ARTICLE
Integrating Research into the Undergraduate Curriculum: 2. Scaffolding Research Skills and Transitioning toward Independent Research

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Undergraduate research experiences are widely regarded as high-impact practices that foster meaningful mentoring relationships, enhance retention and graduation, and stimulate postbaccalaureate enrollment in STEM graduate and professional programs. Through immersion in a mentored original research project, student develop and apply their skills in critical thinking, problem solving, intellectual independence, communication, collaboration, project ownership, innovation, and leadership. These skills are readily transferable to a wide array of future careers in and beyond STEM that are well-served by evidence-based approaches.

The 2019 Society for Neuroscience meeting included a well-attended workshop on integrating research into the curriculum at primarily undergraduate institutions (PUIs). This article is the second of three articles that summarize, analyze, and expand the workshop discussions. In this second article, we specifically describe approaches to transitional research courses that prepare students for independent research experiences such as undergraduate research theses. Educators can intentionally scaffold research experience and skills across the curriculum, to foster participation in scientific research and enhance diversity, equity, and inclusivity in research training. This article provides an overview of important goals and considerations for intermediate undergraduate research experiences, specific examples from several institutions of transitional courses that scaffold research preparation using different structures, and a summary of lessons learned from these experiences.

Key words: undergraduate research; PUI; STEM; scaffolding; CURE; CRE; active learning; research course; mentoring; equity; inclusive; underrepresented populations

INTRODUCTION

Many undergraduates enroll in gateway science, technology, engineering and math (STEM) courses to prepare for careers in the sciences, with only a subset of these students progressing to declare STEM majors, and only a fraction of STEM majors engaging in undergraduate research or capstone projects (Lopatto 2007; Russell et al., 2007; Graham et al., 2013; Freeman et al., 2014; Pinard-Welyczko et al., 2017; Asai, 2020). These culminating research experiences are well regarded as high-impact practices that are particularly effective at addressing the ongoing problem of underrepresentation by numerous underrepresented groups in STEM (Russell et al., 2007; Kuh, 2008; Bangera and Brownell, 2014; Mervis, 2016; Estrada et al., 2018). Subsequently, only a small fraction of students who earn a bachelor's degree in STEM will go on to earn advanced degrees (National Science Foundation 2010, 2018; Asai, 2020). Helping *all* students to see themselves as scientists and experience how science is done is an essential goal of programs that recognize that scientific knowledge is best revealed and communicated by diverse scientists and diverse teams (Page, 2007; Kuh, 2008; Hrabowski, 2015; Hofstra et al., 2020). This article focuses on transitional experiences and courses that can bridge the considerable differences between course design and student skills from onset to completion of an undergraduate STEM degree (Freeman et al., 2014; Wiertelak et al., 2018). We recognize that intentional and targeted strategies for preparing and welcoming students to research are needed at multiple points in an undergraduate timeline (Fernandes, 2020). We offer multiple ways to address students' needs from the first-year undergraduate (Buffalari et al., 2020) to the advanced undergraduate (Chase et al., 2020).

Contrasting Formats within STEM Education

A student's learning experience in introductory and intermediate STEM courses is typically highly structured. In most courses, students enroll through a standard registration process (equal opportunity) and share the experience with many classmates at similar stages of progression in college. Courses with laboratory components typically meet for two or three class sessions each week, have a weekly lab session, and may also include a discussion section. The instructor prepares a detailed syllabus that reveals considerable advanced design, and students can reasonably expect the course plan to be executed with only minor changes (pandemics not included). In addition to the instructor, the student may have access to teaching assistants and/or tutors formally associated with the course, as well as informal access to advanced students who have previously taken the course. Moreover, student learning actions required before and/or after each class session are clearly delineated by the instructor, in the form of selected readings, problem sets, recordings, etc. Materials used in class such as slides or notes are likely available, as are examples of assessments (sample questions on quizzes/exams, rubrics for lab reports, etc.). Deadlines for all of these elements are scheduled well in advance by the instructor, with regular feedback on progress.

The independent learning experience many undergraduates encounter in credit-for-research courses is quite different, and likely unfamiliar to them. Although some institutions achieve universal participation by requiring independent research of all students, for most students, enrolling in independent research requires navigating opaque and unwritten processes. Frequently students need to self-nominate by reaching out to ask a faculty member well in advance if they have room in their lab. This "ask" can feel overwhelming and intimidating for many students, particularly those with limited social capital or knowledge of an institution's hidden curricula (Smith, 2015; Estrada et al., 2018). Not all students navigate this transition effectively. Some never build up the nerve to ask a professor. Many first-generation students and those from groups underrepresented in STEM may be unaware of research opportunities. Others are aware but find the open and unstructured nature of research unfamiliar, daunting, or discouraging. After obtaining a position in a research lab, the numerous structural supports from traditional courses often give way to fewer or no peers, open scheduling, few discrete assessments, little evaluative feedback, and no tutors or TAs as supplementary instructors (AAAS, 2011; Cartrette and Melroe-Lehrman 2012). Research topics evolve, work is self-directed, failure is likely, trouble shooting is necessary, assistance may be limited, and research trajectories rarely follow their initial plans. Consequently, some institutions are implementing transitional experiences to bridge the significant gaps in format between traditional introductory courses and undergraduate research experiences (Pinard-Welyczko et al., 2017; Wiertelak et al., 2018; Chase et al., 2020).

Transitional Courses as Scaffolding

This article focuses on intermediate or transitional courses designed to enable students to expand their skills, knowledge, experience, and confidence in ways that will encourage them to do well in the less structured and more open-ended learning experiences common to advanced independent research. It describes several different course structures designed to scaffold skill development and prepare students for success as beginning researchers investigating original questions with confidence and agency.

The profound differences in structure between college STEM courses and independent research may not be apparent to students transitioning into a research lab (AAAS, 2011; Cartrette and Melroe-Lehrman., 2012; Wilson et al., 2013). To facilitate this transition, faculty members should be explicit with students about the important differences between their experiences taking a lab course versus those engaging in real team-based scientific exploration in the research lab. One author (BL) describes the transition to her students as similar to moving from baking a cake from a mix in a simple kitchen (that has exactly what is needed but nothing more) to preparing a, multi-course meal from scratch in a large commercial kitchen. Starting with a traditional lab course (or cake mix) provides important experience and skills that will be helpful when they enter into wide open research territory that holds considerable potential with far less structure.

To extend this cooking analogy, the transitional research experiences described in this article are designed intentionally to fall between these two extremes, to create intermediate experiences that prioritize learning skills and introduce opportunities for independent thought, but without expecting advanced proficiency. Such transitional courses come in many structures. In this analogy, they might resemble meal kits from a provider such as Blue Apron, carefully scouring cooking blogs and cookbooks to design a novel menu from existing recipes, or a reality cooking show competition with external limitations of ingredients and/or time. Each of these situations allows developing cooks to expand their skills and discover passions and talents.

Goals for Undergraduate Researchers

Using the pedagogical best practices of student-centered and backward design, it is important to ask what undergraduate research students must know and be able to do as a result of a successful transition from gateway lab course experiences to independent research projects (Wiggins and McTighe, 2005; Wilson et al., 2016; Wiertelak et al., 2018).

Significant learning goals across all models described here (Figure 1) include objective outcomes, such as a student's ability to use specific instruments and conduct particular procedures, propose experiments, navigate research literature, and/or produce data. Other learning goals include affective outcomes, such as increased confidence in a lab environment, sustained motivation for a future in STEM, and willingness to examine data carefully and believe them (even when results are unexpected). One of us (MEM) emphasizes that students should embrace unexpected data as the main way that scientists learn new things – even if those things are "only" how to design and run the experiment better next time. Ignoring or trying to hide anomalous data runs the risk of derailing scientific progress (Porter, 2005; Gillen, 2006; Steward and Balice-Gordon, 2014; Firestein, 2012, 2016). Many important scientific discoveries (some that have gone on to earn

Objective Learning Goals
- Navigate research literature
- Achieve technical competence with instruments and procedures
- Think critically, solve problems, and trouble-shoot challenges
- Design experiments
- Analyze and interpret data

Affective Learning Goals
- Boost confidence in the research lab
- Sustain motivation for a future in STEM
- Embrace the value of anomalous data
- Develop resilience and persistence
- Value learning from mistakes

Figure 1. Learning Goals Shared Across Intermediate Undergraduate Research Experiences.

recognition such as the Nobel Prize) began with early data that did not fit expectations.

Additional hallmarks of success are both objective and affective, such as reinforcing each student's ability to solve problems and persevere despite setbacks and challenges (Figure 1). Thus, successful student research requires nurturing environments that welcome questions, do not expect perfection, and normalize mistakes and failures that happen to all scientists (Schwartz, 2008; Firestein, 2012, 2016). Such nurturing environments avoid blame and reframe mistakes into opportunities for improvement, supporting mindsets around grit and growth (Dweck 2007; Duckworth, 2016; Canning et al., 2019). Similarly, a willingness to ask questions and challenge assumptions is also an important hallmark of success in developing research scientists. Finally, curiosity, dedication, self-motivation, and good time management are required for student success. BL uses a travel analogy to communicate that as part of a research course, they are in the driver's seat. She emphasizes that the student is not alone, and promises to be an active companion who is available to provide maps, gas, and help with directions. Students may begin the journey as a passenger, but they will eventually learn to drive for themselves.

EXAMPLES OF TRANSITIONAL COURSES THAT PREPARE STUDENTS FOR RESEARCH

Many STEM curricula preview and encourage undergraduate research by embedding mini research projects and course-based research experiences (CREs) within individual traditional lab courses (Bangera and Brownell, 2014; Dolan, 2016; Fromherz et al, 2018; D'Arcy et al., 2019; Krim et al., 2019; Nahmani, 2019). These curricular designs answer the call for more active learning strategies that enhance student performance and reduce course failures (Lopatto, 2007; Freeman et al., 2014; Theobald et al., 2020). Such experiences facilitate more inclusive research training and recruiting to build interest and confidence in students who might not initially self-nominate for research experiences (Smith, 2015; Estrada et al., 2018). The sections that follow illustrate several specific examples as case studies to demonstrate how building such individual courses into multi-year curricula for research skill development can yield valuable opportunities for helping students develop into independent researchers. From our collective experiences mentoring research students at six different PUIs, getting students involved in our research labs works best when research skills are introduced early and scaffolded across the entire curriculum, rather than being confined within individual courses. We recognize many effective ways to allow students to transition into becoming independent researchers (Mickley et al., 2003; Ramirez, 2012; Dunbar, 2015; Morris et al., 2015; Calin-Jageman et al., 2018).

Scaffolding Research Skills: From Introductory Course Group Projects to Research Methods Courses with Individual Projects

First Research Exposure

Before students engage in whole courses that immerse them in research, it is important to encourage their curiosity and build skills with some smaller projects, often as extensions of regular introductory training experiments that explore different variables (Buffalari et al., 2020). Intermediate courses can also incorporate this introductory mini-project team model, which produces a cadre of students eager for the more involved transitional research experiences that are the focus of the rest of this article.

Assisting in a Research Lab

To continue student skill building and maintain their research labs, faculty members at Lycoming College each select two to three students from the fall semester's introductory biology class, based on students' interests, technical prowess, data ethics, and collaborative skills. These students begin by doing support tasks in individual faculty members' labs, even as they are progressing through their regular intermediate-level lab courses that also include two to four week-long group research projects. At first, they learn lab basics such as cleaning glassware, making solutions, sterile technique, animal husbandry, operating instruments, and conducting routine procedures (biopsies, DNA extractions, PCR reactions, etc.). Much of this work also supports the faculty member's regular teaching labs, so new students can be paid as lab assistants through institutional work-study funds. This paid assistant model also enhances diversity among future student researchers by reducing situations in which students are forced to choose between income and research experience. Periodic lab group meetings with the faculty member and the more advanced research students provide motivation and context for how each student's support work and projects align with the lab's overall research goals. Sophomores and juniors continue these paid duties, and those who demonstrate reliability and curiosity then shadow projects being conducted by more experienced students in the lab, Primary Literature

- Lead a primary literature article class discussion

Lab Notebooks

- Develop a student-generated collaborative rubric for lab notebook grading based on review of a selection of previous research student notebooks
- Keep a lab notebook, graded several times during the semester with specific feedback for improvement

Laboratory Skills

- Carry out the proposed research experiments
- Analyze and interpret the data

Proposal Development, Review, and Revisions

- Write an NSF-style research grant proposal
- Simulate grant panel with peer review
- Revise the proposal using peer and mentor feedback

Communicating Research Results

- Present orally to classmates
- Write a research journal-style article (due in sections)
- Create a poster presentation suitable for a scientific conference such as SfN, ASM, etc.

Research Ethics

- Discuss specific scenarios, including role playing of different stakeholders (researcher, principal investigator, institutional ombudsman, journal editor, fellow scientists, etc.)

Continuing in STEM

- Learn how to apply to graduate programs, professional programs, and/or jobs

Figure 2. Deliverables for students in Lycoming College junior/senior level Research Methods in Cell and Molecular Biology course.

including the Research Methods course projects described below.

A Full Semester Individual Research Course

Beyond the regular courses and paid teaching lab assistantships mentioned above, junior and senior Lycoming students may go on to take Research Methods in Cell and Molecular Biology (Research Methods for short). In Research Methods, students develop original research proposals that spring from the research area in the individual faculty member's lab where each student has previously served as an assistant. The deliverables for Research Methods emphasize experiences critical for research success (Figure 2) and ensure that students embark upon experiments with some relevant technical skills and a basic appreciation for the intellectual drive behind the lab's work. The individual projects from Research Methods often evolve into subsequent independent study or honors projects at higher levels of sophistication (for more on these Honors projects, see Chase et al., 2020).

In this transitional Research Methods course, students learn about the persuasive nature of research articles (Porter, 2005; Gillen, 2006; Osborne, 2010), develop an NSF-style research proposal for their research project, participate in peer review panels with fellow students and the professor, and begin their experiments. This course is taught by a rotating faculty member (instructor of record) each fall, who is the only one to receive contact hour credit, although three to four different faculty members mentor students in their research labs. Students pay regular tuition and receive one course/four credit hours out of a full load of 16 credit hours per semester. They participate in two to three hours per week of formal classroom instruction with the instructor of record and are expected to do six to eight hours of research work per week outside of regularly scheduled class time with their faculty research supervisor. For some students, scheduling time in the lab when the research supervisor is available can be a challenge (see the Structure, Timing and Planning section below). This course strikes a balance between pre-scheduled time with the course instructor and individually scheduled time with the lab project supervisor (often two different faculty members). The research projects are individual, not group efforts. Most students are juniors, although some are seniors who come late to the research program. Making Research Methods a regular catalog course raised the visibility of research opportunities, and it has helped to diversify the group of students engaging in research. Delightfully, most Research Methods students go on to conduct more advanced Independent Study or Honors projects that often build on their Research Methods course projects and experience (Chase et al., 2020). Juniors and seniors also present at regional and national neuroscience meetings (for a list of these, see Chase et al., 2020, Appendix 2; Ramos et al., 2020).

Multi-year Research Transition Within Capstones

An alternate mechanism through which research can be scaffolded across a curriculum is to reconceptualize senior capstone research projects into team projects. Less experienced, transitioning students can take a progression of courses across three years during which they gain research skills while helping to support the seniors' projects. First- and second- year students at Westminster College take a one-credit research course each year, through which they participate in a senior's capstone research project and are introduced to the overall research process (Buffalari et al., 2020). Juniors take a two-credit course, Critical Thinking and Writing in Neuroscience, that places a strong focus on the interrogation of the neuroscience literature surrounding a novel experimental question for proposal writing, with continued contributions as a member of a senior-led research team. Seniors then take a four-credit senior research experience course where they lead a team of non-senior researchers (Chase et al., 2020).

The educational goals and objectives for the junior-level experience are taken from published guidelines (APA, 2013; Wiertelak et al., 2018) and adjusted based on appropriateness for intermediate-level students. These include extensive critical analysis of the primary literature that culminates in a written proposal, which includes the design of a specific novel experiment in neuroscience. Juniors attend one 90-minute course session per week. One half of this session is devoted to team research meetings and is often conducted as a laboratory meeting; plans are made, reports on experimental progress occur, and discussions of experimental design and then data summary and analysis are included. The other half of this session takes the form of a writing course for juniors and seniors. While the Juniors write their proposals, the seniors are converting their junior-year proposals into final research papers. An iterative, scaffolded process is in place to guide junior proposal writing. They begin with experimental questions and reference lists, proceed to structured, referenced outlines, and move through sectioned drafts, with mentor feedback and revision at each step. Structured peer editing between juniors and seniors happens in these meetings as well; juniors are well served by seeing the progression of senior projects from experimental idea to final product. Juniors also complete this course having a strong foundation in the relevant primary literature, as well as a polished proposal that serves as a jumping off point for entry into the senior year, four-credit experience.

Research Projects in Lecture plus Lab Courses

A useful scaffolding experience is to build small group research projects into the lab component of intermediate-level courses that also have lecture components. These projects can be carried out over two to four weeks, and have higher expectations for literature engagement and protocol development than typical freshman mini lab projects.

The College of Wooster sophomore-junior level Behavioral Neuroscience course and laboratory is one model of a scaffolded group research experience. Similar to Lycoming's Introduction to Biology course, students access and read primary scientific literature, cite sources, design small but properly controlled experiments, collect and analyze data, and write a short journal-style article as part of the laboratory component of the course. Because all seniors must complete an independent senior thesis (Chase et al., 2020), this course intentionally scaffolds effective reading of primary research, thinking like a scientist, proposing research experiments with peer review and input, and slowly building expertise in statistical analysis and writing. Over several weeks, in small groups during lab, Behavioral Neuroscience students design rodent research projects, present their experimental rationale and research methods in a "grant panel" poster format, select, refine and conduct a subset of the proposed projects, and use those data for a mini-manuscript. Although students conduct the experiment in small groups, the writing is independent, and often quite varied within a group. With at least two dependent variables by design, students can build different experimental hypotheses and analyze slightly different data from their group mates. Along the way, the writing process is scaffolded with iterative peer-review, beginning with the introduction and methods, a full lab session dedicated to statistical analysis, data reporting and figure development, a full manuscript with peer and instructor review, and then the final paper. This process mimics the senior thesis project in a shortened time frame and with less complexity, so that the students build the skills necessary for later success.

The sophomore/junior-level Neurochemistry and Disease course at Hope College helps transition students from the Introduction to Neuroscience course, where they complete short (four to six week) group research projects (Buffalari et al., 2020), to completion of a year-long senior capstone research experience (Chase et al., 2020). The goals of the course are to continue to build scientific literacy, improve scientific writing, provide more opportunity to develop research expertise, and hone collaboration skills. Students gain valuable experience reading and critically evaluating primary literature in the process of writing a 15-20 page review on a neurochemical disease of their choice. This assignment is highly scaffolded and requires students to read and evaluate at least 20 primary research papers, compile an annotated bibliography, develop a detailed paper outline, and complete multiple drafts that are reviewed by the faculty member and at least two peers. This semester-long project instills important literature analysis skills and writing expertise that will be necessary for writing an NSF-style grant proposal and research manuscript as a part of their senior capstone research project. In the lab, students collaborate across multiple lab sections to contribute to an ongoing structure/function study of a membrane transporter. Pairs of students evaluate how novel mutations in the transporter affect expression, post-translational modification, localization, and function. As a part of this process, students evaluate their findings relative to the other pairs of students in the course, thus developing important communication and collaboration skills which will help prepare them for group research projects in the advanced senior capstone course (Chase et al., 2020).

Group Investigation Courses

Group investigation (GI) courses in the Davidson College biology curriculum allow a faculty member to mentor a small cohort of students conducting original scientific research and/or teach students specific research skills that align with the faculty member's research program. Prerequisites vary and are determined by each instructor, ranging from an introductory biology course to specific intermediate biology courses. All GIs satisfy an upper-level elective in the major, with some satisfying electives in interdisciplinary minors. Examples include: Light Microscopy, Membrane Transport Mechanisms, Avian Behavioral Ecology, Applied Insect Ecology, Dendrology, Genetics of Mitochondrial Shaping, Genome Editing, Diversity and Extinction Analysis, and Biotoxicity of Hookah Tobacco Smoke. Small teams of students learn a set of research skills and/or collaborate to conduct research in ways that go far further and deeper than what can typically be accomplished in the weekly lab session of traditional upper-level lab courses. Intentionally less structured than traditional lab courses, yet more structured than independent research, GIs often feature many elements of research methods courses (Figure 2) and may, on occasion, use elements of traditional courses such as quizzes to reinforce specific knowledge or skills.

Each GI develops a unique set of learning objectives, expectations, products, and deliverables. Collaboration, understanding research literature, developing proposals, data collection, analysis, communication, and rigorous research are vital priorities in all GI designs. Despite varied instructional formats, most GIs culminate in students presenting their work at an end-of-year campus celebration of student scholarly work and/or at appropriate scientific meetings. Many GIs also produce preliminary data for grant proposals, foundations for subsequent research projects, and/or contribute to publications.

Group investigations are designed to provide an efficient way for faculty members to mentor research students within a course that counts as a full course within each instructor's teaching load, and to recognize the importance of providing a variety of accessible opportunities for students to engage in research. Some GIs, such as Light Microscopy or Dendrology, prioritize developing advanced research skills that students may then opt to expand upon via subsequent independent research courses (or summer research). GI designs often include team research projects that are logistically more than what a single student could reasonably accomplish via independent research and other GI designs bring together several students doing largely independent, yet interrelated research projects.

Because GI enrollments use normal course registration mechanisms, they can welcome all students, particularly those who might not yet see themselves as research scientists, might not feel comfortable approaching a professor about research, and/or might not feel prepared to engage in a fully independent research project. Students who enjoy their GI experiences often develop skills, confidence to allow them to continue research subsequently as summer and/or semester projects.

Sequential Project-Based Research Courses

Combining many elements of the programs described above, the Psychology Department at Miami University (Oxford, OH) developed a three-semester curricular program (Fall, Winter, Spring) for third and fourth year students without prior research experience. A strong emphasis of the program is the recruitment of students from under-represented populations. The Broadening Undergraduate Research Program (BURP) in Behavioral Neuroscience facilitates independent research for up to 20 students per year (out of ~1000 psychology majors), by organizing them into teams of two to four students who are mentored by a single faculty member. Across the three semesters, groups meet bi-weekly with the instructor to engage in all aspects of a behavioral neuroscience research project. They develop a research question with testable hypotheses (given program constraints and instructor expertise), design animal experiments, and then collect and analyze their data. Along the way, students also obtain related training, including experience applying for funding (from the department and undergraduate research office), developing and managing an institutional animal care and use protocol, designing and presenting scientific posters, and extensive experience with scientific reading and writing. More information on the advanced stages of this program can be found in the third article of this series (Chase et al., 2020), including a discussion of student assessment, outcomes, and other considerations. Students completing this program can transition directly into independent research, often building on the project they developed in the program.

LESSONS LEARNED

Structure, Timing, and Planning

Intermediate, scaffolded research experiences require careful structure and planning to provide students with an appropriate balance of structure and independence. Mentors must design projects that fit with student availability and skill levels, communicate clear expectations, and provide accessible resources such as detailed protocols (Ruble and Lom, 2008). Many undergraduates struggle with time management skills. It is often helpful to build structures that encourage (or require) students to begin to discuss research projects with mentors in advance of the start of the term to set expectations early and minimize time lost when students must scramble to find a mentor or project at the start of a term.

The multi-stage experimental process and lack of obvious due dates associated with research experiences may cause students to fall behind more easily than in more structured traditional courses. Thus, setting regular benchmarks is essential to helping students build effective time management strategies. Benchmarks can vary considerably in nature, from lab notebook checks to quizzes on lab protocols, to quotas of accrued lab time, to deadlines for performing specific procedures. In addition, few undergraduates transitioning into research have large chunks of time available to devote to the execution of lengthy procedures in full compliance with lab safety regulations, given obligations such as work, family, other courses, and numerous extracurricular activities. Thoughtfully breaking projects up into smaller and shorter pieces that can fit into a busy undergraduate schedule and/or can be conducted by a coordinated team of students is a crucial component for both research effectiveness and lab safety.

Communication

Undergraduate researchers benefit greatly from regular communication with their research mentor and fellow research group members. The overall project plan and desired skill development goals should be frequent topics of these conversations. To sustain excitement, confidence, and engagement, it is important to remind students that they are discovering new knowledge and that they are capable of generating publishable data. At such early points in their research experiences, students frequently need help seeing the relationship of their small part in the lab's research to its larger goals. Student awareness of big picture goals can help to sustain motivation during slow learning curves and technical difficulties. It is important to encourage students to think beyond what their hands are doing that day, to their relationship to the broader scientific enterprise. Meeting with undergraduate researchers one-on-one at least weekly, in addition to their team meeting time, is a best practice. One of us (BL) uses an approach in which students respond to five questions each week to chart their research progress. This approach also normalizes asking questions and provides a mechanism for students to communicate their needs (Campbell and Lom, 2006). When such frequent and individual communication is not feasible, regular group meetings can foster an awareness of the importance of teamwork in science. Moreover, a wide variety of apps (GroupMe, Trello, Google Docs, Slack, etc.) can help to coordinate sequential work that requires multiple students to complete specific tasks in order and track outcomes.

Beginning researchers not only need regular communication with their mentor and peers, but that communication must be bidirectional and open (Ramirez, 2012). Students need to feel empowered to ask any questions that occur to them, and they need to know that they are not expected to know everything, although they are expected to ask questions. Often their previous educational experiences have discouraged asking questions that might reveal what a student does not (yet) know or suggested that their questions are not worth asking. Some international students may come from educational or cultural backgrounds in which asking questions of the instructor is considered disrespectful or insulting. Modeling and rewarding curiosity and questioning behaviors are critically important to developing essential skills in young research scientists. Hearing a research mentor say “I don't know, let's try to figure that out” empowers students to ask their own questions. One author (DB) starts with an icebreaker to normalize the practice of saying “I don't know” out loud, in which students ask questions they expect are unanswerable.

In addition, celebrating successes of all sizes along the way is an important part of lab communication. Developing lab traditions that build community and identity as well as sharing genuine enjoyment of the daily process of research are as essential for undergraduates working in their first research lab as they are for sports teams to create a positive and collaborative environment. These traditions and celebrations may be as simple as a spontaneous dance break in lab, to a recognition at a lab meeting, to lab outings.

Pipelining in Undergraduate Research Labs

Devoting time to setting up a skills pipeline in a PUI research lab where more senior students help to train and mentor newer students yields dividends in faculty time saved. Pipelining also boosts student abilities to collaborate and understand the interdependency of the members of a research team. Promoting continuity in the lab skills of the entire group from one year to the next is another desirable outcome of such intentional skills scaffolding or pipelining. One author (MEM) engages her undergraduate students in planning this skills pipeline, drafting charts of the projects going on in the lab, the skills they require, and which students should be learning these skills across their three or four years with the lab. This process has the added effect of ensuring that each student sees a pathway forward, has peer role models, and maintains an awareness of his/her place in the larger project(s) over time. Consciously choosing a diverse group of students early in their STEM careers and providing them with lab experiences that promote autonomy and responsibility is a good way to foster diversity and inclusivity for the scientific community going forward (Wilson et al., 2012; Haeger and Fresquez, 2016).

BENEFITS

Improved Research Training & Community

Many of the curricular models described in this article were created to help organize and improve the quality of student research in a department or on a campus. At the level of individual students, important benefits included improved training in the practice of science by ensuring that students understand the full context of their individual contributions within larger research projects. Course designs and research practices that encourage students to develop proposals, do experiments, collaborate as a research team, read primary literature, think critically about experimental design, learn from failures and roadblocks, and write scientifically prepare undergraduates for successful subsequent, more independent research experiences. The transitional or scaffolded experiences described here often encourage and prepare students to develop a proposal for a thesis and/or apply for competitive summer research positions such as NSF Research Experiences for Undergraduates (REU). Additionally, many students also begin to experience a sense of belonging and co-ownership of the research enterprise in a research lab. The benefits of role models and mentors are many (Kuh, 2008; Hayes, 2018; Wiertelak et al., 2018; Krim et al., 2019), with a sense of belonging known to be particularly important for retaining students from underserved populations (Wilson et al., 2012; Haeger and Fresquez, 2016; Estrada et al., 2018).

At the level of a faculty member's research program, benefits from scaffolded research training can include reduced data loss, reduced need for retraining, and improved habits in documentation and record keeping, which can powerfully enhance continuity between students as they enter and exit an ongoing research project. At the level of the department or campus, intermediate courses and scaffolded research designs have fostered closer relationships and understanding between faculty members' research areas, including some new collaborations. At the level of the broader scientific community, students gain experiences attending and presenting at scientific meetings (where some return to campus with awards), and build morale and expectations of excellence (for a list of these meetings, see Chase et al., 2020, Appendix 2).

Improved Diversity, Equity, and Research Access

Access to undergraduate research opportunities is not equal; students from populations underrepresented in STEM often experience reduced participation (Kuh, 2008; Weekes, 2012; Wilson et al., 2012; Ramos et al., 2017; Estrada et al., 2018; Martinez-Acosta and Favero, 2018). Most examples of intermediate or transitional research experiences described here were intentionally designed to enhance equity in access to research for all students. Making research experiences accessible through routine course registration systems that are open to all students can improve access for students who do not have the confidence or social capital to ask to work in a faculty member's lab. Similarly, when research experiences are required for all majors, issues of who gets to do research or limits on research participation are reduced or eliminated. In particular, formats that scaffold research throughout the undergraduate curriculum build a culture where all majors observe research as something available to or expected of all students.

Improving economic fairness is an important goal when determining who gets access to do research and potentially become a scientist. When research is a standard academic expectation (rather than an add-on), it becomes more accessible to all students, and is less likely to exclude students who simply cannot afford to take time away from other responsibilities to participate in research. At Lycoming College, the Board of Trustees chair was so impressed by the outcomes of a scaffolded research curriculum that a new research fellowship program was created to pay students a stipend and provide a small supply budget to carry out for-credit honors research projects (Chase et al., 2020). Such fellowships ensure that qualified students can take time off from a campus job to focus on their research, increasing the equity, diversity, and inclusiveness of the campus research culture.

Improved Research Products

When undergraduate research projects are organized and coordinated, research productivity can improve considerably for both the students and for their faculty mentors. By scaffolding students and supporting their transition from learning about science in a traditional course format to creating new scientific knowledge through an independent research project, student participation in presentations and publications become more natural and achievable outcomes of undergraduate research. Student presentations and publications are obviously beneficial to students applying to graduate and professional programs and employment. These same research products also help their mentors establish themselves as productive scholars in their field, can provide preliminary data to support grant applications, and provide evidence of productivity for tenure and promotion.

Teaching Credit for Research Mentoring

Several examples described in this article directly help faculty members with high teaching loads to gain critically important contact-hour credit for supervising student research. Similarly, when teaching credit is provided for mentoring undergraduate research, faculty members have more time and energy available to accomplish their scholarly research objectives and contribute to scientific knowledge. At many institutions, the labor of mentoring and training research students remains an expected responsibility that is not recognized with pay and/or as a component of a teaching load. Supporting course mechanisms wherein a faculty member's teaching and research can interact synergistically, as described in this article, is particularly helpful at critical points in an academic career.

CHALLENGES

Team Dynamics

Not all students will emerge as natural researchers, contributors, or leaders in a research environment, due to variability in ability, interest, understanding, and/or time constraints (either voluntary or imposed by economic necessity to work for pay). Additionally, in team situations, interpersonal conflicts, miscommunications, and procedural errors are challenges to be expected. Clear policies regarding team conduct including communication within teams, processes for raising issues, and the consequences of a lack of team participation are helpful in addressing these challenges. This learning process is also useful even for students who will go on to careers outside of neuroscience (Akil et al., 2016).

An additional challenge is designing scaffolded structures for students entering the process at all levels, with differing needs, experiences, commitments, and even at times different majors, given the interdisciplinarity of neuroscience. Strategies to reduce this tension include giving senior students responsibility as teaching or learning assistants, leading discussions, providing peer editing, and engaging in pedagogy directly. Pipelining more and less experienced students together in group projects or research support tasks can also help to reduce this hurdle.

The team dynamics within and between departments and faculty members engaged in research programming can also represent a challenge. Implementing the multi-year, scaffolded research skill models described here requires detailed and realistic advance discussions among faculty members to produce coordinated courses and syllabi, and this takes time. Cooperating to educate the students about how the research training program works across the curriculum also takes thought and time. Some faculty members may need encouragement and/or assistance to revise existing courses, design new courses, or develop new collaborations that use research-based approaches. This burden may be especially high for junior or pre-tenure faculty, who must develop their own research agendas while figuring out how to integrate them into existing course structure and the broader curriculum. At our respective institutions, however, we have found that the results for both students and faculty members are worth this investment in effort.

Grading and Assessment

Assessment of student learning can also be challenging for research mentors. Careful advance planning that matches student research learning goals not only to student research course activities, but also to explicit assessment methods, enhances the students' experience and saves the faculty member grading time (Wilson et al., 2016). Some research courses with frequent check-ins and/or lengthy writing assignments can pose a significant burden on faculty time. When available, campus resources such as teaching assistants, writing centers, and peer tutors can somewhat lighten the load. In addition, expectations for the quality and/or quantity of research may differ by student stage or type of research, making communication again critically important. Having current students read the work products of past students can provide students with examples of acceptable and/or exceptional work. Strategies wherein students and mentors collaboratively articulate specific goals and expectations can guide end-of-term evaluations in ways that are transparent and fair and can reduce potential mismatches between student and faculty understandings of how student research efforts are evaluated.

At the level of institutional assessment, the diversity of specific local financial and staffing constraints often hampers the development of uniform assessment tools that are applicable across different research labs, departments, programs, and institutions. The terminology used to describe these research experiences varies wildly across institutions (see Chase et al., 2020, Appendix 1 for a summary of terminology). Therefore, institutional-level assessments of undergraduate neuroscience research training are usually developed within each program's unique constraints (Muir, 2015). Some common "core" student outcomes, however, can be applied across institutions (Figures 1 and 2; APA, 2013; Wilson et al., 2016). An increased use of common assessments may promote evaluation of the impacts and benefits of undergraduate research beyond program- or institution-specific levels (APA, 2013).

Funding and Staffing

Covering the costs of instrumentation and supplies for undergraduate research can be challenging, particularly for under-resourced campuses. In addition to material costs for reagents and instruments, undergraduate research also requires staff support for research logistics such as lab safety, animal care, reagent preparation, purchasing, inventory, etc. To support a robust and meaningful undergraduate research program, faculty mentors are often forced to invest considerable time in the traditional duties of a lab technician, such as procuring supplies, maintaining instruments, seeking or developing inexpensive alternatives, training students in routine procedures, and ensuring organized and safe working environments. Advocating for the hiring of lab managers who can assist with safety and inventories can help with this time demand. Consciously planning a skills pipeline with the undergraduate research group or class can also relieve some of this pressure on the faculty member, while building student confidence and capabilities. Some PUIs have modest internal funds to purchase supplies for student research. Others have explicit student research positions with small supply and/or travel budgets.

Mentoring undergraduates as they begin to transition into independent researchers is necessarily a labor-intensive practice requiring considerable individual attention and time investment by faculty members. Moreover, undergraduate neuroscience programs recently have experienced remarkable growth and popularity (Ramos et al., 2016), making it especially challenging for many institutions to offer enough seats in neuroscience courses, driving course ceilings higher, and/or limiting the number of neuroscience students in the major. These constraints can reduce student access and equity of opportunity and increase faculty workload. Thus, several of the course strategies described in this article were developed in response to these pressures of high student demand and scarce staffing and resources.

MINDING OUR MISSION

The most important things faculty mentors can give to their students are their time, their attention, and new opportunities to learn and develop. Undergraduate research is a high-impact active learning practice that can take many forms to influence the trajectory of a young scientist's education, confidence, and motivation to become a scientist (Lopatto, 2007; Kuh, 2008; Freeman et al., 2014). Consequently, cultivating rich environments that support undergraduate research opportunities at the beginning, intermediate, and advanced levels of an institution's neuroscience curriculum is foundationally essential. Beyond benefitting individual students and mentors, undergraduate research also supports the future of the increasingly collaborative scientific enterprise. To address our most challenging and timely questions about how behavior and the brain in both health and disease, neuroscience desperately needs talented and diverse young minds (Page, 2007; Hrabowski, 2015; Hofstra et al., 2020). As Barres (2018) appropriately noted, "Diverse perspectives drive innovation. Diverse young scientists frequently are successful because they enter a field and see the same old data in completely new ways." Consequently, it is imperative that as scientists and as educators we ensure that the next generation of scientists get frequent opportunities to generate and engage with original data, whenever and however possible. Even small research opportunities can have meaningful, long-term impacts that will pay many future dividends for the student, the mentor, and society.

REFERENCES

Akil H, Balice-Gordon R, Cardoza DL, Koroshetz W, Posey Norris SM, Sherer T, Sherman SM, Thiels E (2016) Neuroscience training for the 21st century. Neuron 90(5):917-926.

American Association for the Advancement of Science [AAAS] 2011. Vision and Change in Undergraduate Biology Education: A call to action. Available at www..visionandchange.org.

American Psychological Association. (2013). APA guidelines for the undergraduate psychology major: Version 2.0. Available at http://www.apa.org/ed/precollege/undergrad/index.aspx.

Asai D (2020) Race matters. Cell 181(4):754-757.

Bangera G, Brownell SE (2014) Course-based undergraduate research experiences can make scientific research more inclusive. CBE-Life Sci Educ 13(4):602–606.

Barres B, Hopkins N (2018) The Autobiography of a Transgender Scientist. Cambridge, MA: MIT Press.

Buffalari D, Fernandez J, Chase L, Lom B, Morrison ME, McMurray MS, Stavnezer AJ (2020) Integrating research into the undergraduate curriculum: 1. Early research experiences and training. J Undergrad Neurosci Educ 19(1):A52-A62.

Calin-Jageman RJ, Calin-Jageman IE, Acosta VM, Hardwick J, Johnson BR, Wiertelak E (2018) Best practices for developing, assessing, and sustaining inclusive curricula: Proceedings of the 2017 Faculty for Undergraduate Neuroscience workshop. J Undergrad Neurosci Educ 16(3):A42-A43.

Campbell AM, Lom B (2006) A simple e-mail mechanism to enhance reflection, independence, and communication in young researchers. CBE-Life Sci Educ 5(4):318–322.

Canning EA, Muenks K, Green DJ, Murphy MC (2019) STEM faculty who believe ability is fixed have larger racial achievement gaps and inspire less student motivation in their classes. Sci Adv 5(2):eaau4734.

Cartrette DP, Melroe-Lehrman BM (2012) Describing changes in undergraduate students' preconceptions of research activities. Res Sci Educ 42:1073–1100.

Chase L, McMurray M, Stavnezer AJ, Buffalari D, Fernandes JJ, Lom B, Morrison M (2020) Integrating research into the undergraduate curriculum: 3. Research training in the upper-level neuroscience curriculum. J Undergrad Neurosci Educ 19(1):A74-A87.

D'Arcy CE, Martinez A, Khan AM, Olimpo JT (2019) Cognitive and non-cognitive outcomes associated with student engagement in a novel brain chemoarchitecture mapping course-based undergraduate research experience. J Undergrad Neurosci Educ 18(1):A15-A43.

Dolan E (2016) Course-based undergraduate research experiences: Current knowledge and future directions. Committee on Strengthening Research Experiences for Undergraduate STEM Students (National Science Foundation). https://sites.nationalacademies.org/cs/groups/dbassesite/documents/webpage/dbasse_177288.pdf.

Duckworth A (2016) Grit: The Power of Passion of Perseverance. New York: Scribner.

Dunbar GL (2015) Best practices: The neuroscience program at Central Michigan University. J Undergrad Neurosci Educ 13(3):A150-A154.

Dweck C (2007) Mindset: The New Psychology of Success. New York: Ballantine Books.

Estrada M Hernandez PR Schultz PW (2018) A longitudinal study of how quality mentorship and research experience integrate underrepresented minorities into STEM careers. CBE-Life Sci Educ 17(1):1-13.

Fernandes J (2020) Course models for integrating research into the curriculum. https://neuronline.sfn.org/training/course-models-for-integrating-research-into-the-curriculum.

Firestein S (2012) Ignorance: How it Drives Science. New York: Oxford University Press.

Firestein S (2016) Failure: Why Science is so Successful. New York: Oxford University Press.

Freeman S, Eddy SL, McDonough M, Smith MK, Okoroafor N, Jordt H, Wenderoth MP (2014) Active learning increases student performance in science, engineering, and mathematics. Proc Natl Acad Sci 111(23):8410-8415.

Fromherz S, Whitaker-Fornek JR, Sharp AA. (2018) Classroom-based research experiences to support underserved STEM student success: From introductory inquiry to optogenetics in the embryonic chicken. J Undergrad Neurosci Educ 17(1):A97-A110.

Gillen CM (2006) Criticism and interpretation: Teaching the persuasive aspects of research articles. CBE-Life Sci Edu 5(1):34-38.

Graham MJ, Frederick J, Byars-Winston A,, Hunter AB, Handelsman J (2013) Science education. Increasing persistence of college students in STEM. Science 341(6153):1455–1456.

Haeger H, Fresquez C (2016) Mentoring for inclusion: The impact of mentoring on undergraduate researchers in the sciences. CBE-Life Sci Educ 15(3):ar36:1–9.

Hayes SM (2018) Engaging early-career students in research using a tiered mentoring model. ACS Symp Ser Am Chem Soc 1275:273-89.

Hofstra B, Kulkarni VV, Munoz-Najar Galvez S, He B, Jurafsky D, McFarland DA (2020) The diversity–innovation paradox in science. Proc Natl Acad Sci USA 117(17):9284-9291.

Hrabowski FA (2015) Holding Fast to Dreams. Boston: Beacon Press.

Krim JS, Cote LE, Schwartz RS, Stone EM, Cleeves JJ, Barry KJ, Burgess W, Buxner SR, Gerton JM, Horvath L, Keller JM, Lee SC, Locke SM, Rebar BM (2019) Models and impacts of science research experiences: A review of the literature of CUREs, UREs, and TREs. CBE-Life Sci Educ 18(4):ar65:1-14.

Kuh GD (2008) High-Impact Educational Practices: What they are, who has access to them, and why they matter. Washington, D.C.: Association of Am Colleges and Universities.

Lopatto D (2007) Undergraduate research experiences support science career decisions and active learning. CBE-Life Sci Educ 6(4):297-306.

Martinez-Acosta VG, Favero CB (2018) A discussion of diversity and inclusivity at the institutional level: The need for a strategic plan. J Undergrad Neurosci Educ 16(3):A252-A260.

Mervis J (2016) Genuine research keeps students in science. Science 352(6291):1266.

Mickley GA, Kenmuir C, Remmers-Roeber D (2003) Mentoring undergraduate students in neuroscience research: a model system at Baldwin-Wallace College. J Undergrad Neurosci Educ 1(2):A28-A35.

Muir GM (2015) Mission-driven, manageable and meaningful assessment of an undergraduate neuroscience program. j Undergrad Neurosci Educ 13(3):A198-A205.

Morris JK, Peppers K, Mickley GA (2015) Intentional excellence in the Baldwin Wallace University neuroscience program. J Undergrad Neurosci Educ 13(3):A146-A149.

Nahmani M (2019) Versatile undergraduate neurobiology course-based research experiences using open access 3D electron microscopy image volumes. J Undergrad Neurosci Educ 18(1):A65-A74.

National Science Foundation (2010) Science and engineering indicators. Arlington, VA. https://wayback.archive-it.org/5902/20160210151754/http://www.nsf.gov/statistics/seind10/.

National Science Foundation (2018) Science and engineering

indicators. Arlington, VA. https://www.nsf.gov/statistics/2018/nsb20181/report.
Osborne J (2010) Arguing to learn in science: The role of collaborative, critical discourse. Science 328(5977):463-466.
Page SE (2007) The Difference: How the Power of Diversity Creates Better Groups, Firms, Schools, and Societies. Princeton, NJ: Princeton University Press.
Pinard-Welyczko KM, Garrison ACS, Ramos RL, Carter BS (2017) Characterizing the undergraduate neuroscience major in the U. S.: an examination of course requirements and institution-program associations. J Undergrad Neurosci Educ 16(1):A60-67.
Porter JR (2005) Information literacy in cell biology education: An example from an advanced cell biology course. Cell Biol Educ 4(4):335-343.
Ramirez JJ (2012) The intentional mentor: effective mentorship of undergraduate science students. J Undergrad Neurosci Educ 11(1):A55-A63.
Ramos RL, Esposito AW, O'Malley, SO, Smith, PT, Grisham W (2016) Undergraduate neuroscience education in the U. S.: quantitative comparisons of programs and graduates in the broader context of undergraduate life sciences education. J Undergrad Neurosci Educ 15(1):A1-A4.
Ramos RL, Alviña K, Martinez LR (2017) Diversity of graduates from bachelor's, master's, and doctoral degree neuroscience programs in the United States. J Undergrad Neurosci Educ 16(1):A6-A13.
Ramos RL, Comiskey M, Dowling J, McFarlane HG, Betz AJ (2020) Undergraduate participation in the Society for Neuroscience. J. Undergrad Neurosci. Educ 18(2):A129-A133.
Ruble J, Lom B (2008) Online protocol annotation: A method to enhance undergraduate laboratory research skills. CBE--Life Sci Educ 7:296–301.
Russell SH, Hancock MP, McCullough J (2007) Benefits of undergraduate research experiences. Science 316(5824):548-49.
Schwartz MA (2008) The importance of stupidity in scientific research. J Cell Sci 121(11):1771.
Smith B (2015) Mentoring At-Risk Students through the Hidden Curriculum of Higher Education. Lanham, MD: Lexington Books.
Steward O, Balice-Gordon R (2014) Rigor or mortis: Best practices for preclinical research in neuroscience. Neuron. 84(3):572-581.
Theobald EJ, et al. (2020) Active learning narrows achievement gaps for underrepresented students in science, technology, engineering, and math. Proc Natl Acad Sci USA 117(12):6476-6483.
Weekes NY (2012) Diversity in neuroscience. We know the problem. Are we really still debating the solutions? J Undergrad Neurosci Educ 11(1):A52-A54.
Wiertelak EP, Hardwick J, Kerchner M, Parfitt K, Ramirez JJ (2018) The new blueprints: Undergraduate neuroscience education in the twenty-first century. J Undergrad Neurosci Educ 16(3):A244-A251.
Wilson A, Howitt S, Higgins D (2016) A fundamental misalignment: intended learning and assessment practices in undergraduate science research projects. Assess Eval High Edu 41:869-84.
Wilson A, Howitt S, Roberts P, Åkerlind G, Wilson K (2013) Connecting expectations and experiences of students in a research-immersive degree. Stud High Educ 38:1562-76.
Wilson Z, Holmes L, Degravelles K, Sylvain M, Batiste L, Johnson M, Mcguire S, Pang S, Warner I (2012) Hierarchical mentoring: A transformative strategy for improving diversity and retention in undergraduate STEM disciplines. J Sci Educ Tech 21:148–56.
Wiggins G, McTighe J (2005) Understanding by Design, 2 edition Alexandria, VA: Association for Supervision and Curriculum Development.

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