PARADIGMS FOR CREATING ACTIVITIES THAT INTEGRATE MATHEMATICS AND SCIENCE TOPICS

Janet Bowers
San Diego State University
jbowers@sdsu.edu

Kathy Williams
San Diego State University
kathy.williams@sdsu.edu

Antoni Luque
San Diego State University
aluque@mail.sdsu.edu

Devon Quick
Oregon State University
devon.quick@oregonstate.edu

Mary Beisiegel
Oregon State University
beisiegm@oregonstate.edu

Jody Sorensen
Augsburg University
sorensj1@augsburg.edu

Joan Kunz
Augsburg University
kunz@augsburg.edu

Diane Smith
San Diego State University
dksmith@sdsu.edu

Lori Kayes
Oregon State University
lori.kayes@oregonstate.edu

https://doi.org/10.25891/14f6-by82

ABSTRACT

Research has shown that undergraduate students benefit from seeing examples of mathematics applied to real-world situations. This article describes three different paradigms for how math and discipline partner faculty worked together to create mathematical activities that illustrate applications of the topics being studied in precalculus and calculus. All three examples are discussed within the framework of PDSA cycles to describe the process by which the teams collaborated to plan, enact, study, and refine their lessons. Findings discuss both the difficulties of creating integrated activities (differences in terms and definitions between mathematics and science faculty, different foregrounding of mathematics versus science among faculty), and the value of the resultant lessons, such as increased level of student engagement, higher cognitive demand, and the role that relevant applications can play in piquing student interest in STEM.

KEYWORDS
chemistry, integrated activities, mathematical biology, pH

During the early 2000's, mathematics faculty held discussions with faculty from a variety of client disciplines to identify mathematics concepts usually taught in lower division mathematics classes that deserved either increased or decreased emphasis based on their use in successive courses (Ganter & Barker, 2004). As a follow up to this work, a consortium of ten universities across the U.S., collectively referred to as A National Consortium for Synergistic Undergraduate Mathematics via Multi-institutional Interdisciplinary Teaching Partnerships (SUMMIT-P), is now working to implement the recommendations at various large and small institutions around the country. One of the methods for accomplishing this implementation involves having mathematics faculty at each of the ten institutions form Faculty Learning Communities (FLCs) with faculty from various partner disciplines to create integrated lessons. This article describes how that collaborative process played out at three SUMMIT-P institutions, San Diego State University (SDSU), Augsburg University, and Oregon State University (OSU).

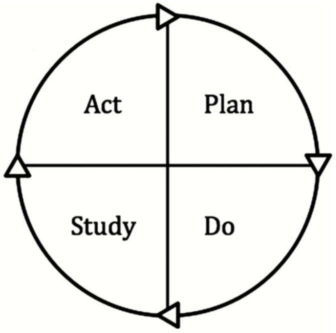
We first describe a theoretical framework outlining how curricular design processes can be characterized as passing through four stages. We then use this framework to describe how the three universities each engaged in these stages in different ways. The first example describes how the FLC at SDSU developed integrated lessons to engage students in the study of exponential and logarithmic functions in a precalculus class. The second example describes how the FLC at Augsburg University developed integrated activities from biology and chemistry to demonstrate critical ideas in calculus. The third example describes how the FLC at OSU sought to find local biological models to apply to calculus. We conclude by comparing and contrasting how the processes played out in each of the universities studied and offer some "lessons learned" to inform other interdisciplinary teams.

The Process of Design: PDSA Cycles

When discussing the development of integrated lessons, all of the authors of this article agreed that the process can be messy, time-consuming, and, at times, frustrating. However, we also agreed that when a lesson goes well, it is one of the most rewarding experiences for educators. Even though there was no single path that any of us took to design lessons, we did agree that our efforts could be retroactively captured using the Plan-Do-Study-Act (PDSA) model shown in Figure 1. This model has been used for Quality Improvement in the healthcare field (Taylor, et al., 2014) and adapted by researchers in the Improvement Sciences (Lewis, 2015; Struchens, Iiams, Sears, & Ellis, 2016).

Figure 1

The Four Phases of the PDSA Model Adapted from Taylor, et al. (2014).



Within the SUMMIT-P adaption, the "Plan" phase begins when the FLC identifies a problem that might be addressed through curricular change. This might involve conducting a needs-assessment in order to identify goals and constraints or asking questions such as "What are we trying to accomplish?" (Taylor, et al., 2014). Successive steps in this phase involve proposing possible lessons. In the "Do" phase, the team works to create an initial prototype and implement it. This could be done as a small pilot or enacted in the target classes at large. The "Study" phase occurs as the lesson is being implemented and can continue with follow up interviews or surveys. At some sites, members of the team study lesson implementation by noting students' ways of engaging with the material, their approaches to problem solving, their level of engagement, and any intended and unintended comments and solutions. In addition, the development team notes their impressions of the instructors and any observers. In some cases, dependent measures may also include items on a test, final exam, or student survey that refer back to the particular application.

The "Act" phase of the PDSA cycle involves making changes to the lesson based on the feedback from the enacted lesson collected during the "Study" phase. This could be revising the materials or re-thinking the discipline application context more broadly within the larger context of the mathematics curriculum it was designed to augment. Collaborations during this phase have also been aided by conducting site visits to other SUMMIT-P schools to share ideas. The "Act" phase completes just one cycle of the process. The full PDSA model envisions a series of micro-cycles until the final outcome is reached (TKMG, 2012).

We first present three examples from three SUMMIT-P institutions. They highlight a few of the unforeseen issues that emerged as the groups progressed through the PDSA cycles. We then discuss some commonalities that emerged across sites, such as differences in emphasis and terminology between partner science faculty and mathematics faculty. We conclude with some suggestions for other integrated teams.

PDSA Cycle Vignettes

Vignette 1: Precalculus Students Need to Learn About Comparing Numbers with Logarithms

Step 1: Plan. Phase I of SDSU's collaborations was initiated by a mathematics faculty member teaching precalculus. The mathematics faculty (Bowers, first author of this article) worked with faculty from three partner disciplines (Williams from biology, Smith from chemistry, and Luque from mathematical biology) to brainstorm where they see deficits in their students' mathematical knowledge. Williams had done some prior research in this area and pointed out that many of the most significant deficits science faculty see involve skills such as interpreting graphs and solving algebraic equations, both of which are taught in lower-level courses such as algebra (see Williams et al., 2018). However, all discipline faculty agreed that students needed a stronger understanding of exponents and logarithms because these concepts are frequently used in science to compare very small or very large numbers.

The lesson planning phase began by discussing the parameters of the situation. SDSU teaches Precalculus in large lectures three times per week with required small breakout sections that meet for 50 minutes once per week. The team decided that the lesson would be taught during the 50-minute break out sessions that are run by undergraduate TAs (See Bowers, et al., 2020). Next, the team focused on the nature of the activities the students would engage in with a specific emphasis on active learning. Two activities emerged from these discussions: a virus spread simulation lab to model exponential growth and a pH lab to model logarithmic conversions. While the group had hoped to use authentic tools such as litmus paper (chemically treated paper that changes color based on the pH of a substance it touches) for the pH lab, the restrictions of time and materials forced us to choose the simplicity of worksheets.

Step 2: Do. The pH lesson was implemented in 23 recitation sections (hereafter referred to as “labs” to indicate the intention of more active learning). The worksheets included three parts. Part I involved having students use Desmos or Excel to graph very small numbers (concentrations of hydronium in various substances that ranged from 0.0000000000316228 to 1.0). Once they realized that base-10 scales were problematic for showing differences of very small numbers, the instructors of the breakout sessions introduced the idea of log scales for the y-axis. Part II involved applying the laws of logs the students had learned in lecture to convert concentrations of hydronium to pH values and vice versa. For example, given that canned artichokes have a concentration of hydronium (denoted $[H+]$) = 0.000034, students use the formula $pH = -\log[H+]$ and their knowledge of the laws of logs to compute a pH value of 4.463. Part III involved comparing magnitudes of other logarithmic measures such as decibels and the Richter scale.

Step 3: Study. SDSU’s FLC team sought three types of feedback: reactions from the instructors, impressions from the students, and performance data on related items from the final exam. The lab instructors stated that the pH lesson was challenging for them to teach because none of them had known exactly what pH measures are or felt prepared to field students’ questions regarding the surrounding science. In this way, several admitted that teaching the lesson helped *them* strengthen their understanding of logarithms beyond the rules they had dutifully memorized because they appreciated the role that the rules played in the conversion algorithm. To the pleasant surprise of the lab instructors and the coordinator, the students were engaged in ways that they had not observed during other worksheet-based labs. They noted that students commented on how “cool” it was to be studying pH, a concept many of them had been discussing in their chemistry class.

Results from an end-of-course survey revealed that the students rated the virus and pH labs very highly. In addition, the students performed well on a related task in which they were asked to compare two pH values. Unfortunately, results from an exam item requiring the procedural implementation of the laws of logarithms to expand expressions into addition and subtraction revealed that many made algebraic errors.

Step 4: Act. Based on the results of the study phase, the lesson was revised to strike a better balance between sufficient science (e.g., enough to explain what pH stands for and what the small numbers represent) with the need to keep the mathematics relatively close to the mathematics teachers cover in their lecture. In subsequent semesters, the lesson has been front-loaded with an activity focusing on the more calculational process of applying the laws of logarithms, noting that the students will need these skills for calculus because they need to learn logarithmic differentiation which will then be used in chemistry.

Vignette 2: Discipline Faculty at Augsburg Present Ways that Calculus Is Used in Biology and Chemistry

In redesigning Calculus I at Augsburg, the FLC included partner disciplines that provided examples of how they use calculus content in their classes that require calculus. Specifically, the mathematicians asked their SUMMIT-P discipline partners to present examples from chemistry, environmental science, and economics calculus.

Step 1. Plan. The calculus instructors were looking for applied settings that could be used in a calculus class with a broad audience. For them, this meant interesting problems that could still be understood by students of varied backgrounds. One example that resulted from these discussions was the titration lab. The team was particularly interested in this process because identifying the inflection point in the data set is a crucial part of identifying unknown solution concentrations. The team used this to create an activity where students worked with spreadsheets containing a real data set to approximate first and second derivatives to identify an unknown acid. The data contained an independent variable, the volume of the titrant in mL, and a dependent variable, the pH of the solution being titrated. After the discipline partner (Kunz, the chemist) presented the problem to the mathematics faculty (Sorensen and others) and provided the data set, Sorensen then wrote a draft of the activity. Working through the lab, Sorensen made several changes, such as asking Kunz for additional data near the inflection point for a more precise analysis. In the final phase, Kunz read the draft lab to suggest correct wording and possible extensions.

Step 2: Do. The titration lab was one new lab in a completely redesigned course full of active learning and applied examples of calculus. This activity has been taught by two different faculty members teaching Calculus I at Augsburg University. The students were asked to talk about the shape of the plot that emerged from the graphs they made with Excel and then to use their new vocabulary to describe it. They used mathematical terms such as increasing/decreasing, concavity, and limits. The partner discipline faculty have occasionally attended class during relevant labs/activities, but the development team decided it was more important that they evaluate the language and questions in the activity before the class.

Step 3: Study. When talking with instructors, Sorensen learned that they enjoy teaching the new course, and student engagement seemed to be high. For example, the instructors reported that it was fun to see students who had done titration in a chemistry class react to the lab and to be able to explain some of the ideas to their peers. But the instructors also noted that even students who had not studied chemistry succeeded and remained engaged.

Step 4: Act. The titration lab, along with myriad other new applied activities and labs, will continue to be used in our calculus courses each semester. The mathematics faculty have a process for re-evaluating and editing the materials during the semester. They also seek feedback from instructors, partner disciplines, and students.

Vignette 3: Incorporating Activities from Biology and Chemistry into Differential Calculus

At OSU, a cross-curricular FLC acknowledged the need for more integration between mathematics and partner disciplines for science students. After spending time examining existing curricula in disciplinary courses (biology and chemistry), the FLC decided to craft relevant activities (applied problem sets) for incorporation into the ten-week Differential Calculus course.

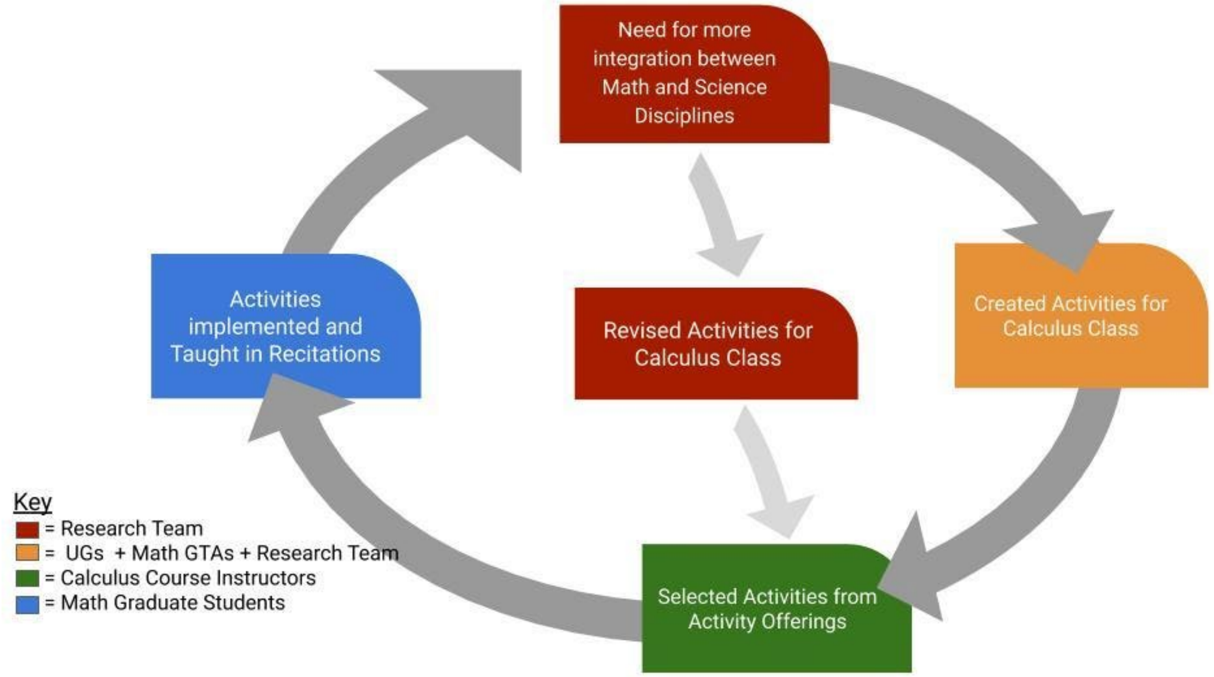
Step 1: Plan. To create the activities, two undergraduates from biochemistry worked with the OSU FLC to create, revise, and align applications for the Differential Calculus course. Broadly, the FLC considered all the topics from the Differential Calculus course (limits, continuity, derivatives, related rates, optimization) and sought to use phenomena from biology or chemistry to suggest the need for calculus concepts. Approximately 30 problems were developed by the two undergraduates. Calculus course coordinators and instructors then selected activities from the list of problems for use in recitations taught by graduate students.

Activity creation occurred iteratively (see Figure 2). First, the two undergraduate students used topics they remembered well from biology and chemistry to craft initial calculus activities.

Then, working with the OSU FLC, the students explored and aligned the mathematical components of each problem to the existing calculus courses by topics. For example, a predator-prey model from biology was examined for the mathematics that would be used to answer questions about rates of change, as well as the relationship between minima and maxima for the predator and prey populations. Next, the FLC consulted with two undergraduate students and calculus instructors to ensure accuracy of disciplinary concepts, provide background information that would be relevant for answering questions, and revise problems for shared language between the partner disciplines and mathematics.

Figure 2

Iterative Cycle of Lesson Development at OSU



The activities that were developed and revised by the FLC with the help of the two undergraduates were not only focused on certain disciplinary topics (e.g., predator-prey interactions); they also considered locally relevant species (e.g., Pacific Northwest organisms) or socially important topics (e.g., effects of radiation from Chernobyl). The final drafts of activities contained questions that covered calculus concepts from the entirety of the 10-week term. By developing activities in this way, they could be used in recitations multiple times during a term.

Step 2: Do. Once the activities were planned, the lead calculus instructor (the calculus course is team taught and coordinated by a lead instructor) selected activities that would be used during the term. The activities were then discussed with other calculus instructors before being deployed to recitations taught by graduate teaching assistants.

Step 3: Study. When the activities were deployed in recitation sections, the recitation GTAs reported an increase in student engagement perhaps attributable to increased critical thinking (GTA interviews). Whereas in the past, recitation activities consisted of strictly computation mathematics problems, the new activities required students to interpret and understand the application of the mathematics concepts before solving. One GTA theorized that, with less critical thinking required, the students were more likely to diverge into social conversations with each other, causing a decrease in student engagement. However, in the new activities, they had to comprehend the meaning of the activity, relate it to a real-world application, and determine which mathematical equation to use. This allowed students to not only understand the real-world application of the mathematics but to also have “a sense of discovery” (GTA interview) while solving the activities, which was lacking in the prior worksheet style.

Other feedback from GTAs stated that, on average, the students thought the activities were more challenging and took longer to solve than the less integrated recitation worksheets. However, one GTA considered this a strength because the activities required students to remain working in the lab throughout the recitation and helped to further develop the students’ understanding and appreciation of the real-world application of mathematics in the biology and chemistry disciplines.

Step 4: Act. The activities are planned to be deployed in future calculus courses at OSU. Due to the feedback of the course instructors and GTAs, instructional guidelines will be provided to the instructors before the implementation of the activities in future calculus courses. These instructional guidelines will contain activity background information, rationale for the science topic, science and mathematics terminology, common science misconceptions, and the representation of math in the activity’s topic. Other revisions to the activities include removing excess background information in the activity for English language learners and implementing the activities earlier in the calculus course.

Discussion: Common Themes Across the Approaches

Although each of the sites had slightly different approaches to engaging in the PDSA cycles, there were several themes that emerged though each collaboration process. In particular, faculty at all three sites noted differences in terms of language use (e.g., what is a “line”) and professional approach (e.g., “what is a conceptual definition?”). We believe that commenting on these differences might inform readers who are attempting to design integrated activities. Despite the differences, we found agreement among all faculty that these lessons are helpful and hold promise for greater transfer of skills from the mathematics to science classes. We also found agreement from students who said that they appreciated the efforts to illustrate real-world uses of the topics they were learning.

Differences Between Mathematics and Science

Using Differing Terms and Definitions

One of the common issues that arises when departments cross-collaborate is the interpretation of terms. For example, in the titration example at Augsburg University, what the mathematicians would call an *inflection point* is referred to as the *equivalence point* in chemistry. Working through this and highlighting the difference to students was an intentional part of the activity that was created. More broadly, science faculty at SDSU have often stated that they focus on systems that seek balance and *equilibration* rather than static *equivalence* of two sides of an equation.

Another example of a term that carries different meanings across disciplines is the term *line*. Mathematicians distinguish between *linear functions* (often called “lines”) and nonlinear functions (often called “curves”). In contrast, many biologists call any graphed relationship between two variables a “curve” even if it is linear.

Different Foci from Mathematics to Client Lessons

A second issue we found is a mismatch in terms of emphasis or process. For example, client disciplines often rely on mathematics to model data and hence begin with numbers rather than equations, whereas mathematics instructors usually focus on known functions. The two institutions that developed activities that focused on pH both encountered this. When chemistry instructors introduce the idea of titration, they are plotting pH as a function of acid added to an unknown substance. The focus of the process is to identify the inflection point *of the data* because it indicates the amount of acid that causes the pH of the unknown acid to suddenly rise. In order to model authentic practices, mathematics faculty at Augsburg University used data and then found a best fit function to illustrate how the mathematical operations could be used to identify the inflection point. Similarly, at SDSU, the lessons shifted from focusing on functions and processes to operations on data (e.g., molar concentrations of given substances or data collected during the virus spread simulations).

At OSU, discussions with calculus course faculty (lead and teaching faculty) revealed that while the project’s goals (integration between mathematics and partner disciplines) were recognized, subtleties of the activities were not. Partner faculty noted that mathematics faculty changed the problems as they perceived they needed but often edited or removed components deemed important to disciplinary partners. For example, in an activity in which students consider the effect of temperature on sex determination in turtles, the original activity expected the students to work more like biologists and consider the implications of the relationship between temperature, turtle sex, and climate change conceptually before starting to use calculus to explain the relationship. However, the lead mathematics faculty revised the activity so that students were expected to engage in computations on functions (such as calculating instantaneous rates) without first predicting or exploring the relationship between the variables.

Working with Undergraduates

Several of the sites in the SUMMIT-P project have found that undergraduate learning assistants can be great resources for developing cross-disciplinary activities. For example, as described, the undergraduate biochemistry majors at OSU identified the activity topics by recalling activities in which they had used mathematics in their biology and chemistry classes. Once topics were identified, these undergraduates worked with a team of mathematics and partner discipline faculty to modify the activities. The undergraduates were then tasked with ensuring the accuracy of disciplinary concepts and providing background information, and perhaps most importantly, they were able to recognize and resolve differences in terminology use between the discipline faculty and mathematics faculty who implemented the lessons. Both of these roles for undergraduates were shared with the SDSU FLC during a site visit. Faculty from OSU provided some insights regarding the ways in which OSU employs undergraduates as learning assistants in their curriculum development process and as helpers who sit in on lecture classes to encourage students to work problems as they are posed during lectures.

At SDSU, undergraduates were also critical in the lesson development and implementation processes. They provided insights from their perspective as students who took the courses and also provided guidance and monitored what “would fly” in terms of activities that would appeal to undergraduates. For example, while planning the logarithm lesson, two undergraduates working on the project said that they had used logarithmic transformations while interning in a virology lab on campus to illustrate differences in very large numbers. They made a video to illustrate this use, and it was added to the pH lesson materials distributed to each lab instructor (see Bowers et al., 2020).

Student Engagement

Reports from all three sites indicated healthy and often enthusiastic student engagement. We believe that the reasons can be organized in two general categories: increased cognitive demand (that differs from what general worksheets require) and the use of practical, relevant problems.

Increased Cognitive Demand

One of our goals is to craft lessons that engage students in non-traditional practices of learning mathematics including hypothesizing, modeling, and making and critiquing arguments. Although not all sites reported hitting all of these goals, each team mentioned some aspects of increased cognitive engagement. The team at OSU reported that the integrated activities required students to interpret and understand the application of the mathematics concepts before solving, which differs from activities consisting of strictly computation problems. The team at SDSU reported that some students were able to understand logarithms at a deeper level by seeing their utility for measuring differences of magnitude.

Practical Applications

Reports from instructors at all three institutions indicate the value of relating content to real-world applications. As one OSU GTA noted, this allowed students to not only understand the real-world applications of the mathematics but to also have “a sense of discovery” (GTA interview) while solving the activities, which was lacking in the prior style of worksheet. At SDSU, the pH lab was voted as the top lab three semesters in a row. When asked on an end-of-semester survey why they liked it the best, student comments fell into three categories: (1) Pertains to a current/future class (e.g., “It helped me define the relationship between pH and logs, and seeing as I'm currently taking chemistry it was really interesting to make that connection and figure out easier ways to solve pH problems without having to use a calculator”); (2) Real life applicability (e.g., “I liked this lab because logs can be difficult to understand, but since this lab did a great job of tying it together with real life examples it made it a lot easier to understand.”), or (3) Helped clarify a mathematics concept (e.g., “I struggled with Log functions so it was very helpful for me.”).

Faculty at Augsburg University who taught the titration lab also felt that it was well received by the students. They noted that students recognized the idea from previous courses, and even if they did not recognize the topic or were not interested in it, they were still able to understand the mathematics that the application was designed to highlight. These challenges have the potential to pique students’ interest in other STEM applications of mathematics in the biology and chemistry disciplines.

Conclusion

Developing and integrating activities from partner disciplines is a challenging but rewarding endeavor. The process benefits faculty and students. Mathematics faculty are challenged to move beyond their silos to learn different terms, applications, and ways of using mathematics that they may not have considered before. In addition, the collaborations also support curricular decisions, such as what topics to emphasize based on STEM utility rather than just the mathematicians' views of conceptual development. The applications can be beneficial to students for several reasons: (1) they can serve as productive disruptors in mathematics classes because they challenge students' expectations for what it means to learn mathematics; (2) they provide a new, more concrete way of looking at concepts that may have appeared only calculational in nature; and (3) they provide insights into how the mathematics they are learning will be used in subsequent classes or in "real life."

It is also critical to be aware that such endeavors may not be widely appreciated or successful. In particular, we found that if students' perceptions of how college mathematics classes should be conducted are limited to introductory lectures in which instructors talk about manipulating symbols, then using applications might be stretching the students beyond their comfort zones. Or, they may resent learning material that "won't be on the test." In addition, if the applications require a good deal of science understanding, some students not majoring in a science discipline may discount the relevance of the particular application. From the perspective of the discipline faculty, although they appreciate being asked to identify areas of weakness, they often indicate that their particular needs rest in general procedural skills such as proportional reasoning and graph interpretation.

Finally, we believe that the PDSA cycle can be a useful way to lay out a plan for moving forward. In particular, the "Plan" phase of the cycle should include both discipline partners and mathematics faculty. While the original intent of our work was for discipline partners to completely lay out the skills they desire students to have, it is also the case that mathematics faculty teaching lower-division courses may be bound to cover certain topics for successive courses. Thus, the planning phase may involve developing a compromise to meet the needs of all involved. All three sites found the "Do" and "Study" phases of the work to be somewhat intertwined. Reflecting on how the mathematics faculty do (or do not) maintain the scientific content of the applications can inform future iterations of the "Act" phase of the cycle. Moreover, while these integrated activities were generally well received, they will become more effective if the partner discipline faculty can "Act" in the future by referring *back* to these experiences when the topics—titration, for example—are discussed in subsequent courses. We look forward to following these students and researching how these ideas proceed and develop over time.

Acknowledgment

This paper was developed in part through the project *Collaborative Research: A National Consortium for Synergistic Undergraduate Mathematics via Multi-institutional Interdisciplinary Teaching Partnerships* (SUMMIT-P, www.summit-p.com) with support from the National Science Foundation, EHR/IUSE Lead Awards 1625771, 1822451, 1942808. The opinions expressed here are those solely of the authors and do not reflect the opinions of the funding agency.

References

Bowers, J., Poole, B. D., Maher-Boulis, C., Schwartz, A., Bloomquist, A. & Young, E. (2020). The roles and benefits of using undergraduate teaching assistants to support the work of SUMMIT-P. *Journal of Mathematics and Science: Collaborative Explorations*, *16*, 84 – 91. https://doi.org/10.25891/zdjg-m390

Ganter, S. & Barker, W. (Eds.). (2004). *The curriculum foundations project: Voices of the partner disciplines*. Washington, DC: Mathematical Association of America.

Lewis, C. (2015). What is improvement science? Do we need it in education? *Educational Researcher*, *44*(1), 54 – 61.

Struchens, M., Iiams, M., Sears, R. & Ellis, M. (2016). A deeper dive into the Plan-Do-Study-Act cycles and measures. In Lawler, B. R., Ronau, R. N., & Mohr-Schroeder, M. J. (Eds.), *Proceedings of the fifth annual Mathematics Teacher Education Partnership conference* (pp. 30 – 36). Washington, DC: Association of Public Land-grant Universities.

Taylor M., McNicholas C., Nicolay C., Darzi, A., Bell, D., & Reed, J. (2014). Systematic review of the application of the plan–do–study–act method to improve quality in healthcare. *BMJ Quality and Safety*, *23*, 290 – 298.

TKMG. (2012, September 15). Micro-PDSA Cycle: Assess results: What do others think? Retrieved from https://www.slideshare.net/KarenMartinGroup/rapid-improvement-how-to-c/46-MicroPDSACycle

Williams, K.S, Bowers, Luque, A., & Anderson, M. (2018, August 8). *From cells to ecosystems: Integrating calculus and statistics throughout biology major's curriculum* [Conference Presentation]. 103rd Ecological Society of America Annual Meeting, New Orleans, LA. https://eco.confex.com/eco/2018/meetingapp.cgi/Paper/74279