Antiviral Drug Research Proposal Activity †

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The development of antiviral drugs provides an excellent example of how basic and clinical research must be used together in order to achieve the final goal of treating disease. A Research Oriented Learning Activity was designed to help students to better understand how basic and clinical research can be combined toward a common goal. Through this project students gained a better understanding of the process of scientific research and increased their information literacy in the field of virology. The students worked as teams to research the many aspects involved in the antiviral drug discovery process, with each student becoming an “expert” in one aspect of the project. The Antiviral Drug Research Proposal (ADRP) culminated with students presenting their proposals to their peers and local virologists in a poster session. Assessment data showed increased student awareness and knowledge of the research process and the steps involved in the development of antiviral drugs as a result of this activity.

INTRODUCTION

Problem-based learning is considered a best practice in active learning (1). The classroom activity reported here, the Antiviral Drug Research Proposal project (ADRP), used aspects of problem-based learning to engage students in learning basic concepts of virology while practicing skills valuable to research. ADRP was a semester-long team project that required students to work cooperatively to address a research problem, devise a solution, and present the solution in a poster session. ADRP engaged students in learning and applying basic virology concepts to the antiviral drug discovery process, beginning with choosing an aspect of the virus life cycle to target and culminating with the issue of how drug development is funded. This required that the students think about viruses and antiviral therapies on multiple levels, from the basic research questions of how the virus replicates and spreads within the host, to the more clinically relevant questions of drug toxicity and efficacy. Participation in the project allowed students to learn important course content and become aware of critical characteristics of the scientific research process. Through the project, students were exposed to authentic practices of a research virologist.

Intended audience

The project design was targeted toward junior- and senior-level biology majors. The research proposal described here was intended to complement a lecture-based virology course.

Learning time and preparation time

The design was formatted to extend/stretch over the whole semester, with four fifty-minute class periods devoted to the project activities, and three to four weeks between each of the four periods (this could be shortened, depending upon course design). The four class periods included:

♦ Period 1 (week 3 of class): project setup/introduction
♦ Period 2 and 3 (weeks 6 and 10 of class): in-class discussions
♦ Period 4 (week 14 of class): poster session

Between each of the four class sessions the students were required to spend time outside of the classroom working on the specialty research, specialty research reviews, proposal preparation, as well as poster design and construction (see Table 1 and details below).

Instructor preparation included identifying appropriate viruses for use in the project, dividing the students into groups, providing lectures on virology, and grading the ADRP.

Selection of viruses: One to two hours should be allotted for a thorough assessment of any new virus added to the project. However, this preparation time is not required if the viruses listed below are used.
Assigning students to teams: Allow approximately one hour. The criteria for selecting specific viruses and assigning students to teams are discussed below in the Instructor’s version of the Procedure Section.

Lectures: The project was designed to complement the lecture portion of an existing course. Lectures targeting topics of viral composition, viral structure, and general techniques for working with viruses preceded the start of the ADRP project, providing students with the necessary background in virology prior to starting the project. Lectures covering the various steps in the life cycle of RNA and DNA viruses were given prior to the virus team discussion (between weeks 3 and 9), to give a broad overview of how various viruses replicate and to provide students with information useful for selection of appropriate viral targets for their project. A lecture specifically targeting antiviral drug development was given three weeks prior to student submission of the final project. The purpose of this lecture was two-fold: 1) to reinforce the concepts that the students had learned while working on the project, and 2) to clear up misconceptions that became apparent during the group discussion. One specific misconception was the confusion of a vaccine for an antiviral therapy.

Grading: To grade the specialty research reports and revisions, allow approximately one hour each. To grade the proposal development for each of the ten groups, allow approximately four hours. A teaching assistant is recommended for classes with 40 or more students to help manage the grading workload. For classes of 20 to 40 students, the project could be implemented with the help of one or two undergraduate TAs who have successfully completed the course. A single instructor should be able to implement this project for a class of under 20 students.

Prerequisite student knowledge

It was expected that students had completed basic introductory biology and genetics courses. They should also have some basic library research skills, such as prior use of search tools and journal databases, and be able to distinguish scholarly or peer-reviewed research articles from popular publications.

Learning objectives

The Antiviral Drug Research Proposal project was part of a larger project involving the development of research-oriented learning activities in Host Pathogen Interaction undergraduate courses (NSF DUE 0837515). Research-oriented learning activity development involved collaboration between faculty members of the Host Pathogen Interactions (HPI) teaching community (7, 8) and selected research-active graduate students serving as HPI teaching fellows. Faculty members’ research was used as the inspiration or as a model system for the design of each research-oriented learning activity. The development of the activities was approached using the Backward Design method (6, 13) whereby learning goals and assessments were first established, and then activities developed to meet the goals. Each activity targeted at least one HPI concept (7, 9), and engaged students in research-oriented learning where students addressed questions/problems relevant to HPI faculty research. The design of each research-oriented learning activity was meant to help students develop higher-order thinking (10), defined as attaining upper levels of Bloom’s taxonomy (3, 4), and a meaningful understanding of the process and the relevance of science (2, 12). To accomplish these goals, the following learning objectives were established for students engaged in the ADRP project:

Objective 1: Gain an understanding of scientific research with an emphasis on the process involved in antiviral drug development.

Objective 2: Improve skills in/provide practice in utilizing library and journal databases to find credible and relevant information in the form of data, information, and graphs.

Objective 3: Improve ability to comprehend and discuss primary literature.

Objective 4: Build upon individual/team communication/presentation skills (oral and written in a poster format) with the expectation that students will be able to present an argument with data to support a hypothesis.

Learning outcomes that allowed us to measure student progress toward these objectives are presented in Table 1.

PROCEDURE

The ADRP project design focused on engaging students in learning processes and practicing skills valuable to researchers. The design was formatted for a semester course where students worked in teams. The progression of the project throughout the semester is shown in Fig. 1. The project was developed using the backward design approach (5, 13). Learning outcomes were first determined to meet the learning objectives stated above. This was followed by development of assessment strategies and, lastly, appropriate activities (Table 1).

MATERIALS

Supplies:

Supplies for collaborative work: index cards (one per student). Supplies for discussions: Nametags (one per student). Supplies for poster session: Nametags (one per student), easels (one per two virus teams), push pins (about fifteen per team).
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Introduction: Students learned project goals and team assignments.
Specialty research: Students independently researched information in the primary literature, and analyzed findings pertaining to a specialty (BL4).
Specialty research discussion: Teams analyzed Specialty research findings of team members and synthesized a team summary to present to the class (BL5).
Specialty research revisions: Students independently evaluated initial research findings utilizing feedback from the Specialty research discussion and posted revised report to the virus team wiki (BL6).
Virus team discussion: Each member proposed data related to their specialty (see Figure 1B). The team worked collaboratively to evaluate member suggestions and to develop the final research proposal (BL6).
Proposal development: Teams met to continue evaluating their proposal and to design an effective poster presentation (BL6).
Poster session: Students first worked with a partner to explain their team proposal to course peers and visiting scientists and then circulated to review posters of other students. (BL4)

Documents

FIGURE 1. Project overview. Top: Timeline of project phases. Bottom: Phase explanations followed by Bloom level (BL) where levels 4 through 6 are higher-order cognitive skills, as described by Crowe et al. (3, 4).

Table 1.

<table>
<thead>
<tr>
<th>Learning outcomes to address objectives. Students will be able to:</th>
<th>Learning objective addressed</th>
<th>Activity to achieve learning outcomes</th>
<th>Assessment (section number within ADRP) Rubric</th>
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<tbody>
<tr>
<td>Articulate an understanding of the research process.</td>
<td>1, 3</td>
<td>All aspects of the ADRP</td>
<td>All sections</td>
</tr>
<tr>
<td>Propose models and mechanisms for antiviral drug development.</td>
<td>1, 2, 3, 4</td>
<td>Specialty research, Proposal development</td>
<td>1, 2, 4a, 4b, 4c, 5</td>
</tr>
<tr>
<td>Evaluate research models considering ethics, efficacy, and feasibility.</td>
<td>1, 2, 3, 4</td>
<td>Specialty discussion, Specialty research revisions, Proposal development</td>
<td>1, 2, 4a, 4b, 4c, 5</td>
</tr>
<tr>
<td>Integrate material about a given virus from different sources.</td>
<td>2, 3, 4</td>
<td>Virus discussion, Proposal development</td>
<td>3, 4a, 4c</td>
</tr>
<tr>
<td>Understand content and concepts of virology including: Viral life cycles and antiviral targets</td>
<td>1, 2, 3</td>
<td>Specialty research report and revisions, Specialty discussion, Virus discussion, Proposal development, Poster session</td>
<td>1, 2, 3, 4a, 4c, 5</td>
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<tr>
<td>Mechanism-based and high throughput antiviral drug screens in vitro, cell-based, antiviral drug testing and in vivo, animal-based, testing, Phases of clinical trials for antiviral drugs. Viral evolution toward drug resistance.</td>
<td>13</td>
<td>ADRP (mission and introduction) Poster session</td>
<td>1</td>
</tr>
</tbody>
</table>

Articulate a familiarity with research programs of the institution faculty  

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Team-building questionnaire (Appendix 1), Student instructions (Appendix 3)

Available primary literature source examples:

Journal of Virology (open access four months after print publication), Virology Journal (open access), Virology (only abstracts are open access, but students could utilize interlibrary loan), PNAS (open access six months after print publication), PLoS Pathogens (open access).

Assessment measures

ADRP Rubric [SR report rubric, SR revisions report rubric, Poster session rubric, PD rubric, Discussion participation rubric] (Appendix 4), Poster session quiz (Appendix 6), Pre-project and Post-project surveys (Appendix 2, 5), Team assessment (Appendix 7).

STUDENT INSTRUCTIONS

See Appendix III.

INSTRUCTOR VERSION

Team Design

Each student worked in two teams for the project: a virus research team and a specialty team. For our course size of 60 students, each virus research team was composed of six students (Fig. 2). Virus research team assignments were based on the student’s responses to a team-building questionnaire given the first day of class (Appendix 1). Care was given to maximize the diversity within each team in terms of grade point average, major, gender, ethnicity, and technological savvy as self-reported. The specialty teams were composed of 10 students, with one student from each virus team, selected at random.

Each virus research team consisted of six students. Each student was assigned to one of the six specialties to allow for an even distribution of the workload among the team members. The total number of virus research teams and the number of students per team can vary based upon course size (see possible modifications for further details). Each virus research team was tasked with the design of an ADRP for a particular virus. According to the Jigsaw method of group work (14), each student on a virus research team was also a member of a second team: a specialty team. In specialty teams, students became experts in a particular specialty area of the drug design process. After learning about their assigned specialty areas, students reunited with their virus research team to discuss and plan the ADRP for their assigned virus.

Selection of candidate viruses for project

The following ten viruses were selected: Xenotropic murine leukemia virus-related virus (Retrovirus), O’nyong-nyong virus (Togavirus), Nounane virus (Flavivirus), Desert Shield virus (Calicivirus), Human papillomavirus 13 (Papillomavirus), Yaba monkey tumor virus (Poxvirus), Metapneumovirus (Paramyxovirus), Thogotovirus (Orthomyxovirus), Parvovirus B19 (Parvovirus), Coltivirus (Reovirus). The criteria for the selection of the viruses listed above were three fold: 1) each virus represented a different viral family, 2) antiviral drugs were not available for the specific virus

FIGURE 2. Team assignments. This figure illustrates how the teams were established for 60 students. Each number in the table represents a student in the class. For example, student 15 was a member of virus team 5 and specialty team 2.
assigned but were available for at least one member of the virus family, and 3) in order to connect the project to faculty research, the viruses were selected from viral families that are currently being studied at the University or at major institutions in the surrounding community.

**Specialty teams**

The topics for the six specialty teams related to steps in the drug discovery process. Each distinct team was tasked with researching one area.

1. Team 1: Life cycle and drug targets
2. Team 2: Mechanism-based or cell-based high throughput drug screens and compound source
3. Team 3: In vitro (cell-based) drug testing to show efficacy of viral inhibition and toxicity
4. Team 4: In vivo (animal-based) testing models to show efficacy of viral inhibition and toxicity
5. Team 5: Clinical trial data analysis and ethical concerns
6. Team 6: Drug resistance scenarios, methods to prevent drug resistance, and finding a funding source for the research

**Activity explanation**

An overview of the design of the project is presented in Fig. 1.

**Pre-assessment**

Prior to the start of the project, students completed the pre-project survey distributed via paper in class (see Appendix 2). They also completed the team-building questionnaire (Appendix 1), which was used to assign students to teams.

**Class Period 1: Project setup/introduction (50 minutes)**

Students were given an overview of the goals and expectations of the project in addition to instructions for their first task, Specialty Research.

Students were instructed to sit with their virus research team. The room accommodated 10 teams of six students. The instructor explained the goals and mission of the activity [Development of an Antiviral Drug Research Proposal], its authentic value [the skills learned and design of the process are authentic to the practice of a research virologist], the learning objectives for the project goals [students will benefit from the project by gaining skills and understanding related to science and particularly related to virology], the project requirements, the expectation for team work, and the grading rubric for the activity. Students received the instructions and information about team assessment (see Appendix 3). Students learned that they were members of two teams: a virus research team and a specialty team, and were told of the relationship of the work between each team. This introduction was followed by a presentation by a university librarian on library research, use of databases, and proper citation of resources.

Students were instructed to read the ADRP handout and begin **Specialty Research**. Each student worked independently to research information specifically referring to primary literature regarding their specialty in the context of their virus (see below). The research was directed toward three topics, which varied depending upon specialty area.

**Specialty 1 (drug target):**

1. How would the development of this antiviral drug benefit the global community?
2. Describe/diagram the life cycle of your virus (or family of viruses).
3. Identify 3 targets for an antiviral drug.

**Specialty 2 (high throughput screen):**

1. Explain the purpose of high throughput screening.
2. Give examples from primary literature of a cell-based screen and a mechanism-based screen using viruses within the same family as your assigned virus.
3. Identify 3 different compound sources.

**Specialty 3 (cell-based screen):**

1. Explain what in vitro (cell-based) screening is and why it is important?
2. Give 3 examples from primary literature of in vitro screens using viruses within the same family as your assigned virus.
3. What does it mean for a drug to have low toxicity? How would you screen for your compounds’ toxicity?

**Specialty 4 (animal-based screen):**

1. Explain 3 different in vivo (animal) models.
2. Give 3 examples from primary literature of in vivo screens using viruses within the same family as your assigned virus.
3. What needs to be shown in the animal model before you can proceed to clinical trials? (Think about toxicity and efficacy).

**Specialty 5 (clinical trials):**

1. Define clinical trial phases I, II, and III.
2. Give one example from primary literature of each of the three phases of clinical trials.
3. List 3 possible ethical issues involved with clinical trials.

**Specialty 6 (resistance):**

1. Give 2 examples of antiviral drugs on the market where the drug has gained resistance (preferably to treat at least one virus in the family of your assigned virus).
2. Give 3 examples of in vitro or in vivo experiments in primary literature where viruses developed resis-
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Students prepared specialty research reports (one page, typed, with citations) that were submitted to course instructors via the Course Management System (assessed with ADRP rubric section 2) and brought as paper copies to the first meeting of the specialty team research discussion.

Class Period 2: Specialty Research Discussion (50 min)

Students met with their specialty teams to discuss and analyze specialty research findings of team members and synthesize these findings to present to the class.

Upon entering the classroom, students were instructed to sit with their specialty team. Students were expected to bring a hard copy of their specialty research reports to class and share their findings with the team. The goal of the discussion was to debate and discuss the accuracy of their individual research after reporting it to their team. The students were challenged to evaluate each other's findings and work collaboratively to integrate the various ideas presented to form a team consensus. Discussion topics included choosing a drug target, in vitro and in vivo screening, advancing to clinical trials, and evaluating viral development of drug resistance. Students were also instructed to consider ethics, efficacy, and feasibility in their discussions. The instructor and teaching assistants circulated to assess student participation in discussions, serve as resources for questions, and to guide teams who were having difficulty resolving discrepancies uncovered in their research. Following thirty-five minutes of discussion, representatives from each specialty team presented a summary of their team discussion and conclusions to the class at large. Minor misconceptions that instructors observed from overhearing group discussions were addressed at this time.

Following the specialty research discussion students were tasked with the second individual task: Specialty Research Revision. The purpose of this revision was to provide students with the opportunity to incorporate new ideas and insights from the group discussion into their proposal. Students were required to post their revised specialty research report to an online wiki that was available to all the students in their virus team, to allow all students within each specialty team full access to all of the information presented during the specialty research discussion. Students were given two weeks to review their specialty research reports and improve, expand, or clarify their initial responses before submitting the revised report to instructors through the Course Management System.

Class Period 3: Virus Discussion (50 min)

Students met with their virus research teams and made critical decisions for the direction of their proposal.

Instructors and TAs circulated to assess student participation in the discussion, as well as respond to students' questions and provide guidance as appropriate. After completion of thirty-five minutes of group discussion, representatives from each team reported their team decisions to the class as a whole. The decisions related to the direction of each virus team's proposal were used as a basis for their Proposal preparation and Poster Design.

After the virus discussion, all students posted their revised specialty research reports to a virus team wiki to serve as an outline for their team's poster presentation. Students worked collaboratively outside of class with their virus research team to design their ADRP proposal and poster presentation. Guidelines for the poster (Proposal Development rubric) and a sample poster were distributed to the class. Each virus research team prepared a poster composed of 8 to 17 PowerPoint™ slides. Information from each specialty was reported in one or two slides, and included at least one relevant graphical representation of data from a primary source with appropriate attribution. We encouraged virus research team members to work collaboratively to integrate the specialty expertise of each team member into the design of the ADRP. This expertise was gained by implementing the Jigsaw grouping design element to the project (14). Each member of the team was expected to be involved in the design of the entire poster presentation and their participation was assessed via the Team assessment (see Appendix 7).

Prior to the Poster Presentation, students printed PowerPoint slides for mounting onto a provided tack board. Each team also submitted one set of poster slides to the Course Management System for grading purposes. Posters received a team grade.

Poster session (50 Minutes)
Team posters were displayed on poster boards in an open atrium and reviewed by classmates, instructors, and invited scientists.

Each presenter and guest received a nametag. During the poster session students were required to both present their proposal and review the other teams' posters. In order to facilitate this, each virus team was divided into three groups of two and the class time was apportioned into three twelve-minute sessions. While one group of two presented their poster, the other four members of the team reviewed the posters of other teams. At the end of each twelve-minute session, the two presenters rotated to reviewing posters and a new group of two presented. Students were graded individually during the session on their explanation of the poster. Additionally, students were graded on their engagement with other students presenting posters (see Appendix 4). It should be noted that a team of six individuals, including faculty members, postdoctoral fellows and graduate students, were recruited to conduct the one-on-one student evaluations during the poster session. As suggested in potential modification, peer-review could be substituted for the instructor evaluation, if desired.

Poster session quiz

To encourage students to meaningfully participate in the poster session, they were asked to respond to the poster session quiz presented in the Learning Management System (see Appendix 6). The questions pertained to content on the various posters.

Post-assessment

After the completion of the project, students completed the post-project survey distributed via online survey tool (GoogleDocs) (see Appendix V).

Suggestions for determining student learning

Student learning was assessed on each student's specialty research report, specialty research report revisions, poster session presentation, and discussion participation using the ADRP Rubric (Appendix 4). Additional assessments included the poster session quiz (Appendix 6) and pre- and post-project surveys (Appendix 2, 5). Student learning was assessed for each team with the proposal development rubric (Appendix 4). This project made up nine percent of each student's final grade in the course.

Sample data

An example of one student's revised specialty research report on the use of clinical trial specialty in the Human Papillomavirus-13 virus group has been included (see Appendix 9). Students designed PowerPoint slides to convey the information of all specialties. For example, the students in Team 5 were assigned to propose the steps to design an antiviral drug for Human Papillomavirus-13 (see Appendix 8).

Safety issues

None.

DISCUSSION

Field-testing

The Antiviral Drug Research Proposal was field-tested with students enrolled in a 400-level three-credit virology lecture that required a prerequisite of a basic biology course and a genetics course. Of the 60 students in the class, 59 were seniors and 1 was a junior. These students included 24 males and 36 females. Their average GPA was 3.4, with 57 students having majors within the College of Chemical and Life Sciences, two within the School of Engineering, and one within the College of Behavioral and Social Sciences. A virology graduate student worked as the Teaching Assistant (TA) for the lecture/activity.

Evidence of student learning

Student learning was assessed at each stage of the project via a set of rubrics and evaluation materials: ADRP rubric, poster session quiz, and the pre- and post-project surveys (see Appendix 2, 4, 5, and 6).

Rubrics are discussed in the Activity Explanation and are found in the Supplementary Materials. The pre/post survey consisted of eight prompts to which students responded “Agree”, “Disagree”, or “Don’t Know”. Students were also asked to explain their response to each prompt. Two of the eight prompts were designed to evaluate students learning of principles targeted by the ADRP. Six of the eight prompts targeted students’ perceptions of the research process. We used mixed-methods analysis to interpret the results. Responses to the open-ended questions were analyzed qualitatively using an inductive approach (11), in which related responses were grouped into subcategories that could be quantified. A team of faculty and graduate students, including a science education faculty member, categorized the responses separately and then discussed their categories until they came to agreement. Their interrater agreement was 90%. The quantitative data was obtained from the Likert-scale (“Agree”, “Disagree”, “Don’t Know”) questions.

Based on the pre- and post-project surveys and the assessment of the students’ proposal development, the following observations regarding the achievement of our learning objectives were made (Table 2 and Fig. 3). Based on the instructors’ evaluation of in-class discussion, the one-on-one student evaluation during the poster session and the overall quality of the students posters, the students demonstrated an under-
TABLE 2.
Proposal development assessment. Each virus team's proposal development was assessed in eleven categories (within section 4 of the ADRP rubric). The possible points for each category are listed with the category in the Rubric categories column and the points earned by each of the ten teams are listed in the following columns under the team number. The final column contains the average score per team over the total possible points. The first six rubric categories are based upon the work of the six specialty teams. Determination of primary literature comprehension (category 7) involved assessing whether the cited information was correctly presented in the poster. Students were also graded based upon whether or not they appropriately cited information, used terminology correctly, and if their proposal was presented in an organized manner (categories 8, 9, and 10). Finally, student groups were assessed based upon the depth of questions they composed for use in the poster session (category 11).

<table>
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<tr>
<th>Rubric categories</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
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<tr>
<td>Target (3pts)</td>
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<td>2</td>
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</table>

FIGURE 3. Knowledge-based survey responses. Students were given statements that pertained to the development of antiviral drugs prior to and following the learning activity. The students were given the prompts: agree, disagree and don’t know and asked to explain their answers. Responses from 60 students were tabulated in the pre-project survey and 50 in the post-project survey. A) Student response to the statement: Prior to releasing an antiviral drug as a treatment for disease, the drug is first tested in one animal model (for example in a mouse model or in a rabbit model), if no complications are observed, the drug is then tested in humans (clinical trials). B) Student response to the statement: Viruses rapidly develop resistance to antiviral drugs.
standing of the overall research process involved in antiviral drug development (Learning Objective #1). Comparison of student responses to the knowledge-based survey questions in the pre-project survey and the post-project survey and the overall team scores for the posters indicated that specific gains were made in student understanding of the use of clinical trials in antiviral drug development and the concept that viruses can acquire drug resistance (Table 2 and Fig. 3). When prompted with, “Prior to releasing an antiviral drug as a treatment for disease, the drug is first tested in one animal model (for example in a mouse model or in a rabbit model), if no complications are observed, the drug is then tested in humans (clinical trials),” 40% of the class answered correctly before the ADRP and 74% answered correctly after the project. Additionally, the precision of the correct answers improved. Prior to the project, one student wrote, “More than one animal is used” and following the project another student wrote, “It is my understanding that at least two rodent models and one non-human primate model must be tested on before proceeding to clinical trials on humans.” Similar results were seen with the second knowledge-based question. When prompted with, “Viruses rapidly develop resistance to antiviral drugs,” 42% answered correctly before and 78% answered correctly after the ADRP. The precision of the correct answers to these questions also improved. Before the project a student wrote, “They mutate.” After the project a student wrote, “Viruses mutate quickly and can develop resistance in response to selective pressure.”

One area of the antiviral drug development that several groups struggled with was the concept of using high throughput screening to identify candidate compounds. Only three out of the ten virus teams accurately explained the use of high throughput screening to identify candidate compounds (Table 2). Several students reported having difficulty finding information about this specific topic, suggesting that the instructors may need to play a more active role in addressing this concept either through the group discussion or in lecture.

Learning Objective #2 was to improve/build upon the student’s ability to utilize library and journal databases to find credible and relevant information in the form of data. We found that most students were successful in finding data and graphs relevant to their assigned topics, as was evident by the quality of their submitted research reports, in-class discussions and data presented in the poster, which were assessed using the ADRP rubric. While most students were able to identify primary literature, several students referenced review articles or even popular literature in their specialty research reports (Appendix 9). This suggests that not all the student were capable of differentiating between primary and popular literature and research reviews at onset of the project. The inclusion of a lecture that discussed finding primary literature and methods to discern it from other forms of communication prior to discussion #1 may improve the relevancy of information submitted for the initial specialty research report. In addition, several groups failed to include citations for all of the figures and graphs that were presented in the final poster (Table 2, ADRP rubric section 4b). To address this issue, the lecture on distinguishing primary literature should also include a review of how to properly cite references and the importance of acknowledging the proper source of information used in the project.

Learning Objective #3 focused on helping students to comprehend primary literature. Evaluation of the final poster project suggested that several of the groups struggled in this area. As evident from the primary comprehension score on the final poster project, there was substantial variability among the viral teams in this area (Table 2, see ADRP rubric 4b for assessment criteria). The majority of virus teams were penalized for either the misinterpretation of the graphs and figures that were included in the final submission of the poster and/or the misuse of terminology. The inclusion of more examples of primary literature during lecture may help the student to gain familiarity with terminology commonly used in virology. In addition, requiring students to interpret graphs and figures either in class or as a take-home assignment may improve their ability to interpret and therefore comprehend data.

The overall design of the project provided the students with multiple opportunities to practice both individual and team oral and written communication/presentation skills (Learning Objective #4). Written communication was assessed in the research report, as well as the poster project, while oral communication was assessed during discussion sessions and the poster presentations (see ADRP rubric sections 2, 3, and 4). The high scores for the organization of the posters reflect the fact that the students’ posters were well organized and flowed smoothly between the assigned topics, indicating that the students working in teams effectively communicated with each other (assessed in ADRP rubric section 4c). Similarly, the written questions submitted by most virus teams were well written and insightful, as reflected the average score of 1.9 out of 2.

One of the major goals for the design of the ADRP was to engage students in higher-order thinking. Higher-order thinking, defined as the use of cognitive skills rated within the upper levels of Blooms taxonomy, was evaluated throughout the project (Fig. 1). The successful completion of the ADRP required students to analyze data both individually and as a group, integrate information from various resources, evaluate information presented by other students, synthesize a coherent proposal, and effectively communicate findings in a written presentation (poster) and an oral presentation (poster presentation). As indicated by team scores for the final project (Table 2), the majority of the students were successfully engaged in higher-order thinking. For those students who struggled with the expectations of the project, the authors are currently testing the implementation of the minor changes suggested above. One surprising observation not mentioned previously was that several students took personal ownership of the data presented in their team poster. This was evident in the one-on-one evaluation of
students during the poster session. Instructors observed that students presented data from primary research articles as if they personally performed the experiments. By doing so, they failed to give appropriate attribution to the source of the information or recognizing the investigators actually responsible for the work.

**Student perceptions**

The second goal of the development of the ADRP was to enhance the students understanding of the scientific process. The responses to the pre- and post-project surveys suggest that students’ perception of the research process was altered by participation in the ADRP (Fig. 4). Furthermore, we saw a shift in students’ awareness and understanding of research on our campus and the overall research process. Students were asked to circle their level of agreement with several statements (agree, disagree, and don’t know) and explain their response choice. When prompted with, “I have an understanding of how the research process is conducted by scientific researchers working in a research lab,” there was a 20% increase in students who agreed with this statement. Prior to the course only 73% of the students agreed with this statement while, by the end of the course, almost all of the students (93%) reported that they were aware of the research process. Of the 51 students who completed the post survey, seven explained that their understanding was a direct result of this course. One student wrote, “After participating in the antiviral project, I have a better understanding how research is conducted and the processes behind it.”

When prompted with, “Team work (collaborative work) is valuable for scientific advances,” almost all of the students responded before (95%) and after (96%) the course that teamwork was important, indicating that students continue to have positive views of teamwork. Prior to the project, students claimed that teamwork is important in general; in the post-survey, they commented on specific attributes of working with a team. One student wrote, “It takes a whole team of researchers and assistants and collaboration from other fields for success in science.”

When asked what they would change about the project, 11 students specifically stated that they thought the project was good and one stated, “I actually think that it was set up good. I liked how we had virus teams and specialty teams. That was a good idea. I didn’t feel like the workload was too much because there were six people in our team. But with that many people, it was hard to find a meeting time between all of us. I liked how class time was allocated to talk about the project rather than just having everything done and talked about outside of class.”

In the group of students who felt there was room for improvement, ten students felt that they needed more direction and five students requested that the antiviral lecture be given prior to the start of the project. The authors have modified the original student instruction handout to more clearly define the expectations of the project (available upon request) and are in the process of assessing whether these modifications alleviate some of the students’ concerns. Additionally, more of an effort has been made to emphasize the usefulness of student-directed learning at the beginning of the project.

**Potential modifications**

This project can be altered to fit classes of varying sizes. The number of team members can be reduced to five by redistributing Specialty Six duties amongst the other five team members. This modification is currently being field-tested and does not appear to substantially increase the workload on the individual students. The

![FIGURE 4. Self-reported awareness survey responses.](image-url)
number of virus teams can be increased or decreased to match the size of the class. For institutions without an online Course Management System, reports could be submitted via email or hard copies.

In order to make the discussions and poster session more comfortable, rooms other than a lecture hall would be preferable. Use of a conference room or a classroom with tables is preferable for discussion sessions, while the use of a large open room is recommended for the poster session.

Depending on the size of the class, it may not be feasible for the instructors to assess all the students during the poster session. The rubric can be altered to replace the instructor’s evaluation of the poster session with a peer-review system.

**Supplemental Materials**

Appendix 1: Team-building Questionnaire
Appendix 2: Pre-project Survey
Appendix 3: Student Instructions
Appendix 4: ADRP Rubric (SR report rubric, SR revisions report rubric, Poster session rubric, PD rubric, Discussion participation rubric)
Appendix 5: Post-project Survey
Appendix 6: Poster Session Quiz
Appendix 7: Example of Students’ Work
Appendix 9: Example of Specialty Research Report Revisions

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**References**