

# Problem-Based Learning in Upper Division Courses: Student Successes, Perceptions, and Reactions

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**Abstract.** This paper presents an experiment in project/problem-based learning (PBL) in an upper division mathematical physics course. The group project in the course involved modeling a zombie outbreak of the type seen in AMC's *The Walking Dead*. Students researched, devised, and solved their mathematical models for the spread of a zombie-like infection. Students independently learned and utilized numerical methods to solve highly coupled systems of differential equations. This work explores student perceptions and reactions to problem-based learning, and the feasibility of using PBL as the sole pedagogy in upper division physics courses.

**Keywords:** Problem Based Learning, Group Problem Solving, Student Attitudes, Pedagogy in Upper Division Courses

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## INTRODUCTION

Problem-based learning (PBL) was first introduced in the 1980s in the context of medical education. Since then, the PBL approach has spread to many disciplines such as biology, law, chemistry, physics, business, and others with great effectiveness. So what is problem-based learning? Briefly, it is a systematic way to introduce active, student-centered learning to both large and small classes. The essential features of problem-based learning include:

1. Learning begins with a problem, which are complex and based on real-world scenarios.
2. Not all information is given; students need to make assumptions and estimations.
3. Students learn how to identify, search for, and use information outside the textbook.
4. Students work in groups and learning is active and connected.
5. Faculty role is that of a guide and mentor.

Since learning occurs through work on a central problem, PBL problems differ substantially from typical homework or other "problems" in a course. A good PBL problem is engaging, multi-staged, complex, open-ended, and perhaps most important, covers course content naturally [1]. The draw of problem-based learning in physics is that classroom instruction more naturally resembles the organic process of research and how physics is done in the real-world: students confront purposeful, open-ended, and ill-defined problems whose answers shed light on an interesting situation/question. Barbara Dutch and collaborators at the University of Delaware have done ground-breaking work on adapting this peda-

gogy to physics instruction [1, 2]. For example, one particularly useful resource developed at the University of Delaware is the PBL Clearinghouse [3].

Despite the success of instructors at the University of Delaware and elsewhere in utilizing PBL methodology to teach physics, PBL in physics has been restricted to the introductory physics sequence, i.e. mechanics and topics in electricity and magnetism. Little work has been done in studying the effectiveness and even the appropriateness of PBL at the upper division physics level. In fact, a search of the physics education literature reveals only one such experiment, in which one module in an introductory thermodynamics course was implemented using PBL [4]. And yet, problem-based learning offers tremendous advantages to students as an example of a systematic, active engagement pedagogy which differs from more traditional, lecture-based strategies such as clicker questions. This is of crucial importance since many if not most upper division courses are still taught in a lecture format. There is a clear and compelling need for more research in this area.

The goals of this project are to 1) examine the effectiveness and appropriateness of PBL instruction in an upper division course, 2) to study student perceptions and attitudes towards the PBL process, and 3) determine if PBL methodology is appropriate for full-scale implementation in upper division physics courses such as quantum mechanics, E&M, thermodynamics, and others.

## THE PROBLEM: THE LIVING DEAD

Two PBL modules were implemented in an upper division course, Mathematical Physics, at Creighton University, in fall 2010. The course lies at the sophomore-junior

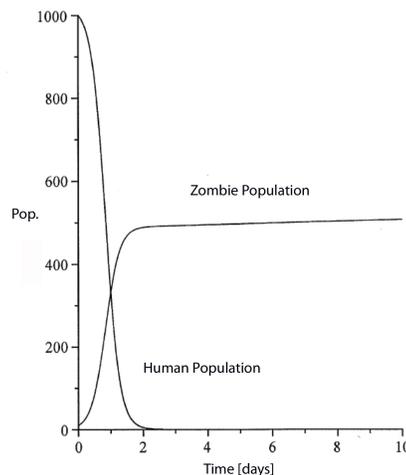
boundary, and is meant to be an introduction to the topics and techniques in mathematics (taught as physicists actually use them) that are crucial for further courses such as classical mechanics, E&M, and quantum mechanics. Course students consisted of 9 undergraduates and three masters students who needed a review of mathematical methods in physics. Topics covered were approximations and expansions of functions, ordinary differential equations, linear algebra, and coordinate systems and transformations.

The second PBL module (the focus of this paper) came about two-thirds of the way through the semester after covering ordinary differential equations in lecture with a particular emphasis on modeling physical phenomena. One important criteria of all PBL problems is that a problem must interest and excite students, and be something they find relevant. During the semester it became obvious that students in the course were particularly excited about the premiere of AMC's *The Walking Dead*, a series which follows a band of survivors as they deal with a zombie apocalypse [5]. For readers unfamiliar with zombies, here is the generic zombie scenario: the dead "reanimate", can pass the infection on to the living by biting, and move about with a particular hunger for living flesh. Zombies can be killed, usually by destroying the brain, and the world quickly becomes full of zombies with increasingly rare uninfected humans struggling to survive.

The PBL project for students became simply this: using a zombie outbreak scenario from popular media or literature, model such an outbreak and predict as a function of time the uninfected human and zombie populations. Note that the problem is purposely ambiguous: students had to choose their own initial conditions, model parameters and model setup, and had to learn themselves how to numerically solve their differential equations. Although most PBL problems would be a bit more well-defined, this problem was stated so broadly to give students a sense of ownership and more individual choice. As in all PBL settings, students worked in groups using both in-class and out of class time. Students justified and defended their choices and assumptions and their work in a written report.

In any PBL problem, it is crucial that the course objectives be embedded in a thoughtful way in the problem. The instructor's objectives for the module included:

- To construct a complex, real-world, differential equation-based model
- To solve more complicated differential equations than typical, back-of-the-textbook problems
- To explore the parameter space of solutions to their differential equations
- To learn and utilize numerical techniques to solve differential equations



**FIGURE 1.** Sample of student work: Zombie and Human Population vs. time. Humans lose.

## Student Work

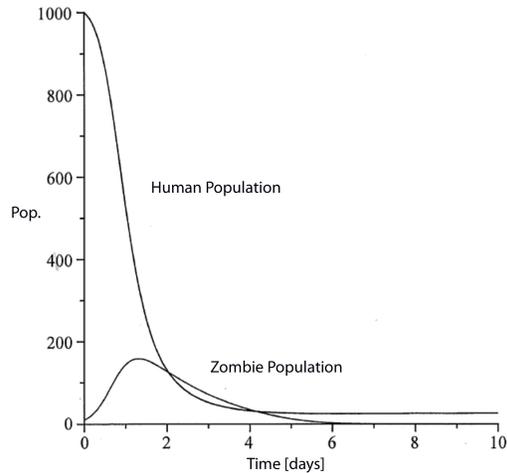
Students were given a copy the paper "When Zombies Attack!: Mathematical Modeling of an Outbreak of Zombie Infection" from an infectious disease modeling journal to use as a resource and as an example of complex mathematical modeling (in the future a staged approach to the problem will eliminate the use of this resource) [6]. Although a zombie outbreak is unlikely, it turns out the mathematics necessary to model a zombie outbreak is similar to those used in modeling a typical infectious disease outbreak (such as H1N1); the project has wider applicability, another hallmark of a good PBL problem. Students began with a basic model:

$$\frac{dH}{dt} = -\alpha_1 HZ \quad (1)$$

$$\frac{dZ}{dt} = +\alpha_1 HZ - \alpha_2 ZH \quad (2)$$

where  $H$  and  $Z$  are the human and zombie populations respectively and  $\alpha_1$  and  $\alpha_2$  are parameters which reflect how easily zombies infect humans and how easily humans kill zombies respectively. Students very quickly found that many solutions to the basic model resembled Fig. 1, where the number of infected (zombies) grows quickly and overwhelms the human population.

However, students very quickly built new complexities into their models. In some models the parameters  $\alpha_1$  and  $\alpha_2$  were functions of time, which might reflect, for example, a model in which humans become better at killing zombies over time. Such scenarios can give results like that of Fig. 2 where a remnant human population can remain. Students explored a diverse set of mod-



**FIGURE 2.** Sample of student work: Zombie and Human Population vs. time. Humans win. This is a variant on the model of Eqs. (1) and (2) in which  $\alpha_2$  increases with time.

els which included a segment of the population being naturally immune to the infection, the effect of human-established safe zones, finite lifetime for zombies (they decay), etc. All of these extended models meant exploring and solving more difficult, involved, and coupled differential equations.

Since the models students devised were coupled and non-linear, students needed to use numerical techniques to solve their DEs. Students were responsible for researching numerical solutions to differential equations, choosing an appropriate technique, and demonstrating usage of the technique with simpler DEs. Students then went on to use Maple and Mathematica (and in some cases Excel) to find the solutions to their models. Very few students had solved even ordinary DEs in this manner before, but by the end of the project all of the students displayed proficiency in finding numerical solutions to differential equations.

## STUDENT SUCCESSES, REACTIONS, ATTITUDES, AND PERCEPTIONS

In a exam subsequent to the zombie modeling project, students performed better and displayed a deeper and more mature understanding of DE-based modeling than students in the previous year of the course. However, more data is necessary to make a statistically significant claim. Instead here we focus on qualitative data. Since educational research has shown the importance of the link between attitude and learning [7], we particularly wanted to explore student attitudes and per-

**TABLE 1.** Student Responses to selected Likert-Scale survey questions (one semester later). N=11.

Survey Question	Strongly Agree	Agree	Neutral
The Zombie Project made the class more interesting to me	63.6%	36.4%	-
I learned more from the PBL project than I would have from lecture	36.4%	54.5%	9.1%
The PBL project helped me understand practical applications of the math/physics we studied	36.4%	54.5%	9.1%

ceptions towards PBL pedagogy in general. Information about student attitudes, perceptions, and reactions to this project, as well as the feasibility of teaching upper division physics courses entirely in a PBL format, were collected from three sources: 1) narrative course evaluations, 2) a survey with both Likert-scale and free-response questions one semester later in spring 2011, and 3) a student interviews conducted during the summer of 2011. Although our sample size is small (11 students), students were extremely consistent in their positive evaluation of the PBL component of the course and of PBL methodology in general.

## Course Evaluations and Survey Results

A fifteen question survey consisting of yes/no, Likert-scale, and open-ended questions was distributed to students in spring 2011, one semester after the completion of the course. Eleven out of twelve students completed the survey.

Student responses to selected Likert-scale questions can be seen in Table 1. The overwhelming majority of students in the course valued and learned from the PBL exercise. It is interesting to note that none of the eleven students responded to the selected survey questions in the negative. The project resonated with students and captivated their interest (and this was true for both male and female students). One student notes:

**Student Comment #1:** “I thought the project was a great way to cover the material. My Maple skills improved dramatically. I’m now very comfortable with solving DEs numerically. I don’t think that I could say that if we had just done a simple example in class.”

Students expressed a trepidation that at least some lecture was necessary; however, as echoed in the Likert-

scale survey responses, they felt they learned as much or more through PBL pedagogy than they would have through traditional lecture and problem sets. For example, a student noted:

**Student Comment #2:** "I found the the PBL project particularly interesting as I am going into biology and medicine. Modeling being applied to something like a disease was fantastic for me. I found the assignment very concrete and it helped in illustrating an application for the math. Since I spent a lot of my time just trying to get everything down in lecture, the PBL allowed me to work at my own pace and think through things with a partner. For me, the PBL was a more natural way to learn something than that standard approach of learning."

After coding the survey responses, other common themes emerged. Students were unfamiliar or uncomfortable using tools like Maple or Mathematica. Although eight out of eleven students had used Maple and/or Mathematica to solve problems in mathematics courses, only three out of the eleven students who responded had ever used these tools for a physics problem or in a physics course. Secondly, although students enjoyed working in groups, they craved more interactivity in the class as a whole. Students wanted to share results and learn from other groups, and insisted that a more successful iteration of the PBL project would include this feature. Finally, students commented on what is termed "staging" in the PBL literature (though they did not use that term). Students felt that breaking the problem down into a series of stages that ramped up in difficulty and complexity would have been beneficial.

## Student Interview Results

Since previous survey results and course evaluations had demonstrated that students enjoyed, valued, learned from, and recommended the PBL exercise be repeated, questions for the student interviews concentrated on the feasibility (in student minds) of applying PBL methodology as the sole pedagogy in an upper division course. Eight out of the eleven survey responders were able to participate in the interview process. Surprisingly, all eight students uniformly agreed that an upper division course could be taught solely in a PBL format. In fact, all expressed a willingness and excitement to take such a course. A common theme which emerged was the principal value of a PBL experience: retention. Several students commented that they felt their learning in the PBL module was deeper and longer lasting. As one student put it, "I remember the zombie project, but I have no idea what I did in Calc II." Another said, "I learn more doing

one tough problem than a bunch of easy ones."

Students were understandably hesitant about entirely removing a lecture component, though they did feel that much of the lecture material could be learned from the textbook. When asked how to compensate for the loss of lecture, students commonly struck upon the theme of resources, the more the better. Students felt that even providing old lecture notes from a previous version of the class would ameliorate the loss of lecture time. They felt an all-PBL version of a course could be successful with sufficient resources. Some examples: lecture notes, written example problems, video tutorials (particularly for math skills like finding eigenvalues/eigenvectors that are rote learning), and tutorials for Maple/Mathematica. And finally, students also expressed a need for help in searching for physics materials on the web. General library tutorials typically seen in freshman orientation programs are not sufficient and need to be supplemented by physics-specific strategies.

## CONCLUSIONS

A qualitative analysis of student narrative course evaluations, survey results, and student interviews demonstrated that students valued, enjoyed, and learned deeply from problem-based learning in an upper division physics course. Contrary to the authors' expectations, students interviewed felt strongly that problem-based learning could be the sole pedagogy in an upper division physics course, and expressed excitement to experience such a course. In fact, students expressed a hunger for innovative pedagogies at the upper division level. Students expressed concrete ideas for making such a course successful.

## REFERENCES

1. B. Dutch, "Problem-Based Learning in physics: The power of students teaching students," *J. Coll. Sci. Teach.* **26**, 529-541 (1996).
2. B. Duch, S. Groh, and D. Allen, *The Power of Problem Based Learning*, Sterling, Virginia: Stylus Publishing, 2001.
3. The PBL Clearinghouse: <https://primus.nss.udel.edu/Pbl/>
4. P. VanKampen et al., "Teaching a Single Physics Module Through Problem Based Learning in a Lecture-Based Curriculum", *Am. J. Phys.* **72**, 829-834 (2004).
5. AMC's The Walking Dead, <http://www.amctv.com/shows/the-walking-dead>
6. P. Munz, et al. "When Zombies Attack!: Mathematical Modeling of an Outbreak of Zombie Infection", *Infectious Disease Modeling Research Progress*, 133-150 (2009).
7. T. Koballa and F. Crawley, "Attitude research in science education: Contemporary models and methods", *Science Education* **78**, 35-55 (1994).