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Scaffolding STEM Literacy Assignments To Build Greater Competence in Microbiology Courses

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INTRODUCTION

The goal of developing improved pedagogy to address undergraduate science, technology, engineering, and math (STEM) literacy development is well-acknowledged, but the methodology and implementation to apply such lessons can be daunting. Varied definitions of STEM literacy add to the need for clearly defined goals and deliverables for students and faculty (1). Ultimately, STEM literacy is the ability to effectively read current scientific literature, develop studies, interpret research results, and clearly communicate scientific findings and theories. Initial benchmarks for literacy gains include familiarity with literacy tasks and ability to successfully present scientific findings and analyses. Course-based undergraduate research experiences (CUREs) provide multiple avenues to facilitate STEM literacy skills (2, 3) and self-efficacy (4) through a series of research and writing tasks. Ongoing research surveys of upper-level (third and fourth year) students in microbiology CUREs report a wide-ranging of familiarity with literacy-oriented tasks, indicating a need for early and continued reinforcement of literacy-based curricula as well as further study (unpublished data [IRB H19106]). Such familiarity may be related to prior exposure to scientific literature and research but is generally unknown, as students taking the CUREs have varied academic backgrounds beyond a prerequisite microbiology course.

Microbiology courses at Georgia State University are highly varied for content (lower-level [first or second year] to upper-level [third or fourth year] majors and nonmajors courses), size (18 to 120 students), and modality (fully remote, hybrid, and fully in-person). Such diversity offers the opportunity to use multiple approaches for developing STEM literacy skills wherein individual tasks are submitted, graded, revised, and built upon toward a final project and/or understanding. This process of scaffolding assignments, with pertinent and timely feedback, facilitates student development of scientific communication skills through writing and analysis of scientific arguments, data analysis and interpretation, and the application of scientific knowledge to real-world issues (Fig. 1). The ASM Curriculum Guidelines (5) and Microbiology Course Inventory (MCI) (6) enable assessment of student gains, including those in data and reading/writing literacy. Microbiology students are asked to complete the MCI to ascertain mastery of learning objectives and literacy skills per course. Furthermore, literacy-based assignments integrate essential career competencies: oral and written communication, critical thinking and problem solving, digital technology, and teamwork and collaboration (summarized from the National Association of Colleges and Employers Career Readiness Competencies [7]).

PROCEDURE

Developing scaffolded assignments throughout a single course provides opportunities for modular teaching and learning while improving STEM literacy. Instructors can maintain flexibility with assignments and personalization of microbiology course development. Intermittent submission and formative assessments for students pace literacy assignments along with progressing through course material. Scaffolding across microbiology courses maintains a central focus on information and communication literacy with growing elements for data literacy. The attention to STEM literacy in most microbiology courses facilitates student preparedness for subsequent courses and careers. The following describes a varied pedagogy to introduce scaffolded literacy elements within the microbiology curriculum.

Scaffolding to support information and communication literacy

In lower-level microbiology courses, the goal is to promote information literacy and public communication through a series of aligned assignments. Each assignment receives timely feedback and scoring to promote scaffolding. Early in the semester, students work in groups to identify broad topic areas for

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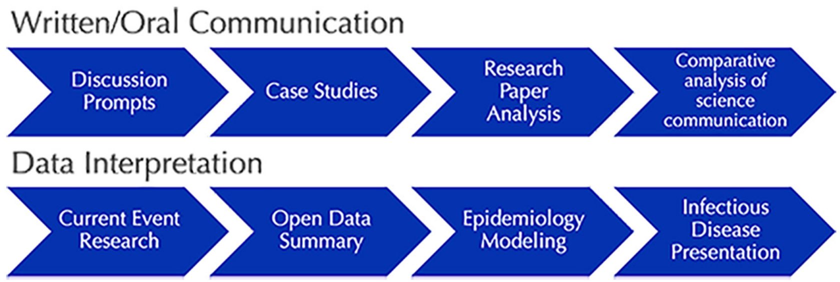

FIG 1. Graphical abstract of a selected scaffolding flow to enhance STEM literacy assignments to build greater competence in communication and data literacy in microbiology courses.

microbial influence, and then each student summarizes a recent news article with a key point about microbiology (see Appendix S1 in the supplemental material). Case study reflections and discussion prompts extend information and communication literacy practice throughout the semester. An example of such pedagogy is when students learn about basic bacterial culturing and metabolism via communication-based literacy skills through discussion prompts, such as "How does the ability of prokaryotes to transfer materials across their cell wall and membrane influence their ability to conduct different forms of metabolism?" Students use case studies, such as Elvis Meltdown (https://www.nsta.org/ncss-case-study/elvis-meltdown), to advance skills through data analysis and activities to facilitate concept and literacy development.

Upper-level microbiology courses continue the scaffolded approach wherein students compare content in peer-reviewed scientific articles and news articles to discern common messaging, language, targeted audience, and discrepancies. They subsequently develop information pamphlets targeted for potential distribution to, and education of, the general public (Appendix S2). Such work prompts students to comprehend scientific writing and evaluate how such information is presented differently to science professionals and the general public, while working to improve their scientific communication skills (Fig. 1). Feedback on the assignments includes assistance with interpretation and student writing.

Scaffolding to support data literacy

For lower-level microbiology courses, the traditional curriculum includes elements that require students to interpret data with trends and charts to understand the core concept (5), for example, bacterial growth and metabolism through population growth curves. Beginning data literacy discussions include identifying dependent and independent variables. Then, students are asked to consider how the graph would change if growth conditions changed, e.g., the addition of new growth media, more bacteria, or introduction of a different microorganism. Students in the major subsequently create their own graphs with publicly available data about microbes in society (i.e., government agencies that monitor for food and environmental safety). Students are first asked to identify one data source and develop a hypothesis regarding influencing factors, with encouragement to focus on time or geography. Students then visualize the data in a format appropriate to address the hypothesis. To complete the project, they present their process and data summary, for example, as a conference poster (Appendix S3).

The lower-level course in the major introduces bioinformatics through an activity to identify a provided unknown bacteria gene sequence. Students navigate through the NCBI BLAST tool (https://blast.ncbi.nlm.nih.gov/Blast.cgi) and then submit their resulting top identity match. A culminating data practice focuses on epidemiology; using data sets and models, students visualize infection and population dynamics (Fig. 1). Students are introduced to the analysis tool RStudio, using the package ShinySIR to create a simple data model (i.e., susceptible-infected-recovered [SIR]) for a disease spreading through a population (8). Students then have the option of visualizing the impact of different pandemic conditions and interventions through advanced disease models by changing specific parameters (9). The lesson concludes with a reflection on the complexities of understanding disease dynamics and management strategies for public health.

A series of meta-analysis tasks are scaffolded for upper-level students in the Introduction to the Human Microbiome course to develop hypotheses and use varied literacy skills to conduct *in silico* research tasks per a semester-long assignment. Students investigate the impacts of specific aspects of the human microbiome upon the holobiont and construct a series of literacy-based figures to develop a meta-analysis poster demonstrating their findings. Initially, students present their process for identifying pertinent key terms for database searches and developing word clouds to identify such terms in the scientific literature and develop a novel hypothesis to investigate. Students subsequently develop data literacy skills through development of two novel figures that facilitate analysis and visualization of data from the identified research. The assignment culminates when students compile their results, conclusions, and figures into a scientific poster for conference presentation (Appendix S4). Such work promotes both literacy and career competency skills. Routine feedback per assignment encourages students to refine their hypotheses throughout the course and reflect upon the correlation of continued work with their meta-analysis study.

CUREs facilitate STEM literacy development through scaffolding

CUREs are ideal opportunities to reinforce literacy skills (2–4, 10, 11). Applied microbiology students build upon prior exposure to literacy skills and become familiar with current trends in scientific research, interpret data, and develop methods for data visualization through scaffolded tasks. General CURE pedagogy includes iterative journal clubs with rotating student leaders, data visualizations, and the peer review process (hypotheses, methods, data analysis, and presentations). Such work further develops STEM literacy skills promoted in lower-level courses, specifically, communication and data literacy.

Individual CUREs extend literacy pedagogy based on specific research and project elements that are assigned throughout the semester with iterative feedback and formative grading (via rubrics) for hypothesis development, research protocols, data analysis, and experimental design and refinement. A Microbial Ecology CURE investigates antimicrobial sensitivity and resistance among soil microbes, enhancing data literacy through a scaffolded *in silico* exploration of phylogeny and metabolism; assignments include key term word clouds, 16S rRNA phylogenetic trees, protein modeling, protein phylogenetic trees, primer design, and analysis. Such assignments are conducted throughout the semester, with students developing their content of study through data analysis, refinement of hypotheses, and scientific presentation with peer evaluation (12). A Metagenomics CURE utilizes data collected from previous CUREs, focusing on the urban aquatic microbiome. Students are introduced to command-line processes and Python scripting, utilizing QIIME2 (13) and additional analysis packages (in RGui) to manage sequence data and present a comparative analysis of microbiome composition and diversity. Each process has growing complexity, peer support, and instructor feedback that helps students move from learning the language and basic process code (e.g, calculating the GC percentage of a genomic sequence), to analysis tutorials, and finally to determining their own analysis pipeline.

CONCLUSION

Scaffolding assignments permit faculty to customize learning and assessments while facilitating student conceptualization of big-picture concepts through the construction of literacy-based projects. Focusing on information and communication literacy in lower-level microbiology courses, such as Microbiology and Public Health, encourages interest and engagement of students. Aligning such courses with the ASM Curriculum Guidelines (5) and assessment via the MCI (6) facilitates pedagogy and subsequent student learning. Literacy skills then build in upper-level Microbiology, Human Microbiome, and CURE courses as students continue to refine communication and data literacy. While the scaffolded assignments presented herein are specifically pertinent to their respective topics, the tasks can be readily revised per content and focused to be adopted by other courses. A further benefit of scaffolding is that educators can choose to omit some tasks from a series while incorporating pedagogy from other courses to best fit specific academic goals. Early observations indicate that the scaffolding approach facilitates undergraduate student STEM literacy development. Such findings encourage further evaluation of the pedagogy regarding both learning gains via the MCI (6) and literacy gains through additional surveys such as the Test of Scientific Literacy Skills (1). Expansion of scaffolding to other courses will further literacy development among students.

SUPPLEMENTAL MATERIAL

Supplemental material is available online only.

SUPPLEMENTAL FILE 1, PDF file, 0.3 MB.

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