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Cover Page Footnote

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VOICES FROM THE FIELD

A Cultured Learning Environment: Implementing a Problem- and Service-Based Microbiology Capstone Course to Assess Process- and Skill-Based Learning Objectives

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Abstract

In this study, a problem-based capstone course was designed to assess the University of Wyoming Microbiology Program's skill-based and process-based student learning objectives. Students partnered with a local farm, a community garden, and a free downtown clinic in order to conceptualize, propose, perform, and present studies addressing problems experienced by these partners. Instructor assessments enabled understanding of student competencies, and according to external subject matter experts students demonstrated mastery of all learning objectives on the final research presentation. Community partners were completely satisfied with the students' solutions, professionalism, and communication. Instructional diagnosis and student course evaluations showed satisfaction, engagement, and growth. Assessments enabled reflective practice by faculty and led to improvements of the capstone course and the microbiology program. Consequently, the course gained institutional support and an official course listing.

Keywords: microbiology, capstone, assessment, problem-based learning (PBL), service learning, Merrill's First Principles of Instruction, Small Group Instructional Diagnoses (SGIDs)

Introduction

There is overwhelming evidence that lecture-based instruction is ineffective (Bradforth et al., 2015; Freeman et al., 2014). By contrast, active, evidence-based teaching aligns student learning objectives with course design and facilitates authentic student learning (Handelsman, Miller, & Pfund, 2007). It has been argued that the only ethical way to teach science is through active problem-solving (Waldrop, 2015). Yet, standard lecture is still pervasive in undergraduate science education (Handelsman et al., 2007).

Until recently, lecture was the predominant type of instruction used by the University of Wyoming's interdepartmental Microbiology Program. Most classes focused on delivery of content, and students' learning assessments were based on their recall of isolated "facts." Thus, in 2011 our program received the lowest possible rating in assessment of student learning. We did not have sustained direct assessment of learning objectives. Like many other educators, we agreed that these objectives (see Appendix: Table 1, second column) centered on the ability to solve novel problems within our discipline (Taylor, Smith, van Stolk, & Spiegelman, 2010). Unfortunately, our

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students rarely encountered the opportunity to solve novel problems in their coursework. Others have noted this problem as well (Jonassen, 2000; Taylor et al., 2010).

We needed to shift our instructional design from recall to application. This shift would promote the acquisition of scientific literacy and allow students to be more prepared for real-world environments where problem-solving skills employing multidisciplinary approaches are required (Jonassen, 2000; Simon et al., 2013; Spektor-Levy, Eylon, & Scherz, 2009).

Rationale for the Use of Course-Based, Problem-Based Learning

Despite knowledge that undergraduate research opportunities (UROs) increase student understanding of scientific research and improve their confidence in their lab skills, these opportunities are not accessible to all students. Rates of participation range from 34% to 74% across STEM disciplines and tend to be awarded to students with high grade point averages (Russell, Hancock, & McCullough, 2007). We wanted to develop a high-impact, authentic research course that would eventually service all 25 of our microbiology program seniors. This type of support allows students to safely fail and grow. By using problem-based learning, assessment of learning could be both performance and product based as opposed to only product based. Problem-based learning would evaluate authentic application of knowledge (Gagne, 1985; Spektor-Levy et al., 2009; Wolf, 1993) and allow for errors, feedback, error recognition, and correction (Merrill, 2002).

Learning environments that are authentic/problem-based facilitate acquisition of scientific communication skills (Allen, Donham, & Bernhardt, 2011; Nelson, 1999; Savery & Duffy, 1995). Compared to alternative pedagogies such as lecturing, problem-based learning allows students to solve a problem or perform a whole task, rather than memorize components of a task (Merrill, 2002). These whole tasks may have more than one solution and may require students to defend their solutions (Spektor-Levy et al., 2009). Allen and colleagues (2011) refer to problem-based learning as "a pedagogy of engagement" (p. 26) and review studies supporting this approach (particularly when writing tasks are incorporated) as nurturing of lifelong learning (Smith, Sheppard, Johnson, & Johnson, 2005), motivation, and level of interest (Ahlfeldt, Mehta, & Sellnow, 2005; Butler, Phillman, & Smart, 2001; Gonyea, Anderson, Anson, & Paine, 2010; Murray & Summerlee, 2007). Learners are most likely to take ownership of problems that they care about (Blumenfeld et al., 1991; Jonassen, 1999).

Problem- and Service-Based Learning to Develop a Capstone Course

In a capstone course, students encounter real-life situations (Dunlap, 2005), advance their critical thought, transfer skills, and take greater ownership of their learning. This frees instructors to become mentors/learning coaches (Eppes, Milanovic, & Sweitzer, 2012; Leonard & Marquardt, 2010) and because students participate in a cooperative and democratic learning environment, these courses, particularly when service-based, can be transformative (Gilbert, 2010). Service-based learning allows students to see the social and environmental change made possible by their work and develop a sense of civic responsibility (Simon et al., 2013). These qualities of a capstone course enhance inclusivity of marginalized students (Malcom & Feder, 2016). Finally, the American Society of Microbiology (ASM) recommends that all students graduating from a microbiology degree program should experience a capstone course (Baker, 2016).

The purpose of this report is to share the process of designing, developing, fully piloting, and gaining official course status for a microbiology problem- and service-based capstone course, referred to as the "Microbiology Capstone Course." Our process included multiple stages: course design and establishment of community partner collaborations; assessment of student learning outcomes; assessment of the student and instructor experience; and, finally, the process of using these to inform pedagogical reflective practice. We share our success of obtaining formal support, evidenced by our official course listing in the University catalog.

Description of Practice

Designing the Course and Engaging with the Community

We used Merrill's (2002) First Principles of Instruction to inform our problem-based course design. This model includes four instructional phases: activation of old knowledge, demonstration of skills, application of skills, and integration of skills in real-world activities (Merrill, 2002). The learning was based on problems presented by community partners. Articles by Jonassen (2000) and Jonassen and Hung (2008) allowed us to recognize that these community problems were moderately ill structured. They had multiple possible solutions, various criteria were needed to evaluate them, and each problem necessitated a level of personal judgment to decide on a solution. We modified Merrill's model to become a service-based model centered on a community problem and to integrate the activation and demonstration phases of instruction. Our phases were thus: (1) activation of old knowledge and demonstration of skills, (2) application of skills, and (3) integration of skills in real-world activities (Figure 1). The integration of the activation and demonstration phases of instruction enabled us to move fluidly between reminding students of old skills needed and demonstrating new skills. It also enabled us to put greater relative emphasis on the application phase of instruction. The course syllabus further details our instructional phases throughout the 15-week semester (see http://uwmicrobiologycaptstone.weebly.com).

Community Problems Addressed by Students

During the 2013 pilot semester, we established community partnerships with a Laramie community garden (Our Laramie Gardens) and a community-serving farm called Agricultural Community Resources for Everyday Sustainability (ACRES) student farm. Memorandums of understanding were established (available upon request). Our Laramie Gardens (OLG) and ACRES student farm were experiencing problems related to sustainable local community food production. OLG was struggling with a discrepancy in food production between two of their sites and considering expensive amendments to improve the low-yield site. Students working with OLG set out to characterize the microbial communities, pH, and total usable nitrogen in both amended and unamended test plots from the two sites. ACRES student farm was threatened with termination or relocation because wealthy neighbors had complained about odiferous compost. ACRES collects 840 gallons of food every week and uses finished compost to grow vegetables for food outreach programs; disbanding of the composting program would have deleterious impacts on the community. The student group working with ACRES farm had the task of assessing how aeration and covering of test compost piles would impact microbial activity, water content, pH, temperature, carbon to nitrogen ratios, and the emission of odorous gas.

In the spring 2014 semester, students continued to work with ACRES student farm. Suggestions for changes in ACRES's composting process had begun, but on-site progress had been slow. Thus, we continued our microbiological investigation of compost odor. We also cultivated a new partnership with the Albany County Downtown Clinic (DTC). The DTC is a community-based organization that provides primary and preventative healthcare to uninsured/impoverished residents. As the DTC reported patients with a high incidence of diarrhea, the student group working with this partner investigated antagonistic effects of probiotics on opportunistic pathogens such as *Clostridium difficile*. In the spring 2013 semester, there were six junior and senior microbiology majors and one agroecology major. In the spring of 2014, there were five junior/senior microbiology majors and two senior molecular biology majors.

Structure of the Capstone Course

Community partners presented their problems to the students during the first week of class and the students wrote a formal National Science Foundation (NSF)-style proposal in which they detailed a research study to address the problem. *Writing Successful Science Proposals* by Friedland and Folt (2009) was used to facilitate instruction and iterative writing of proposals. Classroom activities included mini-lectures facilitating proposal writing, critiques of other proposals, and rewriting and revising proposals in groups. The students sent their finalized proposals to the community partners and continuously communicated with their community partners while they worked on-site and in the lab to test their hypotheses (Figure 1). During their lab and fieldwork students kept a detailed lab notebook, and we used *Writing the Laboratory Notebook* by Kanare (1985) to support instruction on lab notebook maintenance. Also during this phase, we held a one-hour weekly lab meeting during which students provided project updates, shared data, and discussed problems. As needed, key concepts were also demonstrated (e.g., the polymerase chain reaction (PCR), a technique to amplify DNA). At the end of the semester, students presented posters communicating their work. Community partners, subject matter experts, other students, family members, and any interested community members attended this event.

In both the 2013 and 2014 pilot semesters, the course design stayed the same. However, in 2014, a grading change was made; in order to express competence in skills and processes versus rank, we used a satisfactory/unsatisfactory (S/U) system instead of a traditional grade system. In 2014, we also hired two peer mentors who had taken the class in the spring of 2013; one was a senior and the other a graduate student. We made this change because during the 2013 semester students had struggled with discomfort in making prompt, daily lab notebook entries and thus peer mentors were included to serve as role models and assist students with lab notebook maintenance. They did consistent checks of student notebooks, encouraging timeliness and quality entries.

Unrequired Presentations at Professional Conferences and to Community Partners

During the 2013 semester, a small group of students traveled with one instructor to the regional American Society for Microbiology Conference. We were fueled by the success of this trip and thus, in 2014, we encouraged students to attend the conference. Three students attended and the two students in the ACRES group presented collaboratively with one student from the 2013 ACRES group. Later in the semester, two students from the ACRES group (along with the instructor) presented "Being a Good Neighbor, Composting Aroma Study" to the Laramie Garden Club. Student representatives from each of the groups (both 2013 and 2014 semesters) co-presented with the instructors at the 2014 Shepard Symposium on Social Justice. The presentation was entitled "Culturing Justice: Students Use Microbiology to Address Community Problems at ACRES Student Farm, Our Laramie Gardens, and the Downtown Clinic."

Assessing Student Learning Objectives

We assessed students' achievement of learning objectives throughout each phase of the course.

Activation and demonstration instructional phase (the NSF-style grant proposal). As students wrote their formal research proposals, we assessed their written communication skills, including their ability to generate hypotheses and write a literature review. Each student submitted one proposal section at a time; the instructor gave feedback and each student then submitted an individual final version. Students then worked together to complete a group version of the proposal, and this was assessed prior to beginning lab and fieldwork. Complete rubrics used can be viewed in the course syllabi and include descriptions of all four marks that students could attain: unsatisfactory, developing, competent, or accomplished (Hooker, 2005). For ease of viewing here, Table 2 (see Appendix) shows each proposal section that was rubric assessed and gives a description of the work needed to reach a competent mark. If students/student groups reached or exceeded this standard, then we considered them to have reached mastery.

Application instructional phase (the laboratory notebook). During the hands-on lab and fieldwork, we assessed lab notebooks for each individual student two times. On the first assessment, we gave only rubric feedback (no grade). At the end of the instructional phase, student notebooks were assessed for a second time and rubric marks were converted to grades. Table 3 (see Appendix) shows each notebook section that was rubric assessed and gives a description of the work needed to reach a competent mark.

Integration instructional phase (the poster presentation). At the final poster presentation, students were assessed on their written and oral communication. In this presentation, students' abilities to apply their findings to a real-world setting and communicate with the community partner were also assessed. Subject matter experts and instructors completed the same rubric evaluating the students' final poster presentations. Table 4 (see Appendix) shows each poster section that was rubric assessed and describes the work needed to reach a competent mark.

Because instructors assessed posters prior to the formal presentations, only subject matter experts (external raters) assessed the delivery categories of the rubric. For assessment of the final poster presentations, three different external raters/subject matter experts assessed the poster assignment. Because this assessment is purely voluntary and because we hope to eventually involve all faculty and affiliates of the microbiology program in this process, we engaged a group of different raters in the 2013 and 2014 semesters. Community partners used a unique rubric to assess the students on their professionalism, ability to find relevant solutions, and communication. Student groups competent in professionalism took their responsibilities seriously and were punctual and courteous. Competence in the communication rubric category was described as explaining scientific concepts at the appropriate level.

Assessing the Student and Instructor Experience/Feelings of Satisfaction

We used Small Group Instructional Diagnoses (SGIDs) to collect student feedback regarding course strengths and areas for improvement. SGIDs are a method that allowed us to glean formative and summative student feedback regarding their course experience (Coffman, 1991). The SGIDs were suggested and facilitated by the director of our center for teaching and learning, whose expertise includes all forms of active and engaged pedagogy. We obtained approval for the SGIDs from the University's institutional review board. We had four SGID sessions: One session was held at the beginning of the semester and the remaining three at the end of each instructional phase (Figure 1).

In the first SGID, students were asked to consider two broad questions: (1) What learning objectives will this capstone course offer that will be unique to your educational experience and prepare you for life after graduation? (2) What concerns do you have about the course? In all subsequent SGIDs, students considered the following two questions: (1) What areas of the course are working well? (2) What suggestions do you have?

During the SGID sessions, both instructors left the room, and the students worked through the questions with the facilitator. After the facilitator collected student consensus, she asked the instructors to return to the room and she debriefed the instructors. This debrief time was used for discussion and reflection.

In addition to SGID sessions, students and the instructor engaged in other means of course evaluation. Students were encouraged to complete the standard teaching evaluations given in all classes at the end of the semester. Finally, the instructor kept a log recording successes, failures, group interaction/dynamics, general class mood, and pivotal learning moments. The primary instructor maintained this log throughout the course but made the most robust entries during the application phase of instruction.

Overall Assessment of Microbiology Program Learning Objectives

In order to holistically show how effective the capstone course was at addressing the overall microbiology program student learning objectives, we aligned the fourteen learning objectives with the assessments and, where pertinent, the specific assignments or rubric categories that addressed the objective (see Appendix: Table 1). For example, learning Objective 2, proposing experimental tests for hypotheses, was assessed by the hypothesis rubric category (see Appendix: Table 2) in the grant proposal assignment. At the end of each semester, we compiled student mastery data from each phase of instruction and averaged the pertinent assignments/rubric categories or assessments. This allowed us to express overall student mastery in our departmental learning objectives and to provide a summative assessment of our graduating microbiology majors. The purpose of these data is not to engage in tests of statistical significance between the two course offerings, but instead, to document student competence, inform instructional decisions, and provide evidence that the capstone course should become a sustainable course offering.

Evidence of Capstone Course Value

In this section, we present evidence that the microbiology capstone course enabled assessment of the course and program learning objectives. We relate students' areas of competency and areas of struggle. Additionally, we review the qualitative data that speak to students' overarching experience, their feelings of satisfaction, and suggestions for improvement. These data allowed us to implement good reflective pedagogical practice, to monitor the impact of instructional changes, and to gain sustainability for the course.

Assessment of Student Learning Objectives

Activation and demonstration instructional phase (the NSF-style grant proposal). Figure 2A provides a visual that allows clear communication of the proposal rubric categories in which students/student groups mastered or struggled to gain competence. On average, individual students showed mastery in only the title, statement of problem significance, and hypotheses. By contrast student groups only lacked competence in writing the detailed portions of the research plan. This was also where individual students struggled most.

From 2013 to 2014, there were some marked changes in mastery (20% difference or more) on a few rubric categories. Individual students and student groups struggled more in writing their abstract/project summary in 2014. However, individual students and student groups improved in writing hypotheses (86% improvement for individual students and 50% improvement for student groups) and References (29% improvement for individual students and 50% improvement for student groups). Student groups improved by 50% in writing the relevant literature section and the analysis of expected results in the research plan. All tabulated data for each category of rubric assessment can be viewed on the course website at http://uwmicrobiologycaptstone.weebly.com/mastery-data.html.

Application instructional phase (the lab notebook). On average, students mastered many sections of the lab notebook: hardware (all categories), legibility, date and running title, marking off unused space, attachment of loose sheets, sign-out page, table of contents, and preface (Figure 2B). In 2014, students additionally mastered timeliness of entry, exterior title, and table of abbreviations. Error correction and writing in an active voice were the only categories in which competence was lost from 2013 to 2014. In both 2013 and 2014, students struggled the most with recording reflections on meetings with service organizations. No students mastered this in either semester. Assessment data for all rubric categories below the community partner reflections are incomplete because students self-assessed in these categories and full records were not retained.

Integration instructional phase (the poster presentation). Instructor assessment. On average, individual students showed high competency on poster design elements: readability, spacing, and flow. They also achieved mastery in writing their acknowledgements. However, on average, individual students struggled on the content portions of the poster, with the area of least competency being the discussion. By contrast, once students formed groups, they achieved mastery in all categories on average with their lowest scores being in the results section (Figure 2C).

From 2013 to 2014, there were some marked changes in individual student mastery (20% difference or more) on all but the introduction, methods, results, discussion, and color rubric categories. The improved sections from 2013 to 2014 were the conclusion (29%), references (43%), readability (43%), spacing (43%), flow (43%); and tables, figures, diagrams, and graphs (29%). Students lost competency in writing the title (43%) and acknowledgements (28%). Student groups showed marked changes on several rubric categories. They lost competency from 2013 to 2014 on the introduction (50%), methods (25%), references (25%); and tables, figures, diagrams, and graphs (50%) categories. They showed improvement on only the conclusions section (25%).

Subject matter expert/external rater assessment. Subject matter experts also rated student groups as being competent in all rubric categories with their lowest mastery marks being in the results and conclusion sections (Figure 2C). These experts also gave qualitative feedback centering on professionalism, investment, and pride taken in the work: "I was impressed with the professionalism the students showed and their ability to understand complex questions—and to provide a detailed, thoughtful response. They [DTC group] were prepared, enthusiastic, and engaging. Excellent work!"

> Overall, I thought that both groups of students did excellent presentations. It is apparent from their enthusiasm that they are proud of their hard work—they certainly took ownership of their research projects and this was reflected in their poster presentations. Much thoughtful work was needed by the students to conceive, design, carry out, and organize their projects into these posters.

Student posters can be viewed on the course website: http://uwmicrobiologycaptstone.weebly.com/student-posters.html

Community partner assessment. In both 2013 and 2014, our community partners from ACRES, Our Laramie Gardens, and the Downtown Clinic rated the student groups as 100% satisfactory in professionalism, ability to find relevant solutions to the problem, and communication of microbiology principles that were pertinent to the problem. Community partners related having been positively impacted by the collaboration. They indicated that the student projects had spurred meaningful discussion within their organizations. One 2013 community partner commented, "These students were a delight and they represented the University and your capstone course very well. I feel fortunate to have had the experience of being a part of this project and working with these three students. . ."

Overall Programmatic Learning Objectives (Table 1)

Students' achievements on particular components of each of the aforementioned assignments throughout the instructional phases were aligned to allow us to understand whether our students (notebooks)/student groups (proposal and poster) were achieving the microbiology program learning objectives. Students showed greater than 50% mastery in all learning objectives except for proposing experimental tests of hypotheses (Objective 3) (see Appendix: Table 1).

Assessment of Student and Instructor Experience/Feelings of Satisfaction

Small Group Instructional Diagnoses (SGIDs). Table 5 (see Appendix) summarizes the SGID emergent themes. In 2013, all students came to a complete consensus on every item. In 2014, the small groups did not reach full consensus, and thus majority opinion was recorded. Themes of increasing confidence, self-direction, and self-reliance were similar in both semesters; in the second SGID in 2013, students stated that the class was "the ideal academic environment." In both semesters, students completed the term with the suggestion that the course be longer, more fully funded, and incorporate even more assessments.

Course evaluations. In both semesters, all students completed the final course evaluation, and Likert scale questions relating student satisfaction were strongly positive (full evaluation available upon request). Student comments were prevalent in both semesters. The comments below speak to engagement, investment, confidence, and feelings of playing an active role in their learning:

> This was by far the most well-taught, stimulating, and most challenging course that I have taken at UW [University of Wyoming]. . . . The unique aspect of applying knowledge to solve community problems was central to this class and enhanced learning in many ways, as I not only learned lots of "textbook" knowledge, but I also learned volumes about real-world problem solving, communication skills, and working as part of a team (2013).

> . . . This class not only exposed me to what independent self-designed research could be like but it also gave me the confidence to know how to approach these sorts of tasks in the future. Before this course I was unsure what I wanted to do in the future, but now I know that I have not only the skills but the mentality to go through graduate school to pursue a career in research. . . . If possible I wish everyone could have the opportunity to experience a class like this one (2014).

Other comments speak to the way in which class activities enhanced students' feelings of connection to the greater world of science: "I thought that the ASM meeting was critical to adding to capstone an element of integration into the worlds of other schools and research projects." Additionally, students related the importance of the community connection: "The fact that my learning and my efforts in this course will directly benefit the Laramie community made this experience so real, and it took education to a whole new level. Problem solving, hands-on work, creating our own lab manual and methods, and leading our own research was the most worthwhile experience." Few student comments expressed suggestion for change:

> I would have liked to see improvements in group collaboration amongst students. I know this responsibility

> lies on us but time to interact with one another via discussion, team building, [and] social interaction might be advantageous to beginning a full semester of learning closely with one another.

Closing the Circle: Use of Course Assessment to Promote Reflective Practice

Designing and implementing a capstone course in which student learning objectives and student and instructor experience were both formatively and summatively collected enabled the course instructors and the microbiology program as a whole to engage in reflective practice. In this section, we describe how we used our assessment data to make course changes and large systemic change in the program and University curriculum.

Assessing Student Learning Objectives

*Interpreting the assessment from the activation and demonstration instructional phase (the NSF-style grant proposal).*The writing of an NSF-style grant proposal during the activation phase of instruction enabled a baseline assessment of students' incoming skills and process knowledge. The fact that individual student proposals showed mastery in a minority of proposal rubric categories indicated that students did not enter this course with proposal writing skills. In fact, even areas of greatest individual prowess (the statement of problem/significance and title) were areas in which iterative feedback and practice were allowed in the capstone course itself. Thus, strength in these areas is more of a testament to the iterative process in which there is room for error, feedback, error recognition, and correction (Merrill, 2002). This likely also accounts for an improvement in hypothesis writing from 2013 to 2014. In 2014, more in-class time was devoted to practice in hypothesis writing and thus students benefitted from more iterations.

The students' areas of greatest struggle on individual proposal submissions (specific aims, research plan, and justification of research methods) and also on group submissions (specific aims, materials and methods, analysis of expected results, and justification of methods) are mostly areas requiring advanced synthetic thought (Bloom, Engelhart, Furst, Hill, & Krathwohl, 1956). In fact, some educational researchers argue that synthesis (creating a plan) is the most difficult skill (Anderson & Krathwohl, 2001). Additionally, flaws in methodology are cited as one of the most common issues in unfunded NSF proposals written by experienced scientists (Friedland & Folt, 2009).

Students' struggles in the area of planning methodology translates to the overall program learning objectives, the lowest mastery overall being seen on Objective 3, proposing experimental tests of hypotheses. However, students' full mastery of Objective 12, their ability to establish broad significance, agrees with a central premise of problem-based learning: students gain an understanding of the social change made possible by their work (Simon et al., 2013).

Engaging in reflective practice based on the assessment from the activation and demonstration instructional phase (the NSF-style grant proposal). As we have continued to teach the capstone course in subsequent semesters, the above considerations have motivated us, as instructors, to highly value iterative feedback and to unapologetically use class time to allow students to practice assessing their own and their peer's writing. We are gradually shifting the course syllabus to enable greater time spent on writing the research plan. As a microbiology program, we have learned that courses that come earlier in the curriculum need to gradually be restructured to become more active and inquiry-based so as to promote higher levels of critical thought. In fact, General Microbiology has now been restructured to be entirely active.

Interpreting the assessment from the application instructional phase (the laboratory notebook). Assessment of the laboratory notebook showed that students struggled with the type of active, reflective writing that is afforded by this medium. We speculate that this may derive from the focus of many science courses on objective, passive writing (Kanare, 1985; Roy, 2004). Most assessment is confined to formal lab write-ups and these documents are expected to be highly polished. During both semesters, the instructors spent many hours working with students one-on-one during the application phase of instruction. Many anecdotes reflect student discomfort in using the laboratory notebook as a messy, active thinkpad. The following is an exemplary passage from the instructor's log:

> [Students] continue to want to write in another notebook and then transfer [to the lab notebook]. They don't want anything to be messy, amiss, or less than thorough. [A student] says it's the scariest but coolest thing that we have done because she wants to be absolutely sure that someone could repeat their work.

The integration of peer mentors in the 2014 course is thought to be responsible for the students' improvements on the notebook as a whole and expressly in the timeliness of their entries. However, the large decrease from 2013 to 2014 in good active writing was unintended. A differing focus of peer mentors versus instructor may account for this change.

As the primary value of a notebook is in producing a resource that promotes reflection and guides future work, we considered students' self-assessment of their notebook content to be the best type of assessment. However, due to students' disparate ways and timeliness of submitting self-assessment, the organizational recordkeeping of this effort was difficult.

The complete lack of notebook reflection on meetings with community partners in both semesters may be a product of the aforementioned discomfort with writing in a reflective, journaling style. Additionally, it may be that because the first meeting with the community partner occurred before full notebook keeping skills had been learned, students struggled to go back to earlier notes and transfer these community interactions into the notebook.

Engaging in reflective practice based on the assessment from the application instructional phase (the laboratory notebook). As we have learned from students' struggles with writing in the active voice, we have provided students with more lab notebook examples to assess in the activation phase of instruction. This is done immediately after displaying and explaining examples and nonexamples together as a class. While the integration of peer mentors seemed to improve timeliness of entry, the lack of overall improvement from 2013 to 2014 coupled with the novice focus of peer mentors caused us not to continue this practice. Instead, the primary instructor now assesses the lab notebook at regular intervals and gives both written and oral feedback. In order to encourage careful recording of interactions with community partners, students are asked to use their lab notebook to literally take notes during community partner communications rather than as a reflective activity. We ask them to write free-form and be messy. Programmatically, lab notebooking skills have been more formally integrated into the prerequisite general microbiology course with the intention of providing exposure to these skills and processes very early in microbiology major's curriculum.

Interpreting the assessment from the integration instructional phase (the poster). Individual student submissions of poster drafts indicated that overall students did not enter the capstone course with skills in writing/designing an effective poster. No clear competencies were displayed and students struggled to synthesize a meaningful discussion and conclusion section. The vast improvements seen in these two sections once students submitted a group poster may represent the greater relative value of teamwork when synthesizing connections. Less of a relative improvement was seen from the individual drafts to the group posters in the results section. This may make sense because achievement on the results section is limited by the effectivity of the lab work.

Overall, external subject matter experts rated students as having mastered all categories of the poster rubric, and their comments support touted outcomes of problem-based learning. They repeatedly noted students' high level of engagement and ownership of and pride in their work (Blumenfeld et al., 1991; Jonassen, 1999). External raters were, in fact, less critical of students than were instructors. This is likely due to the increased awareness that instructors had of both process and product; external raters only saw the finished exhibit. Decreases (from 2013 to 2014) in overall mastery on both this assignment and the proposal may have been due to cohesion struggles within the DTC group, problem difficulty, or the change to S/U grading.

Engaging in reflective practice based on the assessment from the integration instructional phase (the poster). While the increased mastery of student groups compared to individual students may seem like an obvious and anticipated outcome, this is something that we have deeply considered. We see these gains as being greater than the sum of the parts. That is, with the process of both individual and group iterative feedback and in-class activities structured around facilitating students' appreciation for other students' unique abilities to contribute, we feel that we see an effect in addition to the effect of simple collaboration. In future capstone semesters, we have worked to strengthen this component of the course.

While some students continued to prioritize the capstone course with the change to S/U grading, this was not universal. Despite our hope the course would focus on skill/process competence, in following semesters we returned to a traditional grading system.

Engaging in reflective practice regarding the complexity and structuredness of the problems. In continuing to support students in effective problem solving, we have considered the difficulty of the problems with which they are faced. Jonassen and Hung (2008) remind us that assessing problem complexity and structuredness is essential in selecting problems that are amenable to problem-based learning. As solutions to problems vary in intricacy of the problem-solving procedure and the relational complexity, which can be viewed as the number and configuration of necessary steps to solve a problem (Jonassen & Hung, 2008), these factors should be weighed by us as instructors when we are vetting potential community partners and/or problems for the student projects.

Moderately ill-structured problems, such as those encountered in our course, are most amenable to problem-based learning. However, we have realized that certain parameters of complexity and structure within our problems can be more adequately investigated. The problems addressed by our capstone students require great breadth of domain knowledge. In some cases, this domain knowledge is difficult to reactivate and thus we have added structure to our activation phase of instruction to better support the seamless use of domain skills (e.g., basic bacteriology and dilution calculation).

Additionally, while the writing of the grant proposal—complete with timeline—alleviates cognitive load and addresses burdens associated with addressing the intricacy of problem-solution procedures and the relational complexity, the level of structure associated with our varying problems has not been consistent. That is, problems that students have taken on at the Downtown Clinic have had a very high degree of intransparency compared to the other problems (e.g., ACRES, Our Laramie Gardens). The problem at the Downtown Clinic is presented to the students as simply chronic disease that is inevitable in the face of poverty. The students are left to sort out how this relates to microbiology, and while we try to add structure, some moments of great uncertainty are inevitable. Further, the heterogeneity of interpretations for the DTC group is also higher and thus less structured. Thus, these factors may account for the aforementioned slight decrease in mastery within the DTC group. In the current semester, we have added structure to this problem by providing both students and the community partner with coaching prior to the first meeting.

Engaging in reflective practice informed by the overall assessment of the Microbiology Program. While the poster assignment, in conjunction with the research proposal, enabled us to fully document students' abilities to write a pertinent literature review (learning Objective 1, partial), both failed to assess students' process of accessing and assessing literature. The rubric has already been adjusted for this oversight, and in the current semester students are assessed for their ability to access and assess literature through rich site summary (RSS) feeds, libraries, and other databases. The relative struggle that individual students had on poster draft discussion sections seemed to be remedied by team and iterative efforts; thus, it seems that learning Outcome 5, while clearly a difficult skill, is achieved through collaboration and feedback. Learning Outcome 6, because it is addressed by all three major assignments, speaks highly to overall student learning assessment enabled by the course. When considered in conjunction with learning Outcome 11, it seems that capstone students gleaned the communication skills that are so touted as important to the job opportunities of undergraduates (Crawford, Lang, Fink, Dalton, & Dielitz, 2011). Our combined assessment data have enabled us to confirm that our microbiology majors are achieving a majority of the microbiology program outcomes, and as discussed above reflective practice is enabling us to improve our course and program pedagogies to address deficiencies.

Engaging in Reflective Practice Guided by Student and Instructor Experience/Feelings of Satisfaction

SGIDs. In the first session (SGID1), students showed that they knew that they would need soft skills (problem-solving, self-motivation, and communication) if they were to be successful in a work environment. In fact, even when the students expressed their concerns about the class, they indicated they knew that teamwork and time management (part of the teamwork and self-management soft skill clusters respectively) (Crawford et al., 2011), while important in future work environments, were not skills in which they had much confidence. Students also recognized the value of performing a "whole task" (Merrill, 2002) in their commentary relating that capstone represented "the first time they would work on a problem from beginning to end."

By SGID2, the themes of increasing confidence and independence show that students had come to view the instructor as a mentor/learning coach (Eppes et al., 2012; Leonard & Marquardt, 2010) rather than as the sole center of information. They guided our facilitation by relating areas where we provided adequate facilitation and also areas in which more resources might be helpful. In spring of 2013, by the second SGID, students' agreement that they cared more about what they were doing because they were working with the community echoes earlier research in relating increased engagement in learning when learning is problem based (Ahlfeldt et al., 2005; Allen et al., 2011; Butler et al., 2001; Gonyea et al., 2010; Murray & Summerlee, 2007).

In spring of 2014, in SGID3, students' feelings of increased meaning in their research due to community impact show an evolving sense of civic responsibility (Simon et al., 2013). With this seems to have come confidence in soft skills (communication, teamwork, and self-management) and an ability to take ownership of their research (Blumenfeld et al., 1991). The overt theme of wanting more (more lab time, more on-site time, more funding, more tutorials) is a testament to increased engagement through problem-based instruction. When students are driven by a meaningful and applied problem, rather than watching the clock waiting for class to end, they wish for a time-turner to allow them to accomplish more!

Also in the fourth SGID, students' approval of the poster as a culminating activity in addition to student praise of the iterative approach (individual submission—feedback—group work—group submission) affirmed course design. Most importantly, the continuous SGIDs enabled us to see student appreciation of the very real impact that science could make and to monitor the often-intangible learning outcome of understanding science as a means to make change. Themes of change in knowledge perception seem to prevail and echo other researchers' findings that problem-based learning nurtures metacognitive development (Downing, Kwong, Chan, Lam, & Downing, 2009).

The success of using SGIDs as formative course assessment and to track students' development has caused us to continue this practice through the current semester. Additionally, we have responded to the "more" theme by increasing course credit hours and beginning the course during the summer using an online course shell. To address the concern about resources, we have outfitted a small lab that is equipped with basic research lab supplies. Finally, we have found that familiarity with SGID themes has allowed us to be better learning coaches because we better understand prior student experience.

Student course evaluations and the instructor's log. It was the transformational nature, touted by others (Dunlap, 2005), of problem-based learning that seemed to stand out in students' course evaluations. Nearly every comment related a feeling of independence: increased ability to act, to "be in the driver's seat," to see through one's goals. Students iterated feelings of accountability, experience, independence, inspiration, motivation, and readiness.

We compared the themes from students' course evaluations to those related in the instructor's log: group cohesion, independence, confidence, and balance of ownership. The additional theme that appeared in the instructor's log was one of empathy. The kind of tight-knit cohesion seen indicates increased appreciation for group members' experiences and echoes Dunlap's (2005) testaments. The instructor's log states this:

> Perhaps the most striking thing for me is the immense need just to talk/just to have time to talk . . . about life and future . . . I have seen such a tight-knit group form this semester that it makes me think I have been missing something for my twelve years as an educator.

While the reiterated theme (both in SGIDs and course evaluations) is that the community connection makes the research meaningful, it seems that this tells only the beginning of the story. After establishing these bidirectional community relationships and upon completion of the capstone course, both student and instructor community relationships have flourished. The instructor has continued to give community presentations on topics ranging from composting to greywater. At least one student went on to a summer job with ACRES and several to volunteer at the Downtown Clinic. This certainly seems a testament to this type of course facilitating lifelong learning (Smith et al., 2005).

Barriers and Successes

To garner programmatic support, it was paramount that we in the microbiology program find an authentic way to assess our students' mastery of the skills and processes essential for their eventual career success. The microbiology capstone course has provided an environment in which this was accomplished. However, we had to overcome many barriers to get this course officially listed in the course catalogue.

The problem-based, service-based nature of the course was perceived by some faculty in the home department of the first two authors as counter to the department's basic science focus. We had to overcome this barrier and did so through the careful collection of evidence (that has been reported herein) showing that students were achieving the learning objectives and were reporting high satisfaction/transformative learning in course evaluations. These data also allowed us to write a very strong justification for our course to be listed as a broad university studies requirement. This gave the course a stable course listing, university support, and thus, the sustainability to become a microbiology program required course. It also allowed the program to be moved to the highest tier status by University assessment coordinators. While these are overt and measurable successes of the capstone course, we believe that the most important stride is in buoying student confidence and eventual professional success. We hope that this article will help readers who may be struggling to get meaningful, problem-based courses to be recognized and supported by their institutions.

Next Steps

While we have continued to stably offer the capstone course and changes informed by our reflective practice have affected this course design and instruction, we are only in the nascent stages of vertical alignment of our assessment. Evolution of the general microbiology course has been informed by capstone outcomes, as noted above. However, we have not yet garnered any data to allow us to track microbiology skill and process outcomes throughout the curriculum. We hope to do this in the future and have begun to be able to offer resources that will enable this.

The primary author of this paper also directs a new legislatively funded faculty development program. This program, called the Learning Actively Mentoring Program (LAMP) is an immersive, year-long faculty training and support program. Faculty and graduate student fellows in this program receive stipends and are supported in the development and implementation of evidence-based, active curriculum such as problem-based learning. In the current cohort of fellows, the graduate student and faculty member supporting a junior-level microbiology requirement (pathogenic microbiology) are being trained. They are working to incorporate certain aligned assessments into the pathogenic microbiology course and, with time, this, along with changes in the entry-level course (general microbiology) will allow us to both address missing competencies prior to capstone and allow us to assess the vertical acquisition of the Microbiology Program Learning Outcomes. We would also like to broaden our vertical assessment in the opposite direction; we believe that tracking our capstone alumni (perhaps with interviews, surveys, and observations) will allow us to more authentically understand the impacts of the course.

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Appendix

Table 1. Microbiology skill- and process-based learning objectives; assignments in the capstone course that assess these objectives and mastery of them over two semesters. The lab notebooks were assessed individually (*N* = 14) and for other assessments, group competence was used (*N* = 4).

Learning Objective	Upon successfully completing a microbiology degree, learners will be able to	Capstone course assessment addressing this learning objective	Assignment section/ rubric category specifically assessing this objective	Percent masterya over two semesters (2013 and 2014) on all rubric categories specifically assessing objective
1	perform a thorough overview of a topic (access and assess literature)	The NSF-Style Grant Proposal and the Poster Presentation	*Relevant Literature* in Research Proposal Rubric and *Introduction* in Poster Rubric	81
2	formulate/propose hypotheses	The NSF-Style Grant Proposal	*Hypothesis* in Research Proposal Rubric	75
3	propose experimental tests of hypotheses	The NSF-Style Grant Proposal	*Research Plan Overview and Materials and Methods* in Research Proposal Rubric	50
4	apply appropriate experimental methods to test hypotheses	The Laboratory Notebook	*Discussion of Results: Hypothesis Addressed* in Laboratory Notebook Rubric	Students self-assessed in this category and full records were not retained
5	make and interpret observations/data and relate them to hypotheses	The Laboratory Notebook and the Poster Presentation	*Raw Data, Observations, and Interpretation* in Laboratory Notebook Rubric and *Discussion* in Poster Rubric	81.25 (Poster Discussion only)
6	present, write, and converse using the vocabulary of the field	The NSF-Style Grant Proposal, the Laboratory Notebook, and the Poster Presentation	ALL categories in Research Proposal, Laboratory Notebook, and Poster Rubrics	80
7	communicate important microbiological principles with individuals outside of the microbiology discipline (e.g., within the community or within a stakeholder organization)	Community Partner Communications	*Communication* in Community Partner Rubric	100

Table 1., cont'd.

Table 1., cont'd.

Learning Objective	Upon successfully completing a microbiology degree, learners will be able to	Capstone course assessment addressing this learning objective	Assignment section/ rubric category specifically assessing this objective	Percent masterya over two semesters (2013 and 2014) on all rubric categories specifically assessing objective
8	relate (recognize the relevance of) microbiology concepts to the unique (community or stakeholder) problem	Community Partner Communications	*Relevance* in Community Partner Rubric	100
9	write a scientific research proposal, notebook, and abstract	The NSF-Style Grant Proposal and the Laboratory Notebook	ALL categories in Research Proposal and Laboratory Notebook Rubrics	71
10	understand when and how to reference source material and recognize this process as an important part of communicating with other scholars	The NSF-Style Grant Proposal and the Poster Presentation	*References* in Research Proposal Rubric and *References* in Poster Rubric	88
11	write, converse, and present clearly and thoroughly about microbiological principles/findings	The Laboratory Notebook and the Poster Presentation	ALL categories in Laboratory Notebook and Poster Rubrics	83
12	relate (recognize the relevance of) microbiology concepts to other disciplines and society	The NSF-Style Grant Proposal	*Problem and Significance* in Research Proposal Rubric	100
13	understand the social ramifications/ perceptions, applications, and implications of scientific actions/studies	SGIDs and NSF-Style Grant Proposal	*Problem and Significance* in Research Proposal Rubric	100
14	value scientific knowledge as a tool to enact change (be aware of limits and inherent responsibility)	SGIDs	N/A	see qualitative results

[a]*Note*. Mastery is defined as either "competent" or "accomplished" marks or as "satisfactory" on the community partner evaluations.

Table 2. Rubric categories used to assess the NSF-style grant proposal (activation and demonstration phase of instruction) and a description of the work needed to reach a competent mark. If students/student groups reached or exceeded this standard, then we considered them to have reached mastery.

Proposal Section	Description of work needed to reach a competent mark
Title	Title summarizes the proposal content. It is appropriate and accurate.
Abstract/Project Summary	Justification for the research is included. Hypotheses, objectives, and context are stated. Techniques, study site, and organisms to be used are outlined. Projected results and significance/relevance are also introduced.
Statement of Problem Significance	The problem is described. Broad and discipline-specific interest is established. Funneling is used to lead to the specific aims. The reader understands why the research might be important and can adequately understand predicted impact.
Introduction: Relevant Literature	Background literature is pertinent and adequate (most are peer-reviewed and recent/others are appropriate). Effort is made to competently introduce pivotal references. Holes in literature are adequately elucidated and contentious issues are discussed from both/all sides.
Introduction: Preliminary Data	If preliminary data have been collected, they are presented. Effort is made to show how these data pertain to the proposed research.
Introduction: Conceptual model	A visual schematic adequately elucidates how the research fits into the big picture.
Introduction: Justification of Methods	A sufficient justification is included for all methods. Novel methods are adequately described and citations are included for established methods.
Objectives	A broad, far-reaching statement is given. It adequately presents relevance in a more focused way than the significance section.
Hypotheses	Hypothesis/es is/are testable, grounded, has/have appropriate scope, and is/are clear.
Specific Aims	Specific aims are adequately stated and focus on that which is needed to fulfill the aim or the predicted output of the aim.
Research Plan: Overview	The overview presents an adequate road map of the research and is consistent with the significance, objectives, aims, and hypotheses. The approach is justified.
Research Plan: Materials and Methods	Methods are feasible and will allow for the objectives to be achieved. Methods are sufficiently described and citations are included where needed. All of the following are presented: (1) sampling procedures/population/context; (2) culturing methods; (3) experimental protocols (procedures)/methodological steps/instruments used.
Research Plan: Data Collection and Analysis	Data collection, analysis, and storage are adequately described. Both expected and unexpected data are considered.
Research Plan Analysis of Expected Results	Interpretation of results is adequately discussed. Expected and unexpected results are considered. A helpful diagram/schematic may clarify.
Timeline	Timeline is reasonable, considers need for equipment scheduling, time required for sampling, culture growth, etc. . . .
References	References are primarily recent, peer-reviewed, and accurately cited with names of all authors (in the same order as they are listed on the actual publication), article title, journal/book title, volume number, page numbers, and year of publication (URL where appropriate).

Table 3. Rubric categories used to assess the laboratory notebook (application phase of instruction) and a description of the work needed to reach a competent mark. If students/student groups reached or exceeded this standard, then we considered them to have reached mastery.

Notebook Section	Description of work needed to reach a competent mark
Hardware: Notebook	Notebook is bound, durable, and has serially numbered pages.
Hardware: The Pen	Writing is done with a permanent, black, ballpoint pen.
Hardware: Storage	Notebook is locked, safe, and at standard temperature and humidity.
Writing and Maintaining: Timeliness of Entry	Entries are made immediately after performing the work.
Writing and Maintaining: Legibility	All entries are legible/numbers and symbols are unambiguous.
Writing and Maintaining: Error Correction	All errors are crossed out with a single line and initialed.
Writing and Maintaining: Active Voice	Entries are made in the active voice, thus making it very clear who did the work.
Writing and Maintaining: Date and Running Title	All pages are clearly and appropriately dated and have a running title.
Writing and Maintaining: Unused Space	All unused space is both X'd-out and initialed.
Writing and Maintaining: Attaching Loose Sheets	Loose sheets are pasted into the notebook using high-quality glue or mending tape. These attachments are dated and initialed.
Front Matter: Exterior Title	Project title is clearly/visibly written on the front and the spine.
Front Matter: Sign-Out Page	Includes the date the notebook was purchased, by whom, and a short description of the purpose of the notebook.
Front Matter: Table of Contents	A clear table that gives page number and subject matter for each experiment/ pertinent section in the notebook.
Front Matter: Preface	Identifies researcher, coworkers (project partners), goal of research, and context.
Front Matter: Table of Abbreviations	All commonly used abbreviations are defined.
Reflections on Meetings with Service Organizations	Reflections are included for each meeting with the service organization and each category of self-assessment is appropriately addressed.
Introduction: Distinguishing New Experiments	Each experiment begins on a new page; is dated and titled.
Introduction: Statement of Goals	Goals/purposes/objectives/hypotheses and specific aims are sufficiently stated.
Introduction: Literature Review	Pertinent literature is sufficiently noted.
Introduction: Benefits of Experiment	Benefits of the experiment are sufficiently noted.
Experimental Plan: Description of Procedure	Experimental procedure is fully described (using flow-charts, lists, or outlines where needed). It would be possible for someone to use this plan to repeat the work. All details are included.
Experimental Plan: Safety Concerns and MSDS Properties	Safety concerns are sufficiently addressed as are properties of pertinent substances/chemicals.

Table 3., cont'd.

Table 3., cont'd.

Notebook Section	Description of work needed to reach a competent mark
Observations and Data: Raw Data	All raw data is accurately recorded.
Observations and Data: Observations	Observations are accurately recorded using first person narrative.
Discussion of Results: Interpretation	Raw data are sufficiently summarized in the form of charts, tables, calculations, or ramblings wherever appropriate.
Discussion of Results: Used to Understand Data	Discussion is used sufficiently to understand data, not to recapitulate.
Discussion of Results: Hypothesis Addressed	Hypothesis/es are sufficiently addressed.
Conclusions: Accomplishments	The accomplishments are adequately described. It is very clear whether the goal/s was/were accomplished. It is clear as to whether the hypothesis was supported/ rejected.
Conclusions: Future Changes	Discussion of what should be done differently next time is sufficient.
Conclusions: Novel Ideas	Novel ideas stimulated by the experiment are summarized.

Table 4. Rubric categories used to assess the poster presentation (integration phase of instruction) and a description of the work needed to reach a competent mark. If students/student groups reached or exceeded this standard, then we considered them to have reached mastery.

Poster (Presentation) Section	Description of work needed to reach a competent mark
Title	The title adequately but not elegantly summarizes the research and reflects the findings.
Introduction	Literature overview is adequate; key/pivotal sources are included. Justification is complete. Problem and significance are stated. Reader understands the lead-in to objectives, hypotheses, and specific aims.
Methods	Provides an adequate description of how the data were derived/collected/analyzed. Novel methods are clearly described.
Results	Data adequately convey the central poster message/s. Figures/tables/graphs can be independently interpreted and flanking text is kept to a minimum.
Discussion	Sufficient discussion connects the findings to the introduction and literature. The objectives/hypotheses are addressed. Impacts and contributions of the research are considered.
Conclusion/s	Outcomes are adequately stated and are based on data. Further research is suggested.
Acknowledgments	Funding sources and individuals/entities (all significant contributors) are acknowledged.
References	An adequate list of key references is included in the Vancouver style.
Readability	The poster can be read comfortably from 1 meter away; the title can be read from 5 to 10 meters away.
Color	Colors are used to highlight and add contrast but are not overdone.
Spacing	White space is effectively used. Approximately 50% of the space is white.
Flow	The poster has either consistent vertical or horizontal flow.
Tables, figures, diagrams, graphs	Visuals are adequate. Graphs relate one message and are labeled. Tables have no more than 20 rows/columns. Graphs are limited to three lines/six bars. Photographs seem to support central message.
Delivery: Engagement	Presenters consider their audience, maintain eye contact, and dress to fit the function. They try to ask for questions, pay attention to non-verbal communication, and try to invite bidirectional conversation.
Delivery: Content	Presenters adequately communicate (1) why the work was done, (2) how it was done, (3) what was found, and (4) what it means. They say what they are going to say, say it, and say what they have said.

Table 5. Small Group Instructional Diagnosis (SGID) synopsis.

SGID	Unique learning objective (SGID1)/Areas of the course working well (SGID2–4)	Concerns (SGID1)/Suggestions (SGID2–4)
#1 (2013)	working as a team; applying knowledge in a practical manner; developing problem-solving skills, self-direction, and self-motivation; working on a problem from start to finish [indicated that this was the first time in their college career that they had had this opportunity]; discovering whether they wished to continue in microbiology	group dynamics, time management, and inability to solve the community problem
#1 (2014)	approaching scientific experimentation from a "real-life" perspective rather than "cookbook/recipe" approach, learning professional communication and systematic lab note-taking/report-writing skills	project pacing and time management
#2 (2013)	small class size, group dynamics and flexibility, working with community made them care about learning, "hands on" experience of writing grant proposals, and start to finish engagement in project	more guidance on lab time-management, a more extensive discussion of literature research, more funding to enable the class to continue
#2 (2014)	transfer and apply academic knowledge and skills to real-world issues, planning their own research project and managing their own time, increased confidence with lab procedures (including writing), and being able to ask questions and receive clarification	suggested that groups be formed earlier in the semester, that more discussion of ideas precede the submission of finalized proposals, that instructors do more probing about their intended plans
#3 (2013)	group dynamics, communication from instructor and instructor's pre-planning, course was encouraging self-direction	more time scheduled for lab work, more timely instructor input, more guidance on lab notebooks and more funding for
#3 (2014)	being able to design and "own" their research projects and carry out meaningful projects due to the emphasis on community, small student:teacher ratios and keeping proper notebooks	two semesters needed, "not enough time" to fix mistakes
#4 (2013)	poster construction, individual submission/feedback/final group submission format, in-class work time and EXCEL tutorial	more homework assignments that would allow them to practice data interpretation, wanted the course to be two semesters long
#4 (2014)	poster construction, opportunity to present at the regional ASM Conference	more time practicing oral presentation skills (perhaps of scientific papers), wanted the course to be two semesters long

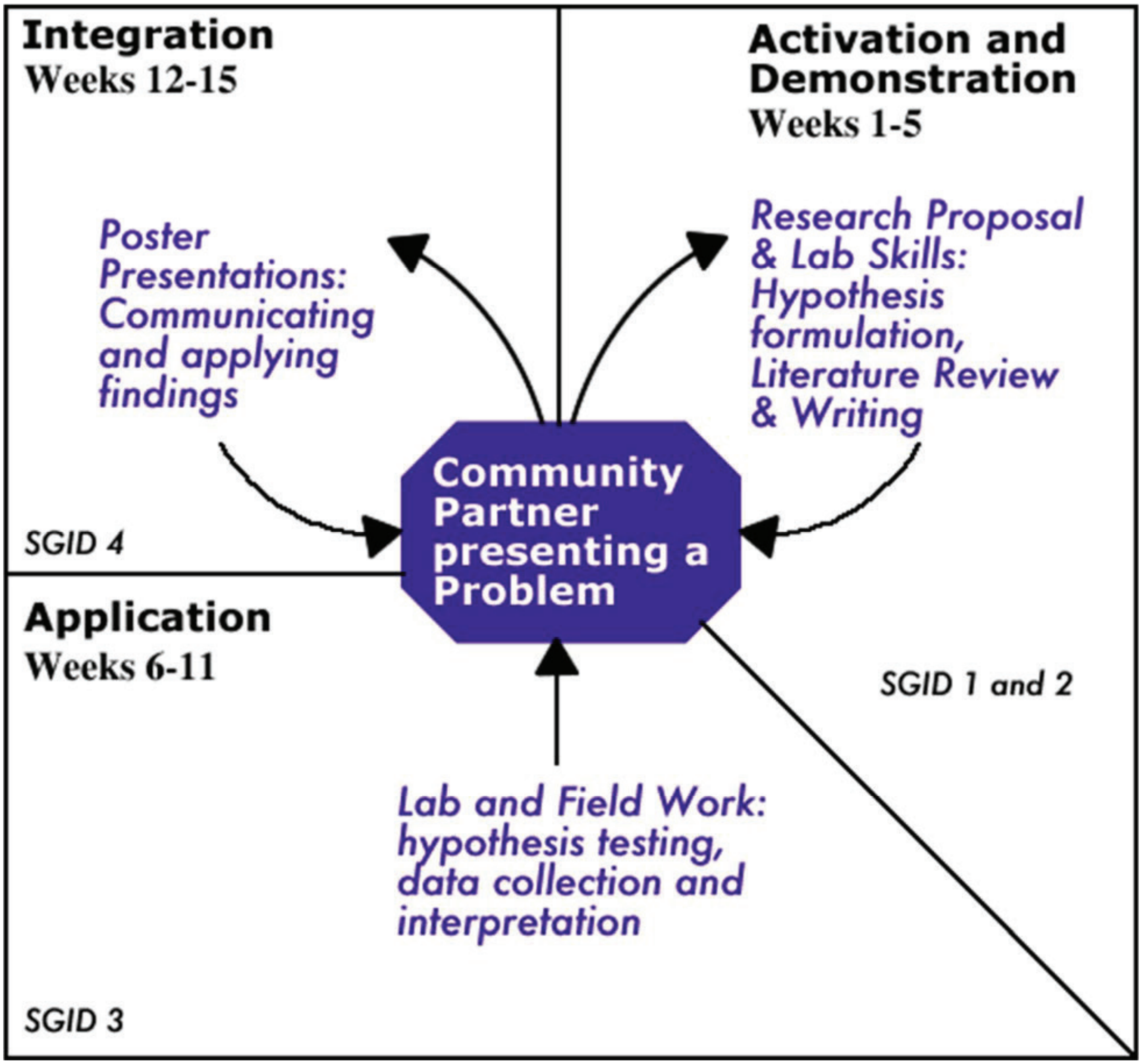
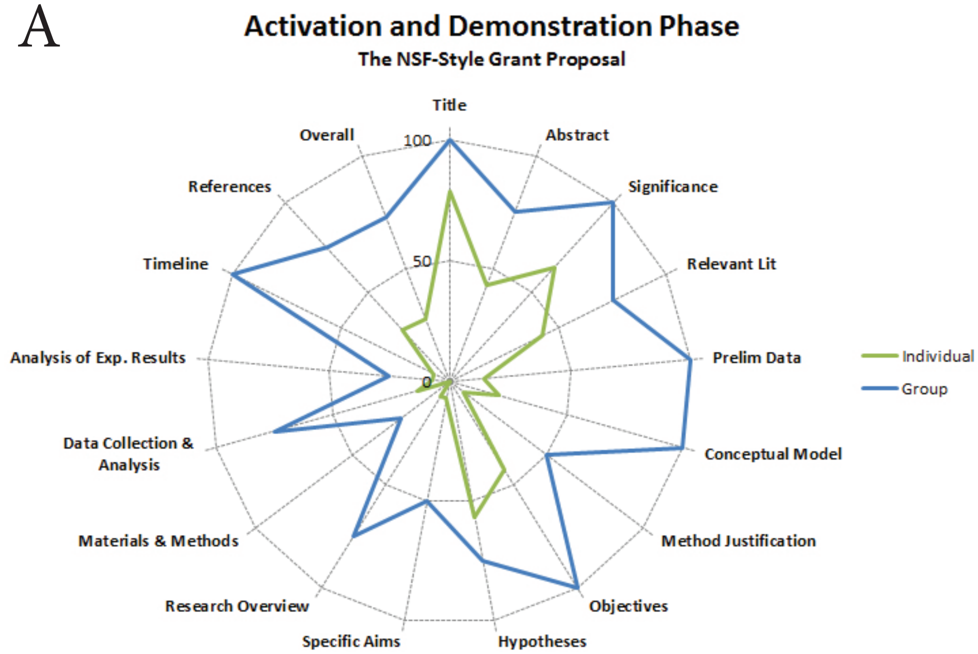


Figure 1. Phases of instruction (adapted from Merrill's First Principles model) indicates objectives, activities, and the role of the communicator (arrows) throughout each course component. As with Merrill's original model, this model begins with activation (upper right) and reads clockwise but shows fluidity between phases as needed to address the problem.

Figure 2. A visual depiction of student competency showing percent mastery for each rubric category on the radial axis. A: The NSF-style grant proposal with instructor-graded averages of individual student submissions and final group submissions. B: The lab notebook with instructor-graded averages of individual submissions by year. C: The poster presentation with instructor-graded averages on individual student submissions and final group submissions along with external subject matter expert averages of final group submissions.

A



B

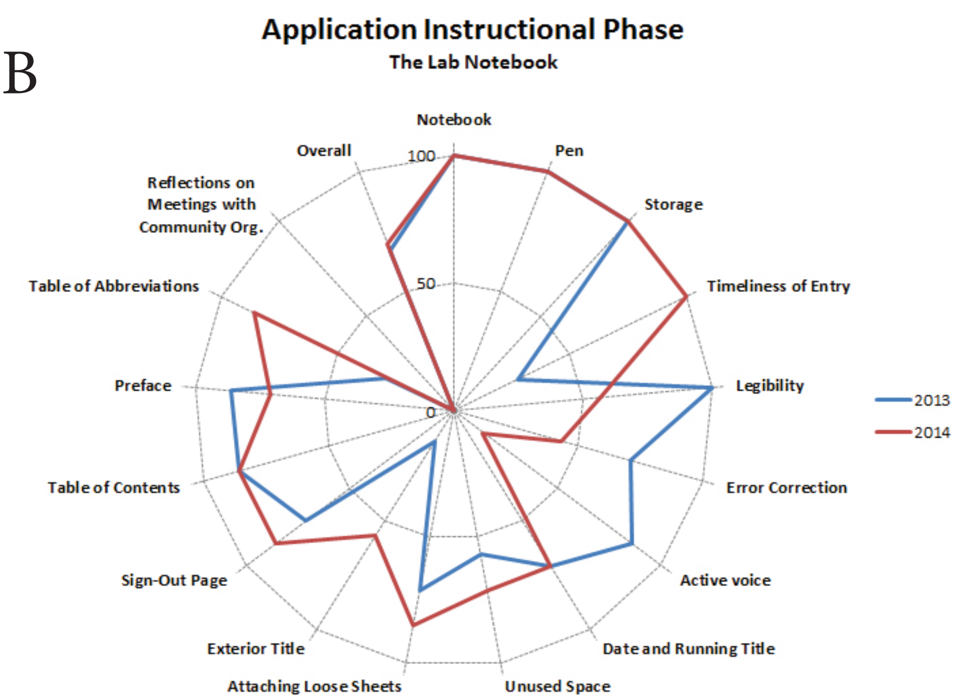


Figure 2., cont'd.

Figure 2., contd.

C