Developing a Gain-in-Research-Ability Test to Navigate and Assess Course-Based Undergraduate Research Experiences

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The authors gratefully acknowledge Nancy Pelaez for the support and advice through the ACE-Bio network. This study was supported by an Innovative Teaching Award from the Association of Public and Land-grant Universities (Academic Programs Section).
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Abstract

Course-based undergraduate research experiences (CUREs) benefit student learning by providing accessible authentic research opportunities. However, the uniqueness of each disciple and variation in instructors' perception of CUREs make it challenging to reach a consensus on how to effectively assess students' research abilities in a CURE laboratory. To address this question, we developed a Gain in Research Ability Test (GRAT) based on seven areas of competencies in research (Identify, Question, Plan, Conduct, Analyze, Conclude, and Communicate). The GRAT framework orchestrates the learning objectives and research activities, providing a quantitative assessment of student learning outcomes. The GRAT scores before and after the interventions revealed a significant growth in students' research abilities, consistent with students' perception of the GRAT-navigated research experience. As the seven areas of competencies in research are commonly observed across disciplines, the GRAT framework circumvents disciplinary boundaries and sets universal milestones for the assessment of CURE. Future larger-scale and cross-discipline studies are warranted to explore the potential of GRAT to provide a common metric for substance and consistency in the assessment of students' gain in research ability across disciplines.

Keywords: gain in research ability test, course-based undergraduate research experiences, anticipated learning outcomes, backward design, assessment

Since the national call for education reform to integrate authentic research experiences into undergraduate curricula, higher education has witnessed increased endeavors to involve undergraduate students in doing science through course-based undergraduate research experiences (CUREs) (Auchincloss et al., 2014; Cooper et al., 2020; Craig, 2020; Krim et al., 2019; Lopatto et al., 2020). CUREs help students increase self-confidence, improve attitudes toward science, build ability to analyze and interpret data, develop more sophisticated conceptions of what it means to think like a scientist, and enhance content knowledge (Shortlidge & Brownell, 2016). In contrast to traditionally structured (or "cookbook") laboratory where students complete a pre-determined series of activities with a known answer, CUREs engage students to solve problems with unknown answers (Shortlidge & Brownell, 2016). CUREs also overcome limitations (vigorous competition and limited openings) associated with research internship by integrating research experiences into coursework, thereby increasing the opportunities for students and offering more opportunities for diverse students to engage in research (Lopatto et al., 2020). Depending on the levels of "open inquiry", CUREs may include authentic research elements such as literature research, generating questions, forming a hypothesis, designing an experiment, collecting and analyzing data, working toward significant findings, and presenting results (McLaughlin et al., 2017). Active participation in authentic research promotes student retention and success in science and increases the interest in pursuing higher education in science, technology, engineering, and mathematics (Cheng & Shelnutt, 2021; Linn et al., 2015; Lopatto et al., 2020).

Thus, CUREs hold the promise to beneficially transform teaching and learning of STEM for students, instructors or educators, and higher education institutions (Govindan et al., 2020).

The origin of CUREs may track back to 1956, when a three-year program for undergraduate seminar and research was described, transforming a senior chemistry seminar course by including a faculty-led lab session for students to work on publishable research (Fromm, 1956). In the past decades, CUREs have developed across STEM disciplines, such as biology and life sciences, chemistry, physics, mathematics, and geoscience (Buchanan & Fisher, 2022). CUREs design and structure may vary with instructors' anticipated learning outcomes (Shortlidge et al., 2017; Shortlidge & Brownell, 2016), while the common components include science practice, discovery, relevance, collaboration, and iteration (Auchincloss et al., 2014; Buchanan & Fisher, 2022). Through CUREs students engage in designing studies, evaluating models, analyzing data, communicating findings, and using scientific techniques and methods (Buchanan & Fisher, 2022). More specifically, students may review primary literature, choose the direction of their research, generate hypotheses, create or correctly select research methods to address research questions, and disseminate their results (Buchanan & Fisher, 2022). For the instructors who are new to CUREs, Govindan and colleagues presented a practical beginner's guide to overcoming barriers in creating a CURE course (Govindan et al., 2020).

As CUREs grow in popularity, educators are seeking effective ways to assessing CURE outcomes (Auchincloss et al., 2014; Irby et al., 2020; McLaughlin et al., 2017; Shortlidge & Brownell, 2016). Table 1 summarizes instruments that assess different scientific practices related to CUREs, ranging from scientific literacy to critical thinking, experimental design, science communication, and collaboration. For instance, the Rubric for Experimental Design (RED) measures changes in students' conceptions about experimental design, understanding of the criteria for good experimental design, or test student ability to design experiments (Dasgupta et al., 2014). The Test of Scientific Literacy Skills (TOSLS) measures undergraduates' evaluation of scientific information and arguments including the ability to organize, analyze, and interpret quantitative data and scientific information (Gormally et al., 2012). The Molecular Biology Data Analysis Test (MBDAT) assesses students' data analysis skills connected with scientific reasoning when analyzing and interpreting scientific data (Rybarczyk et al., 2014). To understand students' perceptions of collaboration, discovery and relevance, and iteration, Corwin and colleagues developed a Laboratory Course Assessment Survey (LCAS) (Corwin et al., 2015). These studies, along with others (Bhaw et al., 2023; Fawkes et al., 2005; Goodwin et al., 2022; Hanauer & Dolan, 2014; Irby et al., 2018a, 2018b; Pisano et al., 2021), have significantly advanced the development of CURE assessment tools. However, an assessment instrument to evaluate all the critical scientific practices is lacking. In addition, an assessment instrument aligned to the learning outcomes for one CURE may not work for another CURE, and instructors may find it challenging to implement the available instruments because anticipated learning outcomes (ALOs) vary with disciplines, techniques, and research focuses (Goodwin et al., 2022; Irby et al., 2018a, 2018b; Shortlidge et al., 2017; Shortlidge & Brownell, 2016). Thus, a universal assessment instrument is in urgent need for CUREs to provide a common metric for substance and consistency.

In this article we report a Gain in Research Ability Test (GRAT) that aligns ALOs with seven areas of competencies in research (Identify, Question, Plan, Conduct, Analyze, Conclude, and Communicate) (Cheng et al., 2022; Pelaez et al., 2017). As the seven competencies are commonly valued across disciplines, the GRAT framework goes beyond the boundaries of disciplines and sets universal milestones for the assessment of CURE laboratory courses. We used GRAT framework to navigate backward-design of a CURE laboratory course (HUN 4813C - Laboratory Techniques in Molecular Nutrition) to enhance scientific practice and authentic research experiences and assess the learning outcomes.

Table 1

Science practices and the related assessment tools

Science Practices	Assessment Instruments	References
Scientific literacy	TOSLS (Test of Scientific Literacy Skills)	(Gormally et al., 2012)
Critical thinking	CCTST (California Critical Thinking Skills Test)	(Fawkes et al., 2005)
Experimental design	RED (Rubric for Experimental Design)	(Dasgupta et al., 2014)
Data analysis	MBDAT (Molecular Biology Data Analysis Test)	(Rybarczyk et al., 2014)
Scientific reasoning	LCTSR (Lawson's Classroom Test of Scientific Reasoning)	(Bhaw et al., 2023)
Science communication	USWR (Universal Science Writing Rubric)	(Pisano et al., 2021)
Project ownership	POS (Project Ownership Survey)	(Hanauer & Dolan, 2014)
Collaboration, discovery and relevance, iteration	LCAS (Laboratory Course Assessment Survey)	(Corwin et al., 2015)

Methods

Course Overview

Laboratory Techniques in Molecular Nutrition (HUN 4813C) is an upper-division course in the Nutritional Sciences (NS) curriculum at University of Florida. Students are NS Majors or Minors who take this course (elective) in their junior or senior year. The course covered the knowledge of nutrition, biochemistry, molecular biology, genomics, physiology, and bioinformatics, and was designed to engage students in such teaching and learning activities as question-guided video watching, lecturing, in class exercise, case study, protocol development, and project design/conduction. The class was administered online (synchronous) but active learning was facilitated by the instructor to guide students in (a) discussing the principles and applications of the laboratory techniques, (b) examining and interpreting published research, (c) virtual laboratory training and simulation with Labster, and (d) addressing real-life research questions regarding molecular nutrition. Mastery of knowledge, technical skills, and application were evaluated by formative and summative assessments (e.g., protocol critique, troubleshooting, reflections, quizzes, or exams), and the course culminated with a semester-long project in which students exercise authentic research practices and address their primary questions of interest regarding molecular nutrition. At the end of a semester, students concluded their projects with oral presentation and structured paper. All the teaching and learning activities served for the overall learning objectives that students were able to (a) explain the principles of laboratory techniques for molecular nutrition research, (b) examine published research, (c) design and plan feasible experiment to address real-life questions, (d) select laboratory skills effectively to meet research needs, and (e) interpret experimental data acquired with commonly used techniques. This study included three cohorts (2021 Spring, 2021 Fall, and 2022 Fall).

Gain in Research Ability Test (GRAT)

Effective assessment methods and instruments will inform what and how students will be assessed, what and how instructors will teach, and what and how students will learn if they are to achieve the desired learning objectives (Irby et al., 2018a, 2018b). To measure students' gain in research ability, we developed GRAT by aligning anticipated learning outcomes (ALOs) with seven areas of competencies in research (Identify, Question, Plan, Conduct, Analyze, Conclude, and Communicate) (Cheng et al., 2022; Pelaez et al., 2017). The GRAT framework overcomes the boundaries of disciplines and sets universal milestones for the assessment of CURE laboratory courses, thereby having the potential to provide a common metric for substance and consistency in assessment. Specifically, students are to accomplish the anticipated learning outcomes (ALOs) in line with seven areas of competencies in research (Identify, Question, Plan, Conduct, Analyze, Conclude, and Communicate): ALO1- the ability to identify gaps or limitations in current research knowledge through the review, filtering and synthesis of relevant literature; ALO2- the ability to generate a research question and formulate hypotheses; ALO3- the ability to plan feasible and ethical experiments to answer research questions or test hypotheses; ALO4- the ability to conduct an investigation to achieve research goals; ALO5- the ability to analyze and process data; ALO6- the ability to conclude about data with inferences that are limited to the scope inherent in the experimental design; ALO7- the ability to communicate research work in professionally appropriate modes, including visual, written, and oral formats (Table 2). The GRAT orchestrates learning objectives, assessments, and the design of teaching/learning activities, serving an effective framework to guide backward design of a laboratory course (Figure 1). Based on the feedback/data of learning outcome, the instructor can further revise or refine the GRAT instrument and learning objectives (Figure 1).

GRAT-navigated research activities and **scientific practices**

In contrast to a traditional "cookbook" laboratory course that focuses on techniques and experimental procedure, authentic research experience engages students to exercise how scientists do science, i.e., literature research, generating questions, forming a hypothesis, designing an experiment, collecting and analyzing data, working toward significant findings, and presenting results (Cheng et al., 2022; McLaughlin et al., 2017; Pelaez et al., 2017). To exercise authentic research practice, students engaged in a semester-long research project to address their primary questions of interest regarding molecular nutrition (Figure 2). At the beginning of the semester, students were asked to identify their primary questions of interest (i.e., knowledge gaps) and prepare a no-shame (the best students knew how, regardless of errors or pitfalls) research proposal based on prior knowledge and literature research. During the semester, students continuously refined their research questions and research proposal, which was in parallel with other learning activities, including attending lectures & discussion of the principles and operations of laboratory techniques, watching laboratory demos, conducting laboratory simulation and troubleshooting, doing case studies in groups, and examining published research. These teaching and learning activities were overarched by the GRAT framework, aiming to build students' research skills and empowered them to apply and conduct the semester-long research project in parallel. Students received project-specific advice and guidance from the instructor through two structured meetings, where students presented their project outlines (meeting 1) and project layouts (meeting 2); students also routinely sought instructor's guidance during office hours. The instructor's feedback guided students in conducting additional literature research and revising their research proposals (including knowledge gaps, hypothesis, rationale, research plan, expected results and justification, pitfalls, and alternatives). All the research activities in the project were aligned with the seven ALOs and culminated with an oral presentation and a structured paper at the end

Table 2

Gain in Research Ability Test

Project title ____________________ Student name ____________

Item	No input	Attempted	Partial mark	Full mark	Scores
• Able to effectively define a research problem or question with sufficient background information (ALO1)					/9
✓ Clearly define a knowledge gap		1	2	3	
✓ Justify the impact or significance of proposed experiment/research		2	4	6	
• Able to effectively state and back up a hypothesis with evidence-based rationales (ALO2)		3	6	9	/9
• Able to choose an appropriate system to meet experimental needs (ALO3a)					/6
✓ Physiological relevance (in vitro, in vivo models)		x	2	4	
✓ Research compliances (IRB, IACUC, IBC consideration)		x	1	2	
• Able to contrast at least two possible methods and justify which to choose (ALO3b)					/6
✓ Functionality		x	1	2	
✓ Reliability		x	1	2	
✓ Feasibility		x	1	2	
• Able to justify why the measurements are critical and how selected methods will be implemented for the measurements (ALO3c)		1	2	4	/4
• Able to specify the key details ensuring experiment reproducibility (ALO3d)					/8
✓ The controls –system controls and reagent positive/negative controls		x	1	2	
✓ Treatment details		x	1	2	
✓ Power calculation for sample size		x	1	2	
✓ Sampling strategy		x	1	2	
• Able to draw out and justify predicted results or trends with evidence-based rationales (ALO3e)		1	2	4	/4
• Able to conduct measurements and make observations (ALO4)					/12
✓ Accuracy		1	2	4	
✓ Precision		1	2	4	
✓ Trouble-shooting		1	2	4	
• Able to correctly analyze and logically organize data (ALO5a)					/10
✓ Data organization		1	2	4	
✓ Sound judgement		1	2	4	
✓ Clarity		x	1	2	
• Able to explicitly interpret the experimental results and justify how they support or reject the hypothesis (ALO5b)		2	4	6	/6
• Able to identify and articulate limitations/pitfalls and propose alternatives to improve the limitations or logically prospect future directions or follow-up studies (ALO5c)		2	4	6	/6
• Able to conclude with evidence how the study addresses the question and advances our understanding of the topic (ALO6)		2	4	6	/6
• Able to effectively present the evidence in writing or speaking (ALO7)					/14
✓ High-quality visual aids		2	4	6	
✓ Logical flow and organization		x	2	4	
✓ Cited information or references – credentialed and relevant		x	2	4	

Total points earned: /100

of the semester. The class design engaged students in constant research activities in and outside the class. The learning outcomes were assessed by GRAT (Figure 2).

Assessments

The semester-long research project accounted for 25% of the course grades. GRAT was applied to the no-shame research proposal (10 points), and baseline research ability was recorded for each ALO and sub-ALO as indicated in Table 2. At the end of the semester, GRAT was applied to the final project presentation (40 points) and paper (50 points), and the post-intervention (post-INT) research ability was recorded according to the ALOs and sub-ALOs shown in Table 2. In addition, students' perceptions of their research experiences and gains in research ability pertaining to the seven areas of competencies in research (i.e., the ALOs) were surveyed using Likert scales before and after the

GRAT-guided interventions. The data were analyzed and organized using Microsoft Excel and PowerPoint. T-test was conducted to assess the differences between groups, and $p < 0.05$ was considered statistically significant. This study was reviewed and approved by the University of Florida's Institutional Review Board as exempt (IRB201902746).

Results and Discussion

Identification of knowledge gaps and questions of interests

The cohorts of 2021 Spring (enrollment = 16), 2021 Fall (enrollment = 9), and 2022 Fall (enrollment = 10) led to a total of 35 enrollments in Laboratory Techniques in Molecular Nutrition (HUN 4813C). These students included 7 juniors and 28 seniors; 9 males and 26 females; and 29 NS majors and 6 NS minors. Based on their prior knowledge and instructor-guided literature research, students develop their primary questions of interest. The questions were regarding

Figure 1

Schematic view of the GRAT overarching the learning objectives and design/administration of teaching activities in the backward design of a laboratory course.

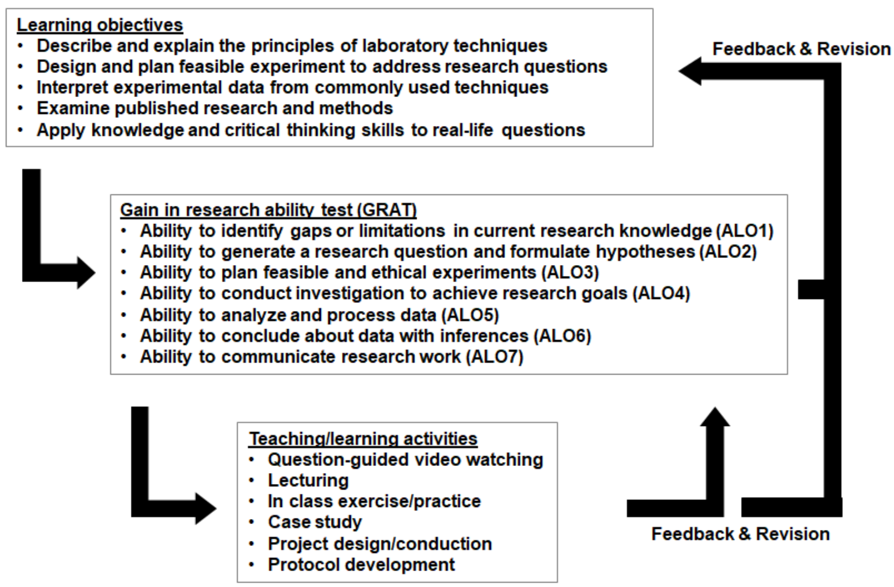
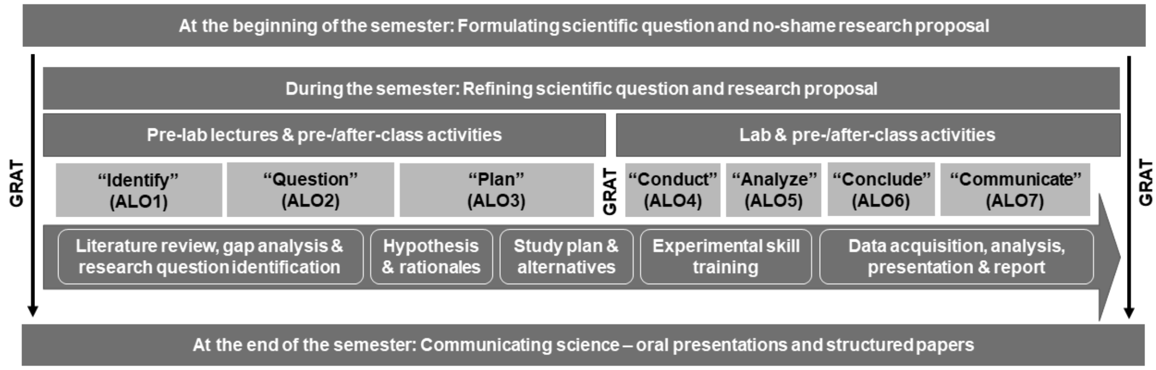


Figure 2

The GRAT-navigated teaching and learning activities in a CURE laboratory



Note. These teaching and learning activities were overarched by the GRAT framework, aiming to build students' research skills and empowered them to apply and conduct the semester-long research project in parallel, including (1) literature review, gap analysis, and research question identification, (2) formulation of hypothesis and rationale, (3) planning study and proposing alternative approaches, (4) learning and practicing experimental skills, and (5) data acquisition, analysis, presentation, and reporting. It requires a hybrid classroom setting where students are immersed in constant inquiry and research activities in and outside class, which pertains to the GRAT-centered seven areas of competencies in authentic research: "Identify" (ALO1), "Question" (ALO2), "Plan" (ALO3), "Conduct" (ALO4), "Analyze" (ALO5), "Conclude" (ALO6), and "Communicate" (ALO7). All the research activities in the project were aligned with the seven ALOs and culminated with an oral presentation and a structured paper at the end of the semester, and the learning outcomes were assessed by GRAT.

molecular roles of different diets, nutrients or antinutrients, and lifestyle in diabetes (7 projects), inflammation and autoimmune diseases (6 projects), obesity (5 projects), probiotics and gut microbiome (4 projects), cardiovascular health and diseases (4 projects), muscle biology and health (3 projects), mental health (2 projects), and other conditions (4 projects). The frequency of top-researched topics suggests that the students' interests went in concert with public health concerns (e.g., metabolic diseases) and leading edge of biomedical research (e.g., gut microbiome, epigenetics, and autophagy).

The transforming role of the GRAT framework

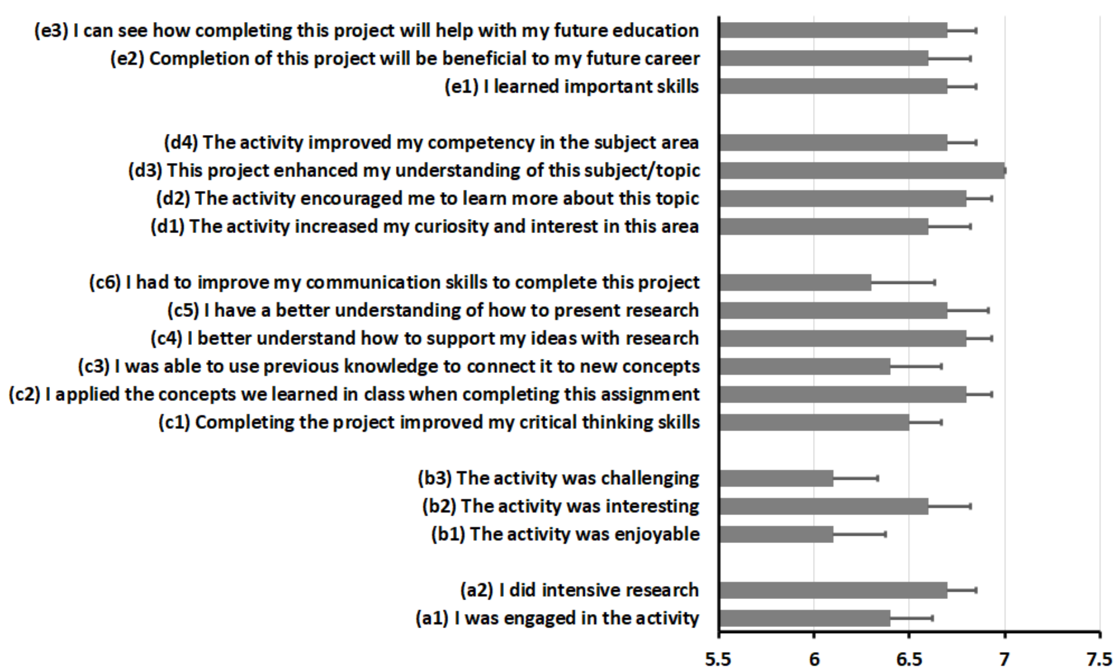
The transforming role of the GRAT framework resided in two major aspects. First, it translates the seven areas of competency in research into anticipated learning outcomes (ALOs), which circumvents disciplinary boundaries or barriers (Table 2, Figures 1-2). Authentic research in any discipline starts with "identifying knowledge gaps" (ALO1) and "developing research questions and formulating a hypothesis" (ALO2), proceeds to "planning study" (ALO3) and "conducting measurements" (ALO4), and ends with "data analysis" (ALO5), "evidence-based conclusion" (ALO6), and "new knowledge dissemination (i.e., communicating science, ALO7). As such, the GRAT framework provides a common metric for substance and consistency in the assessment of students' gain in research ability, thereby having the potential to serve as a universal assessment instrument for CURE courses across disciplines. Secondly, the GRAT framework orchestrates the learning objectives and teaching/learning activities, placing authentic research as the core of a CURE course and navigating the backward design of the laboratory course (Figure 1). To this end, all class activities (e.g., lecturing, video watching, exercise, case study, protocol development, and project design) are designed to achieve the seven measurable ALOs that overarch the descriptive learning objectives. Thus, the GRAT framework makes it possible to quantitatively assess CURE over descriptive learning objectives.

Student perception of GRAT-navigated research and learning

To investigate the effects of GRAT-navigated research on student learning, we implemented a survey on five aspects: (a) the vigor of student participation in research, (b) the nature of research activity, (c) the skills that the students developed or built through the research activities, (d) the impacts of research activities on students' competencies in the subject (or discipline), and (e) the envisioned impacts of research activities on students' future education and career. Students were asked to rate their experience using a Likert scale from 1 to 7 (1 – strongly disagree, 2 – disagree, 3 – somewhat disagree, 4 – neutral, 5 – somewhat agree, 6 – agree, and 7 – strongly agree), regarding the five aspects. As shown in Figure 3, the students were highly engaged (a1 = 6.4 out of 7) and did intensive research (a2 = 6.7 out of 7). They felt that the research activity was enjoyable (b1 = 6.1 out of 7) and interesting (b2 = 6.7 out of 7) although challenging (6.1). The students found that the GRAT-navigated research project and activity improved their critical thinking skills (c1 = 6.5 out of 7), ability to apply

Figure 3

Students' perception of GRAT-navigated research and learning



Note. Students were asked to rate their experience using a Likert scale from 1 to 7 (1 – strongly disagree, 2 – disagree, 3 – somewhat disagree, 4 – neutral, 5 – somewhat agree, 6 – agree, and 7 – strongly agree), regarding the five aspects: (a) the vigor of student participation in research, (b) the nature of research activity, (c) the skills that the students developed or built through the research activities, (d) the impacts of research activities on students' competencies in the subject (or discipline), and (e) the envisioned impacts of research activities on students' future education and career.

knowledge and connect new concepts (c2 = 6.8 and c3 = 6.4 out of 7), and the skills for communicating science (c4 = 6.8, c5 = 6.7, and c6 = 6.3 out of 7). In addition, the research activity had positive impact on students' relationship with the subject or research area, including curiosity (d1 = 6.6 out of 7), motive to learn (d2 = 6.8 out of 7), understanding (d3 = 7 out of 7), and competency (d4 = 6.7 out of 7). Lastly, students learned important skills (e1 = 6.7 out of 7) and reported that the GRAT-navigated research would benefit their future career (e2 = 6.6 out of 7) and education (6.7 out of 7). These feedbacks suggest that the GRAT-navigated research have a positive and profound effects on student learning outcomes.

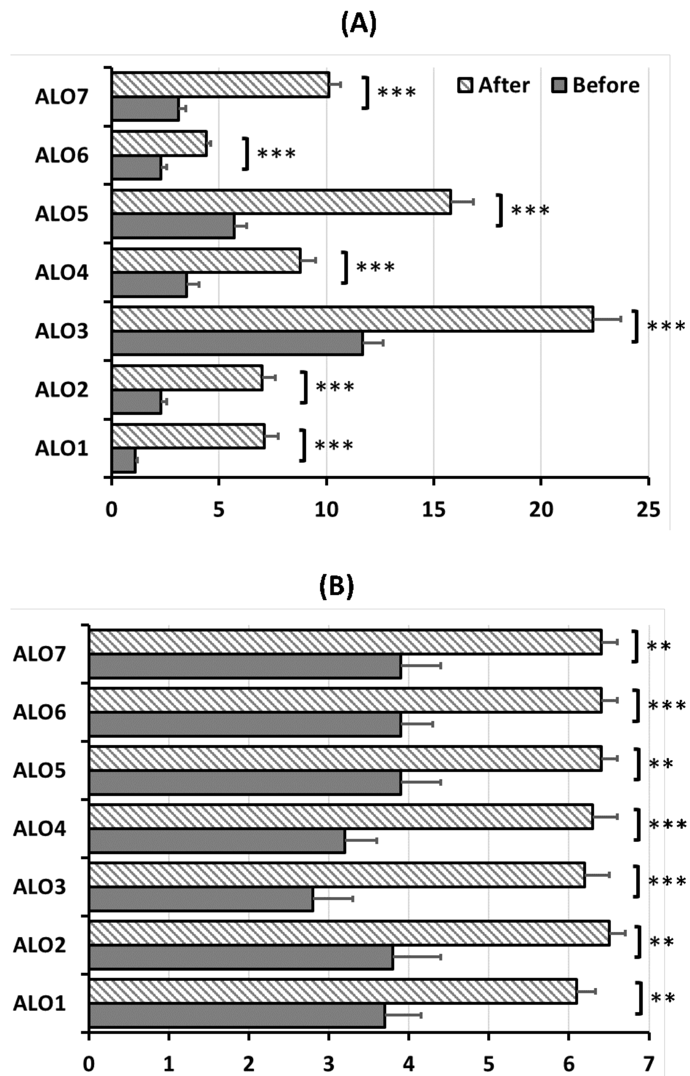
Gains in research ability

Using GRAT rubrics (Table 2), we evaluated students research ability before and after the GRAT-navigated intervention, respectively. Baseline research ability was recorded by assessing the no-shame research proposals that students submitted early in the semester before GRAT-navigated intervention (Figure 4A, grey bars). The research ability after GRAT-navigated intervention was recorded by assessing the final project reports (Figure 4A, striped bars). In parallel, students used a Likert scale from 1 to 7 (1 – strongly disagree, 2 – disagree, 3 – somewhat disagree, 4 – neutral, 5 – somewhat agree, 6 – agree, and 7 – strongly agree) to rate the following abilities before and after the GRAT-navigated intervention: (a) I can identify knowledge gaps or limitations in current research, (b) I can generate a critical research question and formulate reasonable hypotheses, (c) I can plan feasible and ethical experiments, (d) I can conduct investigation to achieve research goals, (e) I can analyze and interpret complex data, (f) I can conclude about data with inferences, and (g) I can effectively communicate research work (Figure 4B). The abilities manifested in Figure 4B correspond or pertain to the ALOs of GRAT framework (Figure 4A). Statistical analyses revealed significantly higher research abilities after GRAT-navigated intervention in comparison to the baseline values ($p<0.0001$ in all ALOs), indicative of a pronounced growth in research abilities (Figure 4A). Consistently, students' perception of GRAT-navigated research revealed a significant increase in their research ability pertaining to all ALOs ($p<0.001$ for ALOs 1, 2, 5, and 7; $p<0.0001$ for ALOs 3, 4 and 6; Figure 4B).

Despite the gains in research abilities, we observed some issues that students experienced (Table 3). Before the GRAT-navigated intervention, the major issues were about lacking key elements of research abilities pertaining to each ALO. After GRAT-navigated intervention, the major issues were more about the qualities of the key elements of research abilities (ALO1-ALO7). For instance, students did not document knowledge gaps when they developed their research questions (ALO1) before the GRAT-navigated intervention. After the GRAT-navigated intervention, their research questions were tied to documented "knowledge gaps", but the "knowledge gaps" had been resolved by published research. In addition, the component of justification with evidence was missing (ALO2 and ALO3) before the GRAT-navigated intervention. After the GRAT-navigated intervention, students did justify their ideas but in some cases the evidence was weak or incomplete. Overall, the issues that students experienced before and after the GRAT-navigated intervention revealed the difference that highlighted a higher level of metacognitive practices (awareness of their strengths and weaknesses) and critical thinking among the students. The GRAT-navigated authentic research experience equips the students with skills that enable them to think and communicate like a scientist and know how to operate the tools that scientists use to address scientific questions (Goodwin et al., 2022; Shortlidge & Brownell, 2016). A longer-term training through

Figure 4

Students' gains in research ability



Note. (A) Assessment of student research abilities using the GRAT instrument before and after the GRAT-navigated intervention. The data were presented as mean values and standard errors (n = 35). (B) Student perception of their research abilities before and after the GRAT-navigated intervention using a Likert scale from 1 to 7 (1 – strongly disagree, 2 – disagree, 3 – somewhat disagree, 4 – neutral, 5 – somewhat agree, 6 – agree, and 7 – strongly agree), regarding the seven areas of competencies in research pertaining to the ALOs shown in Figures 1-2. The data were presented as mean values and standard errors (n = 33). **, $p<0.001$; ***, $p< 0.0001$.

GRAT-navigated research will build the consistency and maturity in students' ability and scientific practice, which have the potential to eliminate the post-intervention issues that students experienced.

Limitations

The limitations or restrictions were identified as follows. First, the sample size was small. The enrollment in the 3 cohorts led to a total of 35. Future large-scale studies (particularly cross-disciplinary studies beyond nutritional sciences) are warranted to validate and refine the GRAT framework. Secondly, the assessment of "Conduct" element (i.e., ALO4) was based on students' protocol quality (operating details, success and troubleshooting tips, and alternatives) and laboratory simulation, which differs from wet laboratory experience. It will be of critical importance for future studies to compare virtual laboratory with in-person laboratory and investigate how the GRAT framework affects the gains in research abilities in two different laboratory settings.

Summary

CUREs are growing in popularity because of such benefits as (a) being more accessible to diverse student populations, (b) providing students with opportunities to do authentic research other than complete experimental procedures, and (c) promoting student retention and success. However, the question of how to effectively assess student research ability remains to be addressed. Particularly, a common metric for the assessment across disciplines is lacking. This study developed a GRAT framework based on seven areas of competencies in research (Identify, Question, Plan, Conduct, Analyze, Conclude, and Communicate) (Cheng et al., 2022; Pelaez et al., 2017), which is commonly observed across disciplines, thereby circumventing disciplinary boundaries

Table 3

The issues that students experienced

ALOs	Before GRAT-navigated intervention	After GRAT-navigated intervention
ALO1	Questions of interest (or curiosity in some cases) were stated but no or few gaps were clearly identified; description of problems was generic with no references cited.	Knowledge gaps and questions of interest were stated with references cited, but some gaps were illegitimate due to incomplete literature research or limited prior knowledge to understand the literature.
ALO2	Hypothesis was formulated and stated but the justification or rationale was missing.	Hypothesis was stated with rationale, but in some cases the justification was vague or based on assumption instead of evidence.
ALO3	Statement of research ethics was missing; methods were selected without justifying the preference; the justification of the predicted results and how measurements inform physiology or pathophysiology was missing or weak; control group, calculation of sample size, and vigor of random sampling, were not clearly specified.	Justification of preferred methods and expected results was weak or incomplete in some cases; how the measurements inform physiology or pathophysiology was inadequately addressed; power calculation to determine sample size was not clearly explained.
ALO4	Replicates of measurement and standard deviation were not specified for the results. The protocols for measurements were missing. Success tips or troubleshooting guide were not noted.	Replicates were not consistently noted for each measurement. Success tips or troubleshooting guide were incomplete or ineffective in some cases.
ALO5	The comparisons among groups and the rationales were vague. The interpretation was loosely related to or lacked strong connection with the hypotheses. Limitations or pitfalls and alternative approaches were not noted.	The legends to Figure or Tables were missing or incomplete. How the results support the hypothesis was inferred but with no elaboration. Limitations or pitfalls were incompletely identified, and some more important ones were missing.
ALO6	No conclusion or only a brief re-statement of importance of the project was presented.	The conclusions were mostly summaries about the data but not on advances in the research topic/field.
ALO7	Text was used more frequently than Figures or charts. Logical flow was vague. No or few publications were cited, and sometimes the references were from non-credentialed sources.	Readability (e.g., color contrast, font size, and ratios of different portions) of Figures needed improvement. Precise and accurate citation of supporting evidence (references) was suboptimal.

and itemizing universal milestones for the assessment of CURE laboratory courses (Table 2). The GRAT framework orchestrates learning objectives and backward design of a CURE laboratory course, setting authentic research elements as the core of teaching and learning activities. Assessment of students' gain in research ability using the GRAT instrument showed significant growth in student research ability in the seven areas of competencies after the GRAT-navigated intervention. Students' perception of GRAT-navigated research experience further confirmed the learning outcome. Therefore, the GRAT instrument has the potential to provide a common metric for substance and consistency in the assessment of students' gain in research ability, thereby serving as a universal assessment instrument for CURE courses across disciplines. Future larger-scale and cross-discipline studies to validate and refine the GRAT framework in both virtual and in-person laboratory setting will be of critical significance.

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