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Development and Implementation of a Bioinfographic Assignment in Second-Semester Biochemistry: Metabolic Pathways beyond the Classroom

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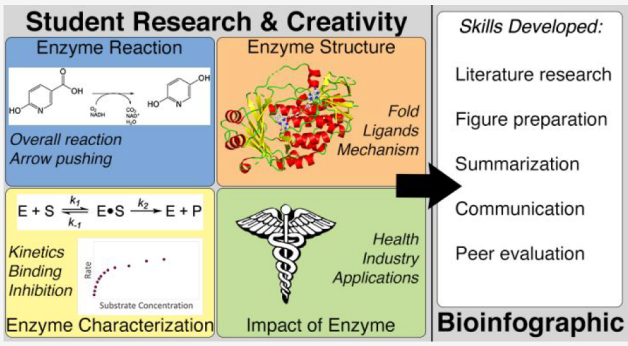
ABSTRACT: Second-semester biochemistry students at two primarily undergraduate institutions, the California State Polytechnic University, Pomona, and the State University of New York College at Cortland, worked on a collaborative, semester-long project that resulted in the production of bioinfographics focused on metabolic pathways. Students were divided into seven metabolic pathway groups, and each student produced a 1-page bioinfographic where they detailed the structure, function, and broader impacts of a metabolic enzyme. Students used a joint Blackboard site for communication throughout the term and met with their metabolic groups at the end of the semester. At the end of this assignment, these bioinfographics were disseminated to a broader audience both in print and online. In postassignment surveys, most students reported that they found this assignment to be a meaningful capstone project and noted the importance of the peer review process in editing their bioinfographic.



KEYWORDS: *Upper-Division Undergraduate, Biochemistry, Chemoinformatics, Communication/Writing, Public Understanding/Outreach, General Public, Enzymes, Metabolism*

INTRODUCTION

References to infographics first began appearing in the literature roughly 20 years ago.[1] However, it is only within the past five years or so that the focus has shifted from using infographics to improve information dissemination and understanding to using the preparation of the infographic itself as a learning tool.[2−6] Scientific infographics have become a popular way of displaying complex information, including via the popular Compound Interest website.[7] Additionally, the COVID-19 pandemic has highlighted the importance of conveying accurate scientific information to the public.[8,9]

A number of pedagogical articles have highlighted using infographics as an educational tool in a classroom setting.[10,5,11,2,12,13,3,14] However, most of these assignments were incorporated into interdisciplinary courses or foundational courses, such as organic, green, and analytical chemistry. At many colleges and universities, cellular metabolism is the central topic of second-semester biochemistry courses,[15] including the metabolism of carbohydrates, nucleic acids, and amino acids. Metabolism is a complex subject, and while a number of innovative approaches have been described in the literature to teach this topic,[16−18] this material is usually taught using a traditional lecture-based format.[19] This approach can be effective but lacks creative thinking and collaborative interactions between students.[15]

A 2022 paper by Sahai and Ivanova described a collaborative infographic project that was part of an upper-level biochemistry course at a university in London, U.K., and a general chemistry course in New York.[14] In this collaborative project, the biochemistry students developed infographics based on the four main classes of biomolecules that were then evaluated by the general chemistry students. Similar to the Sahai and Ivanova study, our bioinfographics project involved biochemical concepts and was also collaborative but was uniquely focused on metabolic pathways as there are limited materials directed at a general audience on metabolism. The most notable resource is the Protein DataBank's PDB-101 collection that highlights the enzymes involved in a variety of metabolic pathways, such as glycolysis[20] and the citric acid cycle.[21] The metabolic pathways selected for this bioinfographics project are pathways with well-characterized enzymes but are often beyond the scope of a traditional second-semester biochemistry course.

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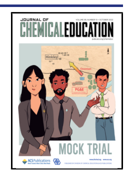

The bioinfographics project described here was carried out during the Spring 2021 semester, when the COVID-19 pandemic forced many schools to move to online or hybrid learning and involved second-semester biochemistry students at two public institutions, the California State Polytechnic University, Pomona (Cal Poly Pomona), and the State of New York University College at Cortland (SUNY Cortland). Between the two institutions, approximately 50 students participated in this assignment. Students were divided into seven metabolic groups based on their interests, which were evaluated in the beginning of the project survey. Each metabolic pathway group consisted of 5−6 students who were part of a joint Blackboard site where they could use the email feature or message boards to contact their group members. This was an especially important aspect of this project during this time, as the pandemic has also highlighted and magnified the feeling of loneliness that many undergraduate students experience.[22] Students also received feedback on a draft of their bioinfographic from both an instructor and multiple peers. Many students reported in end-of-project surveys that these collaborations were among the most meaningful parts of the assignment.

This bioinfographics project served multiple purposes. It (1) allowed the students to create a scientific infographic that is accessible to a general audience, (2) allowed the students to make publication quality figures using PyMOL and ChemDraw software, and (3) allowed for community and network building among students at institutions in New York and California. Students were asked about their expectations for this assignment during a presurvey and were also asked to reflect on their experiences in a postsurvey. While other projects have used social media to disseminate these infographics,[12−14] we took a more targeted approach of displaying these bioinfographics at our home institutions and on a publicly accessible website hosted by the SUNY Cortland library. This paper describes the details of this assignment, presents sample student bioinfographics, and provides suggestions for instructors who would like to include a similar assignment in their courses.

■ PROJECT BACKGROUND

Class Demographics and Project Placement

This project was designed as a collaboration between upper-division undergraduate students at Cal Poly Pomona and SUNY Cortland, two public universities that serve primarily undergraduate student populations. During Spring 2021, 45 students were enrolled in Biochemistry II at Cal Poly Pomona and 7 students were enrolled in Biochemistry II at SUNY Cortland. At Cal Poly Pomona, 43/45 had senior standing, 1/45 was a graduate student, and 1/45 was enrolled through Open University. The Cal Poly Pomona undergraduate student majors were 48% Chemistry—Biochemistry option, 18% Microbiology, 14% Biology, and 7% Biotechnology, with the remainder majoring in Chemistry—ACS certified option, Chemical Engineering, Nutrition Sciences, and Chemistry—General option. At SUNY Cortland, second-semester biochemistry during the Spring 2021 semester consisted of seven students. All students were either juniors (43%) or seniors (57%) who had previously taken first-semester biochemistry. The students were a variety of majors, including biology (14%), biochemistry (43%), and chemistry (43%) majors.

We introduced students to the bioinfographic project during the fifth week of the semester. Prior to beginning the bioinfographic project, students were introduced to the themes of metabolism: regulation, thermodynamics, and organization of enzymes and metabolites within a pathway. Students had also covered glycolysis and thus had seen an example of a metabolic pathway. This initial exposure to metabolism prior to beginning the bioinfographic project provided students with a solid foundation for researching a metabolic enzyme and gave students a known metabolic pathway to reference when working through the initial stages of the bioinfographic project.

Project Rationale

The bioinfographic project serves several functions in the second semester of a year-long biochemistry sequence. Metabolic pathways require students to combine their knowledge of organic chemistry and enzymes to understand individual metabolic transformations, as well as their knowledge of thermodynamics to understand regulation and how metabolic pathways function in a certain direction. When presented in lecture, metabolic pathways can seem exceptionally dense and may give students the impression that biochemistry and metabolism are completely understood. Students may also lack an appreciation of how individual metabolic steps are characterized. This semester-long project provided students with the opportunity to delve into pathways that otherwise could not be covered in class and to discover information from the literature for themselves. Additionally, this bioinfographic project pushed students to develop their research and figure-making skills, learn to use molecular graphics software such as PyMOL, and summarize clearly and succinctly their findings in a visually appealing manner. By the end of the project, students have gained an appreciation for the myriad approaches and analyses that are required to characterize a single enzyme from one metabolic pathway.

Additionally, there are limited resources available online that are accessible to a general audience that explain how specific metabolic pathways function. While funding sources such as the National Institutes of Health mandate that the public have access to results their funding generated, these publications and findings are often densely written and full of jargon. In a similar manner, three-dimensional coordinates must be deposited in the Protein Data Bank prior to publication, but the raw data are not easily interpreted by the public. This assignment develops student skills in locating, analyzing, and presenting information on how metabolic enzymes function in a manner that is more accessible and curated than the primary scientific literature.

Lastly, the collaborative nature of this bioinfographic project, with students from two institutions on opposite coasts of the United States, provided students with a sense of connection and belonging during a period when both institutions were operating in a remote mode of instruction. Students from both schools were assigned enzymes within the same metabolic pathways and were able to engage with each other via peer review and in an end-of-semester "Infographic Extravaganza". Through these interactions, students at both institutions were able to see how other Biochemistry II classes are taught and compare knowledge bases and understanding. Thus, this assignment can also help students have a sense of belonging within the chemistry community.

■ ACTIVITY DESIGN

Assignment Description

Each student prepared one bioinfographic on an enzyme involved in the metabolism of biologically important molecules (for example, purines or carotenoids). Metabolic pathways were

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chosen to meet three criteria: student interest and relevance to human health/environment, a minimum of four enzymes within the KEGG database for the metabolic pathway, and availability of biochemical and structural data for enzymes within the pathway. Students then indicated their preferences by completing a short survey where they ranked their interest in each metabolic pathway.

The final bioinfographic was required to include the enzyme name, metabolic pathway, E.C. number, a ChemDraw figure of the enzymatic reaction catalyzed, the structures and names of substrates and products, kinetic and biochemical data (if available), a figure of the enzyme in cartoon representation, a figure of the enzyme active site with ligands bound (if available), discussion of enzyme use in industry or on human health, and a minimum of three citations. Several assignments were used to provide milestones throughout the semester and are summarized in Table 1.

Table 1. Timeline of Bioinfographic Project

Assignment	Points	Deadline
Preference survey	5	Week 4
Planning guide	35	Week 9
Draft infographic	75	Week 10
Peer evaluation	2 × 25	Week 12
Final infographic	100	Week 13

The planning guide assignment (see the SI, pages S6−S8 and S32−35) served as a repository for the information located by students that was to be included on the bioinfographic. Once complete, student planning guides contained the enzyme name and E.C. number (provided), the enzymatic reaction, names of all molecules, at least 3 relevant citations, a PDB code for the enzyme, kinetic and biochemical data, the significance of the enzyme on human health or other application, and the most recent research into the enzyme. Students were also asked to consider how the enzyme assigned to them was connected to topics covered in class.

Draft bioinfographics, which were uploaded to the joint Blackboard site during week 10, contained a title, enzyme information (E.C. number, metabolic pathway, context for enzyme), an enzymatic reaction prepared in ChemDraw, two PyMOL figures, enzyme kinetic and biochemical information, the impact of the enzyme on human health or industrial application, and at least 3 citations (see the SI, pages S13−S14). In addition to the draft bioinfographic, students also submitted supplemental files such as the .cdxml and .pse files from ChemDraw and PyMOL, respectively.

Each student was assigned two anonymous draft bioinfographics from their metabolic group (Table 2) on which to give feedback. Students were provided with 7 areas of evaluation (see the SI, pages S15−S18) and asked to assign each as poor, good, or excellent with written feedback and constructive criticism supporting their evaluation. Prior to completing peer evaluation, class time was taken to explain what is helpful feedback that would lead to an improved bioinfographic versus feedback that would not be as useful due to vagueness, lack of clarity, etc. Finally, students were asked to provide three main things that were well done and three major items that should be changed for the final bioinfographic. This feedback was then anonymously shared with students as they worked on their final bioinfographic draft.

Table 2. Groups within Blackboard

Group Name	Group Category	Student Visibility
Cal Poly Pomona	Institutional	No
SUNY Cortland	Institutional	No
Caffeine Metabolism	Metabolic	Yes
Carotenoid Metabolism	Metabolic	Yes
Halogenated Ring Degradation	Metabolic	Yes
Naphthalene Degradation	Metabolic	Yes
Pantothenate and Coenzyme A Metabolism	Metabolic	Yes
Purine Metabolism	Metabolic	Yes
Pyrimidine Metabolism	Metabolic	Yes

The final bioinfographic contained the same elements as the draft bioinfographic with changes incorporated from suggestions from peers and instructors. In addition to the final bioinfographic, students were asked to reflect on how peer review did or did not contribute to their final work.

Project Implementation

The bioinfographic project deliverables were collected, and feedback was provided solely through a joint Blackboard (learning management system) organization hosted by SUNY Cortland. A joint Blackboard organization was chosen as it allowed students from both institutions to interact with their peers via Discussion boards, streamlined the process of providing feedback for the instructors, enabled peer review, and adhered to institutional requirements to maintain confidential information (grades, etc.). Two group sets were made within Blackboard: "Institution" and "Metabolic Pathways". Students were enrolled by the instructors into two groups: their institution and the appropriate metabolic pathway. Institution groups were not made visible to students and were used to manage due dates and facilitate grading. Students had access to their metabolic pathway group and were encouraged to engage with peers assigned enzymes within the same metabolic pathway.

Students first completed a pathway selection quiz in which they ranked their interest in each metabolic pathway (1 = most interested; 7 = least interested); the instructors then met to assign metabolic enzymes to each student, and each group had at least one student from each institution. Notably, every student was given one of their top three choices. After receiving their enzyme assignment, students had approximately one month to complete the planning guide and 10 days from then to submit their draft bioinfographic.

The planning guide (see SI, pages S6−S8 and S32−35) provided students with structure and guidance for identifying key primary sources for their bioinfographic. The planning guide was provided as a .docx file for students to fill in electronically or print for hard-copy use. Throughout, students were asked to provide the citation for each bioinfographic component. Prior to completion and during class time, students were introduced to the BRENDA enzyme database[23] and the Protein Data Bank.[24]

The draft bioinfographic was submitted electronically to the joint Blackboard organization, along with supporting files for figures prepared by students. Students were provided with the rubric used by the instructors and a form to use in peer review (see SI, pages S15−S18 and S41−S43). Via the Self and Peer Assessment tool available in Blackboard, students were anonymously assigned two draft bioinfographics from the same Metabolic group and given 10 days to complete the peer

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review process. For peer review, students rated the bioinfographic as Excellent, Good, or Poor and offered an explanation and constructive feedback in seven areas. Students also summarized three strengths and weaknesses of the assigned draft bioinfographic. Instructors then evaluated the criticisms and feedback.

After completion of the peer review process, students had approximately 10 days to incorporate feedback and submit their final bioinfographics. The final bioinfographics were assessed by the instructors according to the instructions and the rubric available to students on the joint Blackboard organization (see SI, pages S19−S21 and S44−S46). Students were asked to also describe the impact of peer review and explain how they incorporated feedback into their final bioinfographics. After submission, students were encouraged to attend an optional "Infographic Extravaganza" where they could interact both with their classmates and their peers at the external institution.

Bioinfographic Assessment

Students were evaluated on both smaller assignments and their final bioinfographic with due dates listed in Table 1. The planning guide was assessed for completeness and accuracy by the course instructors, with feedback and suggestions provided. Students were then required to submit a draft bioinfographic and supplemental files approximately 3 weeks before the final project deadline. Separately, students submitted only the bioinfographic for peer review. Course instructors evaluated eight components of the draft bioinfographic (Table 3) with supporting supplemental files and provided feedback through Blackboard. The quality of peer feedback was assessed by the instructors, who determined if the feedback offered was constructive or actionable to lead to bioinfographic improvement. Lastly, the final bioinfographic was assessed by course instructors according to the infographic components listed in Table 3.

Table 3. Bioinfographic Components

Component	Point Value: Draft	Point Value: Final
Title	5	7
Pathway, Enzyme, E.C. Number	10	13
Enzymatic Reaction	10	13
Overall Enzyme Figure	15	20
Active Site Enzyme Figure	15	20
Enzymatic Characterization	10	13
Significance	5	7
Citations	5	7

One goal from the instructional perspective is to continue development of important scientific skills, such as performing literature searches, preparing scientific illustrations and figures, summarizing findings, and communicating with their peers. The average score on the planning guide assignment (where students had to perform literature and database surveys to gather information) was a 92% and indicates students successfully used their skills to identify relevant papers in the literature. Student ability in using ChemDraw and PyMOL represents their skills in figure preparation; all but one student received a "good" or "outstanding" score on the final infographic rubric for their ChemDraw reaction drawing. Students generally did better at preparing the overall cartoon figure of an enzyme, with 94% of students receiving an "outstanding" score. However, students showed room for growth in preparing their active site figures. 59% of students prepared "outstanding" active site figures, and 37% prepared "good" active site figures. Notably, these lower scores did not result from student inexperience with PyMOL but from issues such as labeling or clarity. Overall, students demonstrated a good ability to prepare a written communication document that summarized findings from multiple sources, as represented by an average score of 92% on the final overall assignment.

Examples and Dissemination of Student Work

Examples of the student-generated bioinfographics are shown in Figure 1 and in the SI (S25−S26). At the end of the Spring 2021 semester, an "Infographic Extravaganza" was held via Zoom where students from both institutions could share their final bioinfographic with their peers. During this 90 min session, students first went into breakout rooms organized by metabolic pathway and were able to move to different rooms to see the final work. The second part of the Zoom session brought all students together, and anyone who wished was able to share their bioinfographic with all attendees.

With permission, this student work was disseminated to the general population both online and in print form. At SUNY Cortland, prints of five student bioinfographics along with a description of the project are currently on display in the lobby of Memorial Library, the main campus library. A photo of this display is shown in Figure 2.

As this is a space that is utilized by the general campus community, and not only STEM majors, the library lobby is an ideal location to disseminate this work to a general college audience. Also, as one of the busiest locations on campus, the bioinfographics are viewed by thousands of students, faculty, and staff each day. In addition, all of the student bioinfographics from the SUNY Cortland students are accessible to a worldwide audience on the College's Digital Commons site at https://digitalcommons.cortland.edu/collaborative_bioinfographics_project/. Cal Poly Pomona student work was displayed on a digital bulletin board outside of the Chemistry Department office.

■ STUDENT PERCEPTION OF BIOINFOGRAPHIC ASSIGNMENT

Student survey data were collected both at the beginning of this assignment in week 6 and at the conclusion of the assignment in week 14. IRB approvals from SUNY Cortland and Cal Poly Pomona were obtained before the administration of the pre- and postsurveys.

For the presurvey, a total of 36 students (out of 52 total students) answered the survey. When asked in a free response question regarding what they anticipated would be the most impactful part of the assignment, the top responses referenced interacting with students from another institution (23%), learning more about metabolism (18%), or communicating scientific ideas to a general audience (13%). The vast majority of students (97%) strongly agreed or agreed that they appreciated receiving peer feedback. Likewise, all students agreed or strongly agreed that it is important for scientists to explain scientific concepts to a general audience. However, only 20% of students either strongly agreed or agreed that they were confident in their abilities to identify the key "take home" concepts of a metabolic pathway.

At the end of the bioinfographic project, a total of 33 students (out of 52 total students) took a postsurvey. When asked how much time they spent on the assignment, 20% said that they spent 8−9 h while 59% indicated that that they spent more than

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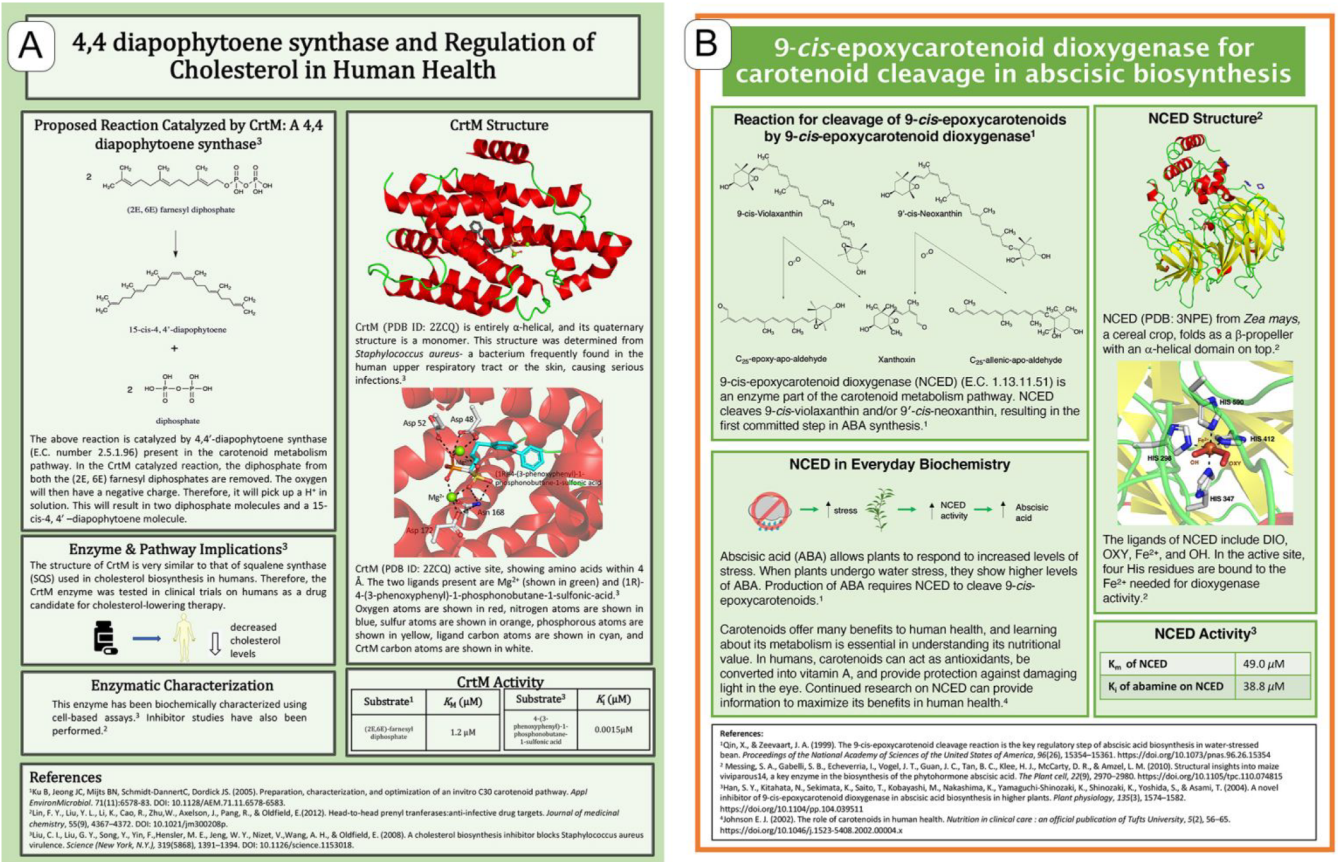

Figure 1. Student-generated metabolic enzyme bioinfographics. Reprinted with permission.

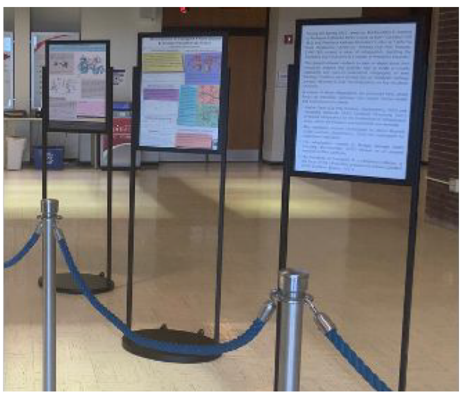

Figure 2. Student bioinfographics on display in the SUNY Cortland Memorial Library lobby.

9 h. When asked what the most impactful part of the assignment was, the most common student response was meeting and receiving feedback from students at another institution (34%). Most of the students (94%) strongly agreed or agreed that assessing another student's work improved their own bioinfographic and that creating a bioinfographic helped them learn how to present scientific concepts to a general audience (84%). Also, 72% of students indicated that the bioinfographics project was useful in helping them consider the "take home" concepts within metabolism. Additionally, 69% of students strongly or very strongly agreed with the statement, "Creating an infographic helped [me] to understand other metabolic pathways we discussed in class."

Student feedback through comments on the postsurvey (see SI, pages S27–S28) revealed that students generally appreciated interacting with other students, which agrees with the findings of the collaborative infographic assignment described by Sahai and Ivanova.[14] As highlighted by Grieger and Leontyev,[13] students greatly appreciated the hands-on experience of learning how to prepare infographics and use scientific software required for figure preparation. Notably, several students in the postsurvey described how beneficial the peer review process was, suggesting that this component of the project be emphasized.

■ ADVICE FOR INSTRUCTORS

Based on student feedback and our own observations, we suggest the following possible modifications for future implementation of this project:

- Build in additional smaller assignments toward creating bioinfographic figures. For example, have an assignment where students create and receive feedback on (1) PyMol figures of the overall protein and active site structures and (2) ChemDraw figure of the enzyme-catalyzed reaction. Along this line, later iterations of this assignment have incorporated refined descriptions, smaller assignments with distributed due dates, and detailed rubrics. Updated documents are provided in the SI (pages S29–S46).
- For instructors who wish to carry this project forward postpandemic, identifying and implementing with a collaborator at another institution will provide students with networking opportunities and the chance to recognize that they are "just like" students elsewhere. However, this project is also fulfilling and worthwhile,

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achieving the desired learning outcomes, when conducted within a single classroom.

■ IMPLICATIONS

Student response to the bioinfographics project was overall positive, and students indicated that they valued the hands-on experience in gathering information and especially in learning how to use scientific programs to prepare high-quality figures. This project was also designed to span an entire term, allowing students to apply their lecture learning to a new metabolic system, pushing students to appreciate the universal nature of metabolism and connections to their daily lives. The online and collaborative nature of the assignment provided students with a much-needed sense of community; this project has since been continued as an in-person assignment where students can collaborate on metabolic pathways within the classroom. Student survey data and comments also highlight the value students gain from the peer review process. Lastly, assessment of the bioinfographic project supported the development of universal skills, such as literature searches and written communication. This bioinfographic project could be adapted to other courses, especially courses that emphasize communication and the application of chemical processes on human health.

■ ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available at https://pubs.acs.org/doi/10.1021/acs.jchemed.2c00502.

Class handouts, peer assessment forms, pre and post surveys, and sample student bioinfographics (PDF, DOCX)

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Notes

The authors declare no competing financial interest.

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