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Commentary

The SkillsCenter: Creating scalable research opportunities for STEM students

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Undergraduate students generally need laboratory skills and experience to be accepted into a position within an academic lab or a company. However, those settings are traditionally where students would develop that necessary expertise. We developed a laboratory course paradigm to equip students with the skills they need to access future opportunities.

INTRODUCTION

Undergraduate STEM students both desire and need access to research training for several reasons. One way is to provide them with the realistic experiences crucial for deciding between the various career options open to them, i.e., which career path is "right" for them. A second way is to enable them to develop and demonstrate their technical competence and their ability to work in a laboratory environment. Such real-world experiences are a critical component to persistence in STEM.[1,2] To be effective, these experiences need to accurately reflect laboratory environments, protocols, workflows, and expectations. Realistic training leads to the development of practical skills and equips students with experience-based confidence and agency, as well as a record of demonstrated competence. While universities provide an incredibly rich source of potential research opportunities, for the traditional undergraduate STEM student, obtaining experience and training in research is not straightforward.[3] Students are usually exposed to experimental practices through required laboratory courses. These are limited in the scope of training opportunities they can provide, and students are exposed to a subset of research techniques. These techniques represent a small fraction of modern methodologies implemented within a single research lab, let alone an entire department or institution. Additionally, lab courses are structured so that the instructors, rather than the students, are regulating valuable components of laboratory workflow such as time management, decision-making, and troubleshooting. Several studies have revealed that providing students with authentic, learner-centered research opportunities is key to enhancing student diversity and persistence in STEM.[4–6]

Historically, students have sought out research experience opportunities themselves. These opportunities have been provided through undergraduate research experiences (UREs), where a faculty researcher agrees to let a student temporarily join their group. These opportunities require a significant investment of time and energy from faculty, as students are often inexperienced and unskilled. If a research faculty member agrees to offer this opportunity, they must train these students themself or call on a senior member of the lab to do so until the trainee achieves a level of independence. Understandably, these opportunities are limited, leaving the majority of students without access to research experience. This leaves many without URE mentorship, which has been shown to improve persistence in STEM and help reduce equity gaps.[7,8] Despite the documented and perceived benefits of UREs, the intensive nature of the training relationship leads to a deficit between the high demand for research skill-building opportunities and the supply of available opportunities. This is particularly problematic at large research institutions in the United States, where less than 20% of undergraduate seniors report URE participation.[9]

In recognition of this deficit, course-based undergraduate research experiences (CUREs) have been developed to expose students to authentic research experiences. This is accomplished through a curriculum designed around a single research topic, where each student or group of students is responsible for developing a small component of the novel research. While assessing outcomes has proven challenging, experts generally agree that these courses are useful for developing students' discipline-specific skills and competencies.[10] A case study in an introductory biology course for majors has even revealed that CUREs can address learning outcome deficiencies found within traditional laboratory courses, such as developing student understanding of research project design and selecting appropriate data analysis methods.[11] However, the challenge still remains: CUREs are not specifically designed to teach research skills—they are designed to recreate research-like experiences. As a result, students still struggle to gain the specialized skills needed for future research opportunities, regardless of career path choice. A recent study described how the shortage of STEM workers is not due to the scarcity of the workers, per se, but rather the scarcity of workers with training in job-relevant skills.[12] Unfortunately, a CURE course cannot cover the breadth of experience students need and want to advance along their chosen career path, let alone satisfy basic entry-level job qualifications.

How then can students equip themselves with the specific skill sets they need? Based on our experiences in the Department of Molecular, Cellular and Developmental Biology (MCDB) at the University of Colorado Boulder, we

have developed a modular research skills training course that allows students to choose which skills they want to learn. The MCDB SkillsCenter (https://skillscenter.colorado.edu/) provides training for students in both general laboratory practice and the practical research skills of their choosing while offering micro-credentials for skills learned. With a diverse catalog of both wet lab and computational modules covering basic to advanced methods, students can customize their skill sets to strengthen their candidacy for joining a research lab, pursuing employment, or seeking further training. Students who are uncertain of which skills they need may seek advice from course proctors who offer guidance aligned with students' interests. The unique format of this course, which is built to mimic the workflow and responsibilities of a primary research laboratory, has the additional benefit of supporting students' agency, as students must manage their own schedule and seek out the resources they need to accomplish each learning goal. This approach not only empowers the student to set their own path but also provides them with valuable exposure to self-directed experimental design and execution (Figure 1).

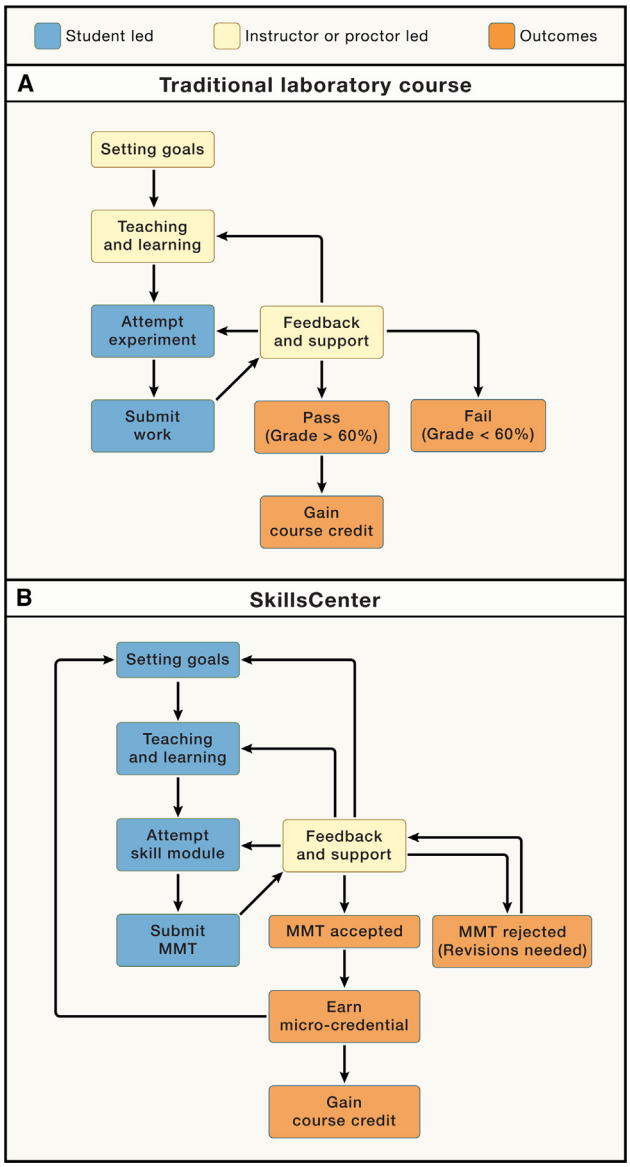

Figure 1. The conceptual workflow of a traditional laboratory course compared with the MCDB SkillsCenter course

(A) Traditional laboratory course workflow with hard fail states.

(B) Modular micro-credentialed training in the SkillsCenter provides students with opportunities to direct their own learning with readily available feedback and support from a team of proctors, supporting their growth and experience in independent laboratory workspaces. Additionally, this format provides students with greater flexibility in workflow due to the absence of a hard failure state from submitted work. This encourages students to learn and succeed through (sometimes repeated) failure. Module methods tasks (MMTs) represent the criteria students must complete to pass each individual skill module.

Modular research skills

Built upon the "learning by doing" principle,[9] the curriculum in the SkillsCenter is designed to support self-paced learning via skills modules that students select. Skills modules currently offer students training opportunities in both wet lab and computational research skills. Modules are scaled by skill level (beginner, intermediate, and advanced) with appropriate prerequisites. Following an in-depth introduction section for all students to establish workflow and course expectations, students start with the SkillsCenter Safety module to standardize safety protocols and lab operations. Following this introduction, students are encouraged to reflect on their past research experience (if any) as well as what types of research opportunities they seek. They work with course proctors to develop a plan for the semester to build useful and appropriate skill sets. For students who have never set foot in a research laboratory, lab proctors guide them to begin with training in foundational sets of skills such as "Pipette Operation and Calibration," "Centrifugation 1," and "Buffers and Stock Solutions." Pathways from beginner to more advanced modules follow specific prerequisites to gate access to more advanced skills. Returning SkillsCenter students or those entering the course with prior experience can test out of beginner modules and build specialized skill sets in preparation for work involving microscopy, DNA, or protein biology, or they can focus on developing analytical computational skills. Each module contains a background section, a standard operating procedure (SOP), and a module methods task (MMT). In the background material, students are first exposed to the "science behind the skill," followed by clearly described applications for the skill to provide context and enhance the perceived value of the technique being learned. The body of each module is an SOP, which guides students step by step through the procedural aspects of the skill. Bullet points in the SOP highlight conceptual definitions, materials and reagents needed for the experiment, a full operating procedure, and useful troubleshooting tips for when students experience unexpected outcomes. Finally, the MMT serves to assess students' conceptual understanding and procedural

knowledge of each skill. Following the methods task prompts, students organize and display raw data, results, conclusions, and interpretations. When complete, students submit their MMT to proctors for review via an online link found on the course website. This MMT becomes the student's work product that serves as a record of their skill knowledge and competency.

LINKED LABS

The SkillsCenter allows students to develop a tailored skill set associated with a research subdiscipline that can subsequently provide them with greater access to a URE with a faculty member. Opportunities for students to work directly with research faculty are valuable for supporting student retention in STEM disciplines, especially for those at greater risk of leaving STEM fields.[13] To provide a direct pipeline for students to access opportunities with research faculty, we have developed a SkillsCenter component known as "Linked Labs." We identify faculty willing to provide research opportunities to students who meet their skills criteria. The course website includes a dedicated section where each of these faculty members display the sets of skills they wish to see in potential URE students. Since students can take the SkillsCenter course multiple times, they can accumulate the skills desired by a particular researcher. We then connect students with a Linked Lab and help them establish their own project, which is supervised by both SkillsCenter proctors and the Linked Lab principal investigator (PI). To expand these URE opportunities and to lower the burden on research labs, students primarily complete their work in the SkillsCenter lab space. With the Linked Labs component, we offer a solution to students in need of experience by providing access to research projects and direct professional training. In the future, this concept could be extended to research opportunities in company settings as well.

Logistics of operation

One of the key drivers in designing the SkillsCenter was to create a scalable and flexible course that could serve as many students as possible. The SkillsCenter is a fully stocked laboratory organized with distinct "skills bays" (e.g., buffer station, centrifuge station, DNA and protein gel station, etc.) that students can reserve through an online resource calendar. Proctors staff the lab during normal work hours and provide students with on-site support. Students also have off-site/online support and can communicate with lab proctors and others through a dedicated course Microsoft Teams page. Personal communication with students is organized into personal chat groups with each student and all course proctors. These chat groups allow proctors to communicate feedback about submitted modules and for students to respond to feedback with any questions or concerns. Once a student completes and passes a module, they are sent certificates of completion through their personal chat group.

The SkillsCenter is structured as a for-credit course. Students enroll and register for the number of credit hours associated with their desired workload. Students typically register for 1–4 credit hours, which equates to 12.5–50 total module hours. If needed, students can talk with a course proctor to plan their workload for the semester. Following registration, students set personal goals to build their experience starting from their current skill level. Students then translate their goals into a workflow plan, building skills-work time into their calendar.

After students establish their goals for the semester, they are ready to start their work. Beginning with the first skill module in their list, students are encouraged to read through all parts of the module, familiarize themselves with relevant background information including the protocol and methods tasks, and to seek proctor help for support or clarification wherever they need it. An introduction to technical equipment is usually paired with descriptive figures and/or external links to operational training videos. After students have prepared for their experiment, they reserve the necessary resources and execute the SOP. This involves documenting all work, observations, and experimental data. MMTs follow every SOP, providing students with point-by-point descriptions of the requirements for passing each module. Once all methods task prompts are addressed, students submit their work as a single Word document for proctor review.

To support the course, we built a custom learning management system that is synchronized with the course Microsoft Teams page, allowing the team of proctors to process students' module submissions and provide timely feedback. Once students submit their completed MMTs, which include files with students' names, and the modules they are submitting, the dates of submission are populated into the "Proctor App." All feedback is linked to students' personal Teams chat group; upon module "acceptance" or "rejection, with revisions requested," students receive customized cards with appropriate feedback when necessary. When a skill is successfully completed, the grade book is automatically updated, and a certificate is created and placed in the student's course folder. For additional questions or discussion, students can communicate directly with their proctors in this chat group or visit them during lab proctor hours. This automated system has allowed us to expand the course from 10 to 15 students per semester to over 80.

Supporting student autonomy and providing a bridge to success

Aside from the opportunities to gain practical credentials, the SkillsCenter provides students with opportunities to develop additional scholarly skills, competencies, and self-perceptions. As students desire experience that accurately represents the workflows and expectations in a primary research laboratory, whether in academia, biotech, or Big Pharma, we have designed the course to offer these experiences as much as possible. To achieve this, we provide open lab hours, accessible support from senior lab members, resource scheduling calendars, and training that encourages students to participate as a collaborative member of an active research space. Students also direct their own learning, deciding what they want to learn and when they choose to learn it. Making these decisions helps students engage in the self-regulatory skills of planning, monitoring their progress, and evaluating their learning after each skill learning cycle.[14] As a result of this design, a variety of options become

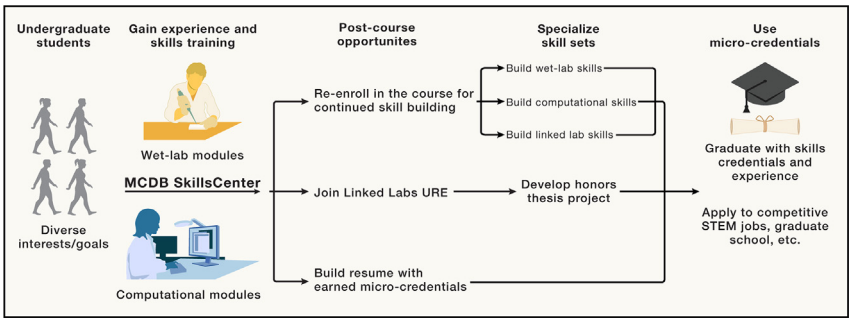

Figure 2. Pathways to success are driven by students' interests and goals and supported by enhanced access to opportunities

available to students upon completion of the course, from re-enrolling to learn additional skill sets to joining a linked lab and participating in an URE (Figure 2). We predict that this approach will not only enhance students' access to future opportunities but also support students' development of agency, self-efficacy, and feelings of belonging in science. We are currently monitoring students' development in these areas via voluntary pre- and post-course surveys and a post-MMT questionnaire that students submit after the completion of every skills module. We are also working with the MySkills Program that is part of the University of Colorado's Career Services and its Office of Data Analytics to evaluate the impact of SkillsCenter participation on students' post-graduation paths.

Vision for the future

Currently, the SkillsCenter offers micro-credential certificates for each module that are signed and dated by the course instructor. Students can download and display these on their resumes or on professional networking sites (e.g., LinkedIn). The SkillsCenter is working toward digital badging, perhaps through systems such as ORCID, that would provide students with digital credentials embedded with their own experimental data. In this way, we can enhance the credibility and value of the credentials earned and offer students the chance to provide direct evidence of their skill proficiency. The use of badge technology will open new avenues for recognition and enhance professional visibility in the scientific community. Finally, we have recently begun enrolling local community college students who are transferring to the University of Colorado Boulder. Taking a SkillsCenter course provides a valuable transition experience for these students prior to their official arrival on campus. As community colleges currently enroll a higher proportion of underrepresented minorities and non-traditional students than four-year institutions, extending bridges to success in this way has the potential to directly enhance the equity and diversity of STEM research communities.[15] We are also excited to begin offering the SkillsCenter opportunity to transfer students who seek to equip themselves for future research opportunities.

While we plan to continue developing the SkillsCenter program by increasing the number of skills offered, refining current operations, and forming connections with those interested in supporting student success through micro-credentialed opportunities, we recognize there will be challenges and problems in broadening access to this modality of STEM teaching. As this format is new to the undergraduate teaching curriculum, we hope to work with others who teach laboratory courses so that together we might enhance the power of skills training and opportunities for students in undergraduate STEM degree programs.

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DECLARATION OF INTERESTS

The authors declare no competing interests.

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