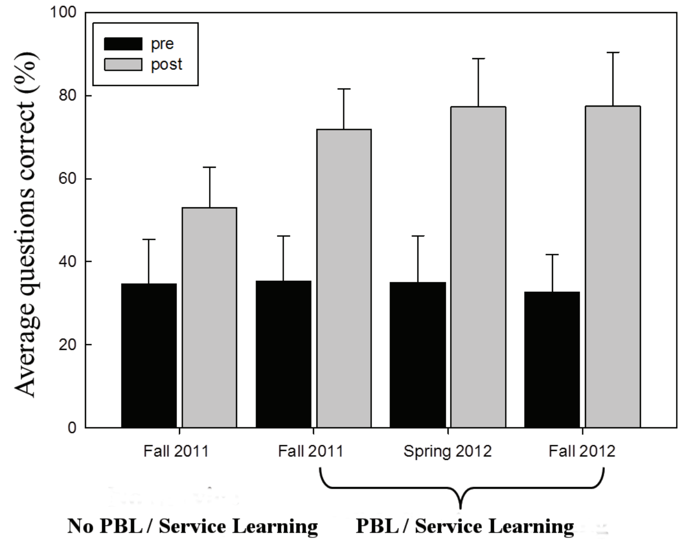
Semester	Fall 2011	Fall 2011	Spring 2012	Fall 2012	Average
Male	70%	56%	33%	48%	51%
Female	30%	44%	67%	52%	49%
White	70%	59%	80%	66%	69%
African-American	10%	30%	15%	18%	18%
Hispanic	20%	11%	4%	16%	13%
First Generation Students	45%	48%	30%	41%	41%
Total	20	27	46	44	34

external environmental sustainability company for over five years on the lake restoration project. We sought out an additional subject matter expert who had worked with an external environmental sustainability company for over five years on the lake restoration project.

Tests were given on multiple occasions to assess improvement over time. The pretest was administered before the PBL and service learning activity was assigned (Week 6). The posttest was identical to the pretest and given towards the end of the semester, after students had completed Phase 2 of the project (Week 14). Lastly, the final exam was administered two weeks after the students had completed their project (Week 16). Our results found that student grades improved as we incorporated more PBL and service learning aspects into the curriculum (Table 3). The class experienced 100% retention, most likely because the course was a general education requirement.

When we compared pretest and posttest results from students that had completed the PBL and service learning components, we found that the average pretest score was 34.5%, while the average posttest score after lecturing on the material was 56.7%. However, results of the t-test showed the PBL and service learning components significantly improved post-test scores (M = 75.5%; $p = < 0.001$; Figure 4).

Figure 4. Comparison of student scores.



Instructor Reflection

There were several benefits to the PBL and service learning approach for this STEM course. We have found that when students were empowered and engaged, they felt more comfortable to ask questions, present ideas, and proffer solutions. This was especially true when we were onsite at the lake. In many ways, these pedagogical methods employed were different from the students' experiences in previous science classes. By removing students from a circumstance where they had previously felt uncomfortable, we felt we were able to provide them with a new STEM learning experience.

The PBL and service learning techniques allowed students to apply knowledge to solve authentic problems encountered within the STEM domain. From a teaching perspective, this was particularly important because we believed students had experienced a disconnect between the laboratory and the world around them. By combining PBL and service learning, the students were able to implement solutions to ill-structured problems and later see tangible community benefits as a result of their action (Figure 3).

From an instructor's point of view, it was encouraging to see how the combination of PBL and service learning could motivate and engage the non-scientist in biology. In many ways, this caused individuals to approach biology in new ways. As such, some of the barriers fell by the wayside as individuals approached the material in new and creative ways that showed tangible benefits for the community. Based on our experience, this curiosity led to engagement and later strengthened the instructor-student dynamic. These activities required a great deal of extra work, but the experience was worthwhile.

Next Steps

We believe that one of the ultimate goals of science education should be to create an informed citizenry who have a strong fundamental grasp of science. In their everyday lives, individuals make choices about energy policies, biotechnology, the food system, etc. Even if they are not formally employed in the STEM discipline, they should still

Table 3. Final exam grades in "Biology in the World Today."

Condition #	Course Section	Percentage of Final Exam Letter grades				Number of students
		A	B	C	D	
1	Fall 2011	17%	42%	42%	8%	24
2	Fall 2011	48%	37%	15%	0%	27
3	Spring 2012	48%	28%	10%	3%	29
4	Fall 2012	59%	34%	0%	0%	44

contribute responsibly to the ecology for future generations. It is important that citizens feel comfortable thinking about science and reflecting on its importance in their lives, but also contribute in positive ways to their community.

Based on our experience, the next logical steps would be to introduce PBL and service learning to other science courses. Another step would be to integrate service learning into education beyond just higher education. If these techniques prove as beneficial at the high school level as they have been at the collegiate level, the implementation might lead more people to see STEM as a solution to our world's ecological problems.

We believe the class could also explore other problems that face our society. As such, projects could also be centered around topics and outreaches that more directly impact individuals. For instance, we could expand the project to include citywide informational campaigns that apprises individuals of pollutants prevalent within their region. This type of project would support the ill-structured nature of PBL, while also simultaneously encouraging students to serve the needs of the community.

We believe this experience has implications for others looking to apply PBL. At its core, PBL is about solving ill-structured problems that represent the complexities of a given field. Service learning extends this by asking students to solve problems and applying them to benefit their community. As such, there is great potential to mix these two strategies further. For instance, an instructor in computer science could ask students to design an educational app for special needs students at a nearby high-school. Alternatively, business students could apply concepts related to finance and marketing to organize a community pledge drive. In each case, students learn how the concepts are applied to resolve authentic problems, and engender a sense of responsibility for their community.

References

Barrows, H. (1996). Problem-based learning in medicine and beyond: A brief overview. *New Directions for Teaching and Learning*, *1996*(68), 3–12. http://dx.doi.org/10.1002/tl.37219966804

Beddoes, K., Jesiek, B., & Borrego, M. (2010). Identifying opportunities for collaborations in international engineering education research on problem and project-based learning. –*Interdisciplinary Journal of Problem-based Learning*, *4*(2), 7–34. http://dx.doi.org/10.7771/1541-5015.1142

Cawthorn, M., Leege, L., & Congdon, E. (2011). Improving learning outcomes in large environmental science classrooms through short-term service-learning projects. *Journal of Environmental Studies and Sciences*, *1*(1), 75–87. http://dx.doi.org/10.1007/s13412-011-0001-8

Gallagher, J. (2013). Using problem-based learning to explore unseen academic potential. *Interdisciplinary Journal of Problem-based Learning*, *7*(1), 111–131. http://dx.doi.org/10.7771/1541-5015.1322

Gorman, W. L. (2010). Stream water quality and service learning in an introductory biology class. *Journal of Microbiology & Biology Education*, *11*(1), 21–27. http://dx.doi.org/10.1128/jmbe.v11i1.140

Grant, M. (2011). Learning, beliefs, and products: Students' perspectives with project-based learning. *Interdisciplinary Journal of Problem-based Learning*, *5*(2), 37–69. http://dx.doi.org/10.7771/1541-5015.1254

Herrington, J., Reeves, T. C., & Oliver, R. (2013). Authentic learning environments. In J. M. Spector, M. D. Merrill, J. Elen, & M. J. Bishop (Eds.), *Handbook of research on educational communications and technology* (4th ed., pp. 401–412). New York: Springer.

Hmelo-Silver, C. E. (2013). Creating a learning space in problem-based learning. *Interdisciplinary Journal of Problem-based Learning*, *7*(1), 24–39. http://dx.doi.org/10.7771/1541-5015.1334

Hmelo-Silver, C. E., & Eberbach, C. (2012). Learning theories and problem-based learning. In S. Bridges, C. McGrath, & T. L. Whitehill (Eds.), *Problem-based learning in clinical education* (pp. 3–17). New York: Springer. http://dx.doi.org/10.1007/978-94-007-2515-7_1

Hung, W. (2006). The 3C3R model: A conceptual framework for designing problems in PBL. *Interdisciplinary Journal of Problem-based Learning*, *1*(1), 55–77. http://dx.doi.org/10.7771/1541-5015.1006

Hung, W., Jonassen, D. H., & Liu, R. (2008). Problem-based learning. In J. M. Spector, M. D. Merrill, J. van Merrienboer, & M. Driscoll (Eds.), *Handbook of research on educational communications and technology* (3rd ed., pp. 659–670). New York: Routledge.

Jonassen, D. H. (2011). *Learning to solve problems: A handbook for designing problem-solving learning environments* (1st ed.). New York: Routledge.

Keen, C., & Hall, K. (2009). Engaging with difference matters: Longitudinal student outcomes of co-curricular service-learning programs. *The Journal of Higher Education*, *80*(1), 59–79. http://dx.doi.org/10.1353/jhe.0.0037

Larios-Sanz, M., Simmons, A. D., Bagnall, R. A., & Rosell, R. C. (2011). Implementation of a service-learning module in medical microbiology and cell biology classes at an undergraduate liberal arts university. *Journal of Microbiology & Biology Education*, *12*(1), 29–37. http://dx.doi.org/10.1128/jmbe.v12i1.274

Leary, H., & Walker, A. (2009). A problem based learning meta analysis: Differences across problem types, implementation types, disciplines, and assessment levels. *In-*

terdisciplinary Journal of Problem-based Learning, *3*(1), 12–43. http://dx.doi.org/10.7771/1541-5015.1061

Levesque-Bristol, C., Knapp, T. D., & Fisher, B. J. (2010). The effectiveness of service-learning: It's not always what you think. *Journal of Experiential Education*, *33*(3), 208–224. http://dx.doi.org/10.7771/1541-5015.1061

McClam, T., Diambra, J. F., Burton, B., Fuss, A., & Fudge, D. L. (2008). An analysis of a service-learning project: Students' expectations, concerns, and reflections. *Journal of Experiential Education*, *30*(3), 236–249. http://dx.doi.org/10.5193/JEE.30.3.236

Merrill, M. D. (2002). First principles of instruction. *Educational Technology Research and Development*, *50*(3), 43–59. http://dx.doi.org/10.1007/BF02505024

Savery, J. (2006). Overview of problem-based learning: Definitions and distinctions. *Interdisciplinary Journal of Problem-based Learning*, *1*(1), 9–20. http://dx.doi.org/10.7771/1541-5015.1002

Strobel, J., & van Barneveld, A. (2009). When is PBL more effective? A meta-synthesis of meta analyses comparing PBL to conventional classrooms. *Interdisciplinary Journal of Problem-based Learning*, *3*(1), 44–58. http://dx.doi.org/10.7771/1541-5015.1046

Andrew A. Tawfik is an assistant professor of Instructional Design and Technology at Concordia University Chicago, where he serves as the program leader. He earned his PhD in Learning Technologies from the University of Missouri. Dr. Tawfik's research interests include problem based learning, case-based reasoning, case library instructional design, and computer supported collaborative learning.

Rebecca J. Trueman is the chair of Applied Science and Environmental Technology at Algonquin College in Canada. She holds a PhD from the University of Illinois at Chicago in Biology and served as a Biology professor for the previous 10 years. Recently, she has been developing educational technology to enhance the understanding of science. Her work has been funded by the National Science Foundation.

Matthew M. Lorz is the chief technology officer of Sustainable Environments, LLC. He has spent many years involved with research that attempts to detangle anthropogenic effects on ecosystems. His background in the arts has assisted in the development of learning environments.