Designing Cancer-Killing Artificial Viruses to Improve Student Understanding of Microbiology

Andy Kuniyuki1* and Gwen Sharp2
1Dean, School of Liberal Arts & Sciences; 2Department of Social Sciences, Nevada State College, Henderson, NV 89002

Our objective was to assess the effectiveness of a “learning by designing” group project used in a lower-division Microbiology course. Students used knowledge gained from the course to design an artificial virus that would kill cancer cells. The assignment required groups to integrate the individual course topics into a unified, complex understanding of the field of microbiology. Throughout the course, students and the instructor collaborated in creating a rubric to evaluate the groups’ final presentations. This paper reports the results of an assessment of the project by comparing the instructor’s and the students’ scores for the presentations. Students’ and the instructor’s scores were correlated; the Pearson coefficient of 0.52 was statistically significant. The results indicate that students gained sufficient knowledge to accurately evaluate proposed designs. Additionally, the overall course grade distribution improved compared to the semester before the project was introduced. Finally, in order to engage students in thinking about their own learning process, they completed a reflection assignment that required them to discuss the changes in their understanding of microbiology over the course of the semester. Our assessment indicates that a design project can serve as an effective and useful learning technique in undergraduate Microbiology courses, though modifications are suggested.

INTRODUCTION

Pedagogical research has illustrated the effectiveness of active learning techniques for engaging students (24) and improving knowledge retention (22). Active learning refers to teaching methods or exercises that involve students in their own knowledge acquisition by applying course concepts (rather than passively consuming information provided by the instructor) and that engages students in thinking about what they know and how they know it (5, 6). Active learning includes a wide variety of exercises such as debates (31), in-class small group activities (4, 25), role-playing (10), and teaching a topic to classmates (30). Janssen and Waarlo (19) suggest ‘learning biology by designing,’ which involves having students redesign biological organisms as a useful active-learning technique. Students are presented with a problem faced by an organism and asked to propose biologically-possible potential solutions. Students then discuss the possible solutions and select the best one. This solution is then taken as the next design problem for students to solve. For instance, students might begin by considering how an organism can destroy harmful bacteria. A potential solution to this is to produce cells that consume the bacteria; the new design problem posed by this solution is to ensure such macrophages eat only harmful bacteria and not the organism’s own cells. Students work in an iterative process from the general to increasingly specific aspects of biological systems.

Fifteen graduate students teaching Biology classes implemented a version of the biology by designing technique after receiving training in how to adapt lesson plans accordingly (18). Participants reported that the technique forced them to think more carefully about what students already knew and how to incorporate that knowledge into the next lesson plan, and allowed them to be less dependent on a textbook. They believed the technique would have positive benefits for student engagement and learning.

Active learning involves not just applying knowledge, but thinking about that knowledge and the learning process itself (27), or ‘making thinking visible’ (9). Interest in this aspect of learning has grown with the increasing influence of constructivist approaches to pedagogy, which depict learning as a long-term process in which previous understandings provide a scaffolding on which to build, as well as emphasizing learners’ creation of meaning (1). Reflection-based exercises can help students identify their own knowledge and recognize what — and how much — they have learned (7), involving students in thinking about their own learning process and providing valuable feedback about instructors’ teaching effectiveness (33). For instance, nursing students have benefited from keeping reflective journals about their clinical experience (29). Students reported that revisiting a
day’s events to write a reflection encouraged them to think about how they reacted and what knowledge they had drawn on, how they might have reacted differently, and how they had improved as nurses as a result of their clinical experience. Requiring students to engage in reflective exercises or assignments has been used effectively across the curriculum, including computer science, business, public affairs, and service learning (12, 14, 21, 34).

Including students in the process of designing assessment rubrics can also serve as a form of active learning, by encouraging critical thinking and recognition of how various course concepts fit together into a larger framework. In order to help create a rubric, students must think carefully about course material and how a student would demonstrate mastery of it (11). Others advocate collaborative creation of rubrics, with instructors guiding students as they identify key concepts and agree on acceptable standards for assignments (32). For instance, allowing students in an art production course to help develop the rubrics used to evaluate their artwork improved students’ confidence and gave them a sense of ownership over the course, increasing their commitment to coursework, as well as reinforcing their knowledge of class material (17). Students’ discussion of assessment criteria may help instructors identify concepts that need reinforcement or clarification (35).

In addition to helping design rubrics, students may also benefit from peer evaluations, which can serve as formative assessments (3). Combining peer evaluation with student-created rubrics may encourage a sense of ownership of the course among students (16), and peer evaluation can provide students with useful feedback without the anxiety caused by formal grades, leading to higher-quality final products (28).

Finally, students’ ability to evaluate their own and classmates’ work can provide a form of assessment of student learning, as well as a teaching technique (26). The use of correlations between students’ evaluations of classmates’ work and the scores assigned by the instructor to measure the accuracy of students’ assessments is well established in the pedagogical methods literature (2, 8, 15, 20). A meta-analysis of 48 assessments of the correlation between students’ and instructors’ assessments of student work found that students’ assessment accuracy was improved when they were expected to evaluate the overall product rather than multiple dimensions of each item, and when students had been involved with developing, and clearly understood, the scoring criteria (13).

The main objectives of this project were to integrate students’ knowledge of individual topics into a broader, more complex understanding of the field of microbiology, to assess students’ mastery of class concepts, and to involve them in thinking about their own learning process. This paper describes the implementation and assessment of a project from a lower-division general Microbiology course in which, rather than redesigning an existing organism (19), students presented a design for an original artificial virus. The assessment includes a comparison of students’ ratings of classmates’ presentations to the instructor’s ratings. We expected to see a positive correlation between the ratings, and our analysis revealed a statistically significant positive relationship. The correlation in ratings, as well as students’ self-reflections on the difference in their knowledge about viruses and biological responses to them at the beginning of the semester and after completing the project, indicate that the group project based on the idea of “learning by designing” increased student understanding of the principles of microbiology.

**METHOD**

**Class attributes**

The artificial virus design project was assigned to 180 students in several sections of an introductory Microbiology course, all taught by the same instructor. To enroll in the course, students had to have completed one introductory course in both Biology and Chemistry. The average section enrollment was 30 students; overall, 78% of students included in this assessment were female, while 22% were male.

**Project description and assessment**

On the first day of class, students were asked to individually describe a potential artificial virus that would eliminate some type of cancer from the body. They were assured that the written assignment was for informational purposes only and would not be graded. Despite the prerequisite courses in Biology and Chemistry, the students’ responses revealed limited knowledge of how viruses work and how the body reacts to them. The instructor’s evaluation of the responses indicated that, had the assignment been formally assessed, 100% of the students would have received a grade lower than a C. This assignment established their pre-existing level of knowledge and provided a benchmark to measure changes in their understanding as the course progressed.

Students were assigned to small groups of 5–6 students each, which functioned as corporations engaged in microbiological research. Students were informed that the corporations were all competing for a grant that would be awarded to the most promising artificial virus. The work students completed in the course was not simply a theoretical exercise; they were investigating an issue with significant real-world implications (23).

The design project was the key assessment for the course, accounting for 35% of the final grade (350 out of 1,000 points). The remainder of the course grade consisted of five exams (50%), a lab notebook (10%), and participation in online discussions (5%).

As students learned about each topic in microbiology, they were asked to explain its relevance to the virus design project. The assignment provided a unifying framework that tied together the various concepts covered in the course, and required students to draw connections between them. Students’ final proposals had to include an explanation of how the virus functioned, what would differentiate the virus’s...
interaction with cancer cells from its interaction with normal tissue, how the virus would kill cancer cells while leaving normal ones unharmed, and what would become of the virus after the cancer was eradicated. Each group had to support its choices regarding the genome (single- or double-stranded DNA or RNA), whether or not the virus would be enveloped, whether host recognition was an essential function and, if so, what would spark this recognition, and the mechanism used to kill cancer cells. Otherwise, students had significant freedom in the construction of their viruses. Students were required to turn in a written proposal and give an oral presentation to the class. The proposal counted for 300 of the 350 possible points for the project, or 30% of the entire final grade.

Incorporating the design project did not require major alterations in the curriculum, as the concepts students must understand to complete the project are central components of standard undergraduate Microbiology courses. However, to ensure students had the tools they needed to write a successful proposal, the instructor emphasized several key concepts throughout the semester that were particularly relevant to the project (see Table 1).

To encourage students to reflect on the purpose of the project and important features of a cancer-killing virus, students and the instructor developed a rubric after each course module that helped students build their own virus and judge the quality of other groups’ proposals (see Table 2). Creating a rubric aided students in identifying distinguishing features of their artificial virus and enhanced their understanding of how course material cumulatively provided a broader knowledge of microbiology.

Students were asked to assess each group’s project based on a thorough reading of their papers, as well as listening to the in-class oral presentations. These evaluations reflected the student's own understanding of microbiological principles. Students ranked the projects and used the rubric to assign scores.

To encourage students to complete the assessments, this aspect of the project was worth 20 points (5.7% of the project grade, or 2% of the final course grade). The intent was to provide sufficient motivation for students to complete the assessments but not unduly skew grades upward, since the students’ assessments were graded in a more lenient fashion than the proposals themselves. In order to grade the students’ assessments of each project, the instructor first graded the proposals and then divided the grade distribution into thirds and compared each student’s ratings distribution. Students’ grades were calculated not based on exactly matching the instructor’s scores or specific rankings of the proposals, but by the degree to which their rankings fell into the same third of the distribution as the instructor’s ranking for each project, earning up to 20 points if all of their ratings fell into the same third of their distribution as the instructor’s ratings for the same project and 0 if none did.

To assess the degree to which students’ and the instructor’s scores were correlated, students’ overall scores for each proposal (converted to percentages) were averaged and the mean was compared to the instructor’s scores. This provided one form of assessment of the effectiveness of the assignment, as well as additional feedback to the groups. We calculated Cronbach’s alpha to test inter-rater reliability and the Pearson coefficient (r) to measure the strength of the correlation. The Pearson coefficient was chosen as an appropriate measure of the strength of the correlation in scores since the ratings provided an interval-level variable, and a scatterplot revealed no significant outliers in the data. We hypothesized that mean student ratings would be significantly and positively correlated with the instructor’s ratings.

As an additional measure of student learning, we compared the final course grade distribution for the sections in which the artificial virus project was assigned to the grade distribution for the same course in the semester before the project was introduced.

Finally, each student completed a written reflection in which they compared their descriptions from the first day of class to their final papers. The reflection was worth 30 points (8.6% of the project grade, or 3% of the course grade). As with the students’ peer assessments, this encouraged students to complete the assignment, which could make a significant difference in a student’s final letter grade in the course. However, the intent of the reflection assignment was to engage students to reflect on their own knowledge, not to provide a rigorous, formal assessment of their understanding. Setting the worth of the reflection at a small proportion of the final grade allowed students and the instructor to focus on the pedagogical intent of the assignment rather than using it to make objective distinctions between students. Students were told to address the following questions: Were there differences in your description of how to design an artificial virus to kill cancer between what you wrote on your first day in class and your final paper? If so, what were they? How did your understanding change? If not, why do you think this is?

<table>
<thead>
<tr>
<th>TABLE 1. Key concepts.</th>
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<tr>
<td>Virus host recognition</td>
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<td>Viral binding to specific receptors outside a targeted cell</td>
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<td>Characteristics of single- and double-stranded DNA and RNA, positive and negative RNA strands, and retroviruses</td>
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<td>How viruses direct the process of killing cells, including:</td>
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<td>• targeting traits essential for cell survival</td>
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<td>• introducing new genes that lead to apoptosis</td>
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<td>• lytic replication that leads to cell destruction</td>
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<tr>
<td>• soliciting the immune system to kill cells</td>
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<tr>
<td>Immune system recognition of and response to viruses, including humoral and cell-mediated responses</td>
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<td>Viral mutation and their implications</td>
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TABLE 2. Grading rubric designed by students and instructor.

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<tr>
<th>Assessment Measure</th>
<th>Score</th>
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<tr>
<td><strong>Molecular Handshake:</strong> Is there host recognition that the virus must bind specifically to some target/receptor that is on the outside of the cancer cell? (40 points total)</td>
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<td>Concept understanding (5 points)</td>
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<tr>
<td>Outside of cell (10 points)</td>
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<tr>
<td>Cancer-cell specific (15 points)</td>
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<tr>
<td>Positive and negative aspects of design choices (10 points)</td>
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<tr>
<td><strong>Viral Genome:</strong> Is there a description of the virus as being RNA or DNA, single- or double-stranded, and if single-stranded RNA then whether it is a positive or negative strand or a retrovirus requiring reverse transcriptase? (20 points total)</td>
<td></td>
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<tr>
<td>What type of genome is used and why? (10 points)</td>
<td></td>
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<tr>
<td>Positive and negative aspects of design choices (10 points)</td>
<td></td>
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<tr>
<td><strong>Method of Killing Cancer Cells:</strong> Is there a description of how the virus participates in and directs the process of killing the cancer cell? Does the virus target a cancer-specific trait that is required to maintain the life of the cancer cell and will the virus shut down this function? Will the virus bring in a new gene that will cause the cancer cells to die like P53, which initiates cell suicide through apoptosis? Will the virus replicate in a lytic process to destroy the cancer cell? Will the virus solicit the adaptive immune system to participate in killing the cancer cell? If the immune system's participation is evoked, is there a correct pathway involving the use of MHC 1 in its presentation to T-cytotoxic lymphocytes to now recognize cancer cells because of internally-replicating viruses that present a danger signal to this killer cell system? Are positive and negative aspects discussed? (60 points total)</td>
<td></td>
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<tr>
<td>What type of immune response is evoked? (15 points)</td>
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<tr>
<td>When does the immune response happen? (5 points)</td>
<td></td>
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<tr>
<td>Positive and negative aspects? (10 points)</td>
<td></td>
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<tr>
<td><strong>After the Cancer Is Killed, What Happens to the Virus?</strong> Is there a recognition of a mechanism to clear the body of the virus? Will the virus so depend on the cancer cell that it remains inert in the absence of its cancer host? Will there be a process that evokes the immune system to clear the body of the virus? (30 points total)</td>
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<tr>
<td><strong>Viral Mutation Potential:</strong> Is there a discussion about the possibility that the virus can mutate? What is the consequence of having mutations in the artificial virus? (20 points total)</td>
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**RESULTS**

Our analysis indicates that the instructor's ratings and mean students' ratings of the proposals had a high degree of inter-rater reliability (Cronbach's alpha = 0.66). As hypothesized, there was a statistically significant positive correlation in ratings, with a Pearson coefficient of 0.52 and $p = 0.002$ (see Table 3 and Fig. 1).

These results indicate that over the course of the semester, as they completed the project, students gained sufficient understanding of the principles of microbiology to evaluate one another's proposals with a significant degree of accuracy, when compared with the instructor's ratings.

Overall, the instructor was impressed with the quality of the groups' designs and the effort and energy they put into the project and into their assessments of their peers' work. However, the design proposals, as well as students' ratings using the detailed rubric, demonstrated that as a whole, students mastered some course concepts more successfully than others. The strongest aspects of the groups' proposals were their explanations of how a virus would distinguish cancer cells from normal cells and the role of receptors in this process. The groups also displayed a thorough understanding of the various ways of killing cancer cells, and most included multiple methods in their artificial virus design. On the other hand, groups...
seemed to find it more difficult to imagine an appropriate solution to eliminating or neutralizing the virus after it had killed the cancer.

Table 4 shows the final course grade distribution for the sections studied here to the grade distribution for the same course taught by the same instructor the semester before this project was introduced as the key assessment. Students’ final grades increased markedly over the previous semester.

Students’ reflections on the project and their learning over the course of the semester revealed that they found the assignment enlightening and that it contributed to their knowledge of principles of microbiology:

… the different (sic) in my ability to support my argument between the [first] assignment and this is like night and day. For the first assignment, I had a few ideas of how the virus would work. For the second assignment, I added on a few more ways, and I had very specific examples for how the virus would work to support these ideas.

Our group paper was leaps and bounds better than my original paper. With what I learned in the class, I can fully understand what needs to be done to address and perhaps even cure cancer because I understand most of the major processes that take place in the formation of cancerous tumors as well as the body’s responses … Even though cancer was the topic for our project and the main focus, you gave us the tools to address many of the numerous diseases…and perhaps even more important, the ability to think and address things for ourselves…

The information I have learned in this course enabled me to describe exactly how the virus interacts with the host cell … in my second paper I was actually able to describe the immune response and be specific by including factors such as the different immune systems, macrophages, interferons, antibodies, etc.

DISCUSSION

The level of agreement between the instructor’s and the students’ ratings indicates that, over the course of the semester, students developed a sufficient understanding of biological processes that they were able to accurately evaluate the quality of each group’s attempts to address the
requirements of the assignment, as well as the overall quality of their final products. In order to do so, students had to draw on material from throughout the semester, understand how different topics in the course related to each other, be able to think through advantages and disadvantages of various artificial virus designs, and explain to others why their design would be effective at treating cancer. Students’ reflections on the project indicate that they found the design component engaging and informative and were excited by the improvement in their understanding of viral processes. This enabled them to work on a problem that researchers in actual biomedical corporations are currently investigating. Based on these findings, the project appears to successfully meet the requirements of effective active learning techniques, and indicates that this “learning by designing” activity is a useful classroom tool.

The existing literature on peer evaluations suggests adaptations to the project that might improve students’ ability to accurately assess their peers’ work. The rubric developed by the instructor and students (see Table 2) was quite detailed, including multiple dimensions, most of which were further broken down into several specific points. This ensured that students fully understood the requirements of the assignment. Students and the instructor felt a more detailed rubric would lead to more accurate ratings, drawing each rater’s attention to all aspects of the assignment. However, the literature reveals lower levels of student–instructor ratings correlation when students are asked to judge multiple dimensions than when they make a global judgment based on clear, well-understood standards (13). Our use of a rubric that required students to assign points for multiple subtopics within several different dimensions may have reduced the accuracy of students’ ratings. Creating a detailed rubric serves as a learning opportunity for students, as it forces them to think about which concepts are most central and essential for a student of microbiology to master and how an observer could measure such mastery. It may also give them confidence as they work on their design proposals. For this reason, we are hesitant to advocate entirely discarding the detailed rubric, as the level of detail resulted from students’ intense discussions of the particulars of virus design and behavior, and we believe was a valuable teaching method. However, instructors who implement this project may wish to provide a simplified version.

The assignment could also be modified to make better use of peer feedback as a formative assessment. As our course was designed, groups were unable to benefit from peer evaluation, as they were assessed by peers at the same time they were assessed by the instructor, after the final project was due. However, the literature indicates that one of the primary benefits of peer evaluation is its use as a formative assessment that identifies potential problem areas. Students can then use such feedback to improve their final product. As implemented in the course assessed here, peer evaluations were used to measure students’ own understanding of the material through their ability to evaluate others’ work. While these assessments provided additional feedback to each group about their proposal, they provided only summative evaluation (3). Instructors planning to use this project should consider capitalizing on the learning opportunities provided by peer evaluation, such as allowing groups to revise their proposals in response to the feedback received from their peers, with the instructor grading the revised version.

Based on experiences with the assignment thus far, there are a few challenges an instructor may face when first assigning a design-based project. Instructors must plan ahead because of the need to plan lessons that continually relate course material to the larger project and ensure that students are provided with the necessary information to successfully complete the assignment. If the project is to be completed by groups, instructors must also provide guidelines for working together, including guidelines and suggestions for effective group collaboration and a clear explanation of how students’ individual grades will relate to overall group grades. Finally, because students must work in small groups, present their findings, and evaluate their peers’ work, the project is most appropriate for relatively small classes and may become unmanageable in classes with an enrollment of more than forty students.

Orienting a class around a semester-long project of this sort may require an instructor to significantly alter the course, and thus may be intimidating. However, we believe the benefits of the project justify the initial burden.
of additional time and planning that it requires. Use of this project has improved student engagement; their end-of-semester reflections illustrate the excitement they feel when they realize they worked on a real-world problem and gained sufficient understanding to write a proposal for something that, on the first day of class, seemed utterly impossible. Designing an artificial virus provides an overarching project that integrates each topic that students encounter throughout the semester, making it clear how the information builds on — and connects to — their previous knowledge. It also engages students in the type of critical thinking and problem-solving increasingly emphasized in science education (20). For instructors who wish to make classes more discussion-based and interactive without sacrificing students’ mastery of the subject matter, and who want students to view course concepts as part of a larger knowledge base rather than discrete bits of information to be discarded after each exam, this learning by designing assignment is an initially challenging, but ultimately rewarding, teaching technique.

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REFERENCES


