Advancing Metacognitive Practices in Experimental Design: A Suite of Worksheet-Based Activities To Promote Reflection and Discourse in Laboratory Contexts†

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INTRODUCTION

Recent efforts to reform postsecondary STEM laboratory education have resulted in the genesis of course-based undergraduate research experiences (CUREs). In contrast to expository and inquiry-based laboratory curricula, CUREs are designed to engage students in the authentic process of scientific discovery, from development of a novel research question to experimentation, data analysis, and dissemination (1, 2). Evidence within the biology education literature indicates that CUREs are effective at promoting students’ acquisition of scientific reasoning skills, attitudes, motivations, and conceptual understanding in the discipline (3–7). Furthermore, CUREs have been shown to foster students’ ability to “think like a scientist” and, in concert with the aforementioned outcomes, lead to increased student interest and persistence in STEM (8, 9).

Despite these findings, and an emphasis on scientific thinking, little attention has been afforded to explicitly developing students’ metacognitive skills within research contexts, including CUREs. In its broadest sense, metacognition refers to “one’s knowledge concerning one’s own cognitive processes... [as well as] self-regulation—the ability to orchestrate one’s learning—[and] the ability to reflect on one’s own performance” (10, 11; as cited in 12). Within the laboratory arena, Dahlberg et al. (13) note that students engage in metacognitive practices via execution of the scientific method (see also, 12). In addition, Dahlberg and colleagues demonstrated that a brief metacognitive intervention implemented within a modular CURE at their institution was effective at advancing students’ reflection and recalibration skills, suggesting that curricular activities can serve as a feasible method to address the need for developing metacognitive skills in STEM laboratory contexts. In considering this and other studies (e.g., 8, 14, 15), we contend that a greater emphasis on the multifaceted and dynamic nature of the scientific process is needed (e.g., troubleshooting; communication), as this more accurately reflects current advances in our understanding of the structure and benefits of CUREs and other similar research-driven opportunities (1, 16–18). Furthermore, while existing exercises (e.g., 13) require students to reflect on the actions and outcomes defining their research project, this is frequently done at the recall level (i.e., use of “what...” prompts), with limited, if any, opportunities for evaluation (i.e., use of “why...” and/or “how...” prompts). The Advancing Metacognitive Practices in Experimental Design (AMPED) exercises described in this article seek to address these concerns, offering a novel approach to engage students in metacognition within laboratory learning environments.

PROCEDURE

Developing AMPEDs

Congruent with Auchincloss and colleagues’ (1) CURE framework, AMPED exercises were created to reflect the diversity of scientific practices that researchers commonly employ in the course of their professional lives. Exercise topics are presented in Table 1. In an effort to further ensure that AMPEDs could be implemented in an accessible manner, we elected to construct these activities as a series of worksheets containing, on average, four reflection prompts. AMPEDs described in this article (Appendix 1) consist of both general and course-specific prompts (see 19, for a description of the CURE at our institution), reflecting the fact that AMPEDs can be easily customized to address the individual needs of each instructor.

Implementing AMPEDs in the laboratory classroom

AMPED exercises are designed to be implemented in tandem with the introduction of the related topic within the laboratory course; as such, AMPEDs are distributed periodically throughout the entirety of the semester (Table 1). We encourage instructors to deploy AMPEDs
in a manner conducive to their own instructional context. For instance, we used AMPED 1 as an icebreaker activity during class time to provide an opportunity for students (N = 18) to get to know each other while simultaneously discovering and discussing their strengths and weaknesses as a team (with assigned group, four students per team). Subsequently, teams began to work collaboratively to identify possible research areas to explore in the course, which were then discussed in a larger class dialogue. Conversely, AMPED 3 (*Research Updates*) was assigned weekly as homework and was used to initiate discussion at the start of the subsequent class session around the successes and challenges of engaging in the research process.

Importantly, two additional scaffolds were integrated into the course to support students’ development of metacognitive skills. The first of these was the Individual Development Plan (IDP; 20), which we adapted for use with undergraduates and which students completed in the first week of the semester (Appendix 2). The IDP requires that students reflect on their goals for the semester, as well as their self-reported strengths and areas for growth associated with each goal, both individually and in concert with the course instructor. In our context, students were asked to revisit their IDP at the end of the semester in order to encourage them to reflect on their “evolution” as researchers over the course of the term. The second scaffold was weekly “PI meetings.” These meetings were, in effect, office hours held outside of regular class meeting times and were weekly “PI meetings.” These meetings were, in effect, office hours held outside of regular class meeting times and were designed to provide student teams with additional opportunities to converse with the instructors (N = 2) about any challenges the team might be experiencing (see identified, for instance, in AMPED 3). Support materials needed to effectively execute their project, and/or mechanisms for dissemination of their research findings.

**CONCLUSIONS**

Prior research demonstrates that metacognitive strategies, such as post-exam reflections, are effective at advancing students’ awareness of their own learning approaches and enhancing students’ ability to engage in self-regulated learning (12, 21, 22). Despite the critical importance of these outcomes, relatively few studies (e.g., 13) have sought to examine the use and impact of metacognitive practices in laboratory contexts. The AMPED exercises described herein seek to address this concern, offering a no-cost, adaptable mechanism to explicitly engage students in reflection and discussion around core elements of the scientific process, particularly within CUREs (1). One student enrolled in the Health Disparities CURE at our institution who completed the AMPEDs noted, for instance, that “knowing when to talk to the professors about roadblocks and how to overcome them is what challenged [their] group, and, in the end, was beneficial to [their] growth and research.” A second student stated that “the weekly meetings and data analysis workshops (AMPED 4) were beneficial because [they] allowed [her] to ask questions and address errors in [her] team’s data to reach [their] goal.” While implemented within a CURE, AMPEDs can be employed in a diverse array of lower- and upper-division courses for majors and nonmajors alike, as they can easily be customized to meet the learning objectives of any research-intensive lecture or laboratory course with minimal investment of time and resources.

**SUPPLEMENTAL MATERIALS**

**Appendix 1: AMPED exercises**

**Appendix 2: Individual development plan**

**ACKNOWLEDGMENTS**

Development of the AMPED exercises was part of a larger course reform initiative funded, in part, through a curriculum pilot grant awarded by The University of Texas at El Paso’s BUILDing SCHOLARS initiative. BUILDing SCHOLARS is supported by the NIGMS/NIH under linked award numbers R01GM118967, T44GM118971, and UL1GM118970. This study was approved by The University of Texas at El Paso’s Institutional Review Board (IRB) under protocol #789648. The views expressed in this article are those of the authors and do not necessarily reflect the views of the NIGMS/NIH or its constituents. The authors declare that there are no conflicts of interest to report.

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## Table 1.

AMPED exercises and implementation schedule.

| AMPED Exercise | Topic | Implementation Schedule*
|----------------|-------|----------------|
| 1              | Collaboration and Goal-Setting | Week 1 (C)  |
| 2              | Developing Research Questions and Hypotheses | Week 2 (C) |
| 3              | Discovery, Implementation, and Reflection | Week 4 (HW) |
| 4              | Data Analysis (Scientific Practices) | Week 11 (C) |
| 5              | Broader Relevance (Science Communication) | Week 14 (HW) |
| 6              | Broader Relevance (Community Engagement) | Week 15 (C) |

*The implementation schedule is aligned to a standard, 16-week semester.

**C** = AMPED was completed in class during the laboratory session (total time required for implementation of in-class AMPEDs ranged from 60 to 90 minutes, dependent largely upon the duration of in-class discussion, within the context of a 180-minute laboratory session); (HW) = AMPED was assigned as homework, and student responses were discussed during the subsequent laboratory session (approximately 45 to 60 minutes of discussion per AMPED).

AMPED 3 was distributed weekly throughout the semester beginning in week 4 and concluding in week 10.

7. The Health Disparities CURE described in this article is offered as a two-course sequence as part of the BUILDing SCHOLARS Freshman Year Research Intensive Sequence (FYRIS; https://fyris.utexas.edu) at The University of Texas at El Paso. As such, AMPED 6 was delivered at the end of the first semester in order to prime students for their work in the second semester (where the student population is retained between the two semesters).

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