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Transitioning students to researchers: Instructional baby steps

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Structuring a course, or part of a course, to include a **C**ourse-based **U**ndergraduate **R**esearch **E**xperience (CURE) involves both changes in the course format and changes in the instructor's role and perspective(s). For the past three years we have facilitated authentic research experiences in two ways within the confines of a traditional course structure: (1) by including CURE elements in a traditional lab course and (2) using the CURE format for a complete three credit unit course. In both settings, learners have transitioned from thinking like 'students' to thinking, doing, identifying as, and becoming 'researchers'. This workshop provides the opportunity to move step by step through the process of integrating CURE attributes and principles into a traditional lab course. By the end of this workshop, you will have: (1) a clear understanding of the CURE approach and the related pros and cons, and (2) developed an actionable plan that integrates CURE approaches into your traditional lab course.

Keywords: instructional methods, undergraduate research, team science, molecular biology, biochemistry, microbiology, inquiry-based learning, experiential learning

Introduction

Undergraduate training in the sciences traditionally includes a mix of didactic lecture courses covering diverse topics in the discipline, and laboratory courses focusing on specific skills acquisition and training. There is often a focus on knowledge transfer in lecture courses in which students passively receive instructions and information. Traditional laboratory courses operate as a series of carefully staged "experiments" in which the research question being addressed has been previously answered (and is often foundational in the field) and students are being walked through a reenactment where they are provided all reagents and equipment to successfully obtain the expected result. While this form of training can help consolidate an appreciation of how we know what we know currently, and provides some training in performing classical protocols, it fails in preparing students to be researchers. The research process involves the following steps: (1) observe and identify something of interest that requires an explanation, (2) construct a testable hypothesis(es) that can provide insight, (3) create or find appropriate methodologies to test the hypothesis(es), (4) conduct experiments to obtain data, (5) analyze and reflect on whether the tested hypothesis(es) was/were validated or disproven, (6) create new hypothesis(es) as required, and importantly (7) share findings with others interested in the area of study.

Traditional laboratory exercises do not mirror the research process in that learners: (1) do not observe for themselves the initial insight that defines the problem under investigation, (2) do not formulate the question they are told to address, (3) do not construct the hypothesis to be tested, (4) are not asked to design experiments, (5) do not develop or choose methodologies, or (6) do not share their findings beyond handing in their report as an assessed assignment. Comparing typical student activities and outcomes with an external reference such as the

Research Skills Development Framework (RSD) (Willison et al. 2018) highlights the fact that traditional labs limit student development to the lowest development levels (prescribed research and bounded research). Integrating research training into undergraduate programs requires an alternate approach. One approach we have found to be exceptionally effective is to integrate principles of CURE courses into traditional lab courses. The inherent structure of the CURE approach has learners functioning at RSD Framework levels 3 and 4 (scaffolded research and self-initiated research). This workshop will walk instructors through the development of their own new laboratory activities that incorporate CURE principles.

The CURE Approach

CUREs are experiential learning opportunities that share five main attributes (Auchincloss et al. 2014): (1) the use of scientific practices, (2) discovery (outcomes are unknown by learners and instructors), (3) relevant work that has meaning beyond the course context, (4) collaboration (learners work in self-directed, self-managed research teams), (5) iteration. Learners learn by trying, failing, and trying again following active review and reflection, and by critiquing one another's work, especially to the extent to which claims can be supported by evidence. How is this all accomplished? The framework and premise are very straightforward. Students conceive, develop, and perform experiments in small teams to address a research question they have defined within the bounds of the course. They then publicly share their findings either publishing for others to review (see Sun, E. et al 2020a for an excellent example) and/or sharing their findings in a short public presentation. Implementation of CURE courses in undergraduate programs is beginning to gain traction at Canadian universities (Sun, E. et al. 2020b). The CURE approach is also applicable to smaller modules or projects within existing traditional laboratory courses.

Instructor's Role

In a course with CURE components the instructor switches into an advisory role. Learners have greater freedom to explore their own projects yet benefit from regular guided mentoring to ensure they address hurdles that arise, think about required controls, alternative approaches, and perspectives on their chosen topic. Additionally, the instructor needs to have scaffolded the course environment to define the potential scope of projects, and ensure required support is available both for learner safety, and for mentoring. Notably, most of the instructor's work is done before the course/activity is initiated.

Student Outlines

Overview

This workshop will focus on how instructors integrate a CURE approach to sections of their own traditional laboratory course. We have included here, as illustrations only, two examples of integrating CURE approaches. We have indicated each as -A, -B.

Example-A: Altering the Actin Cytoskeleton in Mouse 3T3-Swiss Albino Cells

Objectives

Practice tissue culture techniques
Learn to work effectively in a team
Develop critical thinking skills
Design an experiment in a team

Introduction

In the initial weeks of the course, and concurrent with other experiments, you will study experimental design, how to be an effective team member, and practice tissue culture techniques. You will research ways to alter the cytoskeleton of mammalian cells and bring an inspirational journal article to your first group meeting. In your team of four or five, you will discuss all the papers brought by individuals and choose one to use as your inspirational foundation for the design of your authentic research. You will be given four weeks to carry out your experiment using limited supplies and a common staining method. Progress reports will be submitted and discussed weekly with the instructor. At the conclusion of the project, your group will share their findings in an oral presentation and a written lab report.

Methods, Data Collection, and Analysis

Researching Topics and Creating a Research Plan

The first part of this project involves selecting your topic. You will each search primary scientific literature to determine how to alter the cytoskeleton of a eukaryotic cell and will bring one inspirational paper to a team meeting. The team will discuss the topics and choose one paper to use as the inspirational foundation for the group project. This should be novel research and not something that has been done before. You will submit a request for any materials or chemicals not found on the supplied chemical inventory prior to commencing your experiment. As well, a research plan must be submitted that includes the following components: (1) a short summary of the background, (2) aims of the research, hypothesis, research tasks and questions, (3) detailed research methods and controls, (4) working plan for the tasks, (5) experimental schedule, (6) foundational paper.

Altering the Cytoskeleton of Tissue Culture Cells

In your group, you will develop a novel experiment that has the potential to influence the overall morphology of the cytoskeleton of 3T3-SA cells. Prior to the start of four weeks of experimentation, each group will submit requests for novel reagents and prepare any unique reagents needed. Each week, groups will be given 6 35-mm dishes of 3T3-SA cells grown to confluence. Groups coordinate treatments so that all endpoints occur within the scheduled lab time. This allows for cells to be stained with Oregon Green 488-conjugated phalloidin and DAPI (4', 6-diamidino-2-phenylindole) by the end of the lab session. Unique treatments are prepared by the groups. All other materials are supplied to the groups. Images are collected using a fluorescence microscope and distributed to the groups the day following the lab. Groups are encouraged to use analysis software such as ImageJ, but all analysis of images is left up to the discretion of each group.

Presenting the results

Each group will meet with the instructor to discuss the updates they provide each week. At the conclusion of the four weeks of testing each group will give a 10-minute oral presentation of all relevant background, data analysis, conclusions, and future directions of their experiment to the class. A final written report is also submitted in the style of a scientific paper.

Example-B: Plasmid purification, quantification, and transformation

Objectives

Purify and quantify plasmid DNA from *E. coli*
Transform *E. coli* with purified plasmid DNA
Determine the efficiency of transformation

Introduction

Most introductory didactic biochemistry and/or microbiology courses routinely refer to plasmid DNA purification and transformation as standard molecular biology protocols. Many introductory laboratory courses include some aspects of plasmid purification, quantification, or transformation. For example, students may be provided with an aliquot of purified plasmid and a protocol (and reagents) to transform that DNA into a recipient cell line. We have transitioned these objectives into a two-week project with CURE principals by providing students with stated required goals (i.e., purify and quantify plasmid DNA from a supplied host strain, determine how much DNA they have purified, transform into a provided recipient cell line, determine the efficiency of their transformation). The key differences between this project and traditional labs lies in the support (or rather lack thereof), and the fact that learners work in small teams of three or more.

Methods and Data Collection

Plasmid Purification

Learners are provided with a binder containing Standard Operating Procedures (SOPs) for routine molecular biology procedures such as plasmid purification, agarose gel preparation and running buffer preparation. Commercial plasmid purification kits are also made available. Notably, none of the reagents are pre-made by instructional staff. Learners must work as a team to decide which protocol to follow, who is to make which required reagent, determine timelines for when reagents need to be made, etc. Teams must grow their own stocks of the plasmid containing strain, selecting growth conditions and media (stock concentrated antibiotic solutions are available).

Quantification and purity of plasmid DNA

Teams must determine how they will quantify their plasmid DNA (gel electrophoresis and spectrometric analysis are available). They must also devise a means of determining the relative purity of their plasmid preparation.

Transformation of provided E. coli *strain with their plasmid DNA*

Teams are provided with an *E. coli* strain as isolated colonies on a nutrient plate. They are required to create chemically competent cells and transform them with their DNA. They must also report the calculated efficiency of transformation. The SOP manual contains at least two methodologies for generating competent cells as well as methodologies for transformation via a transient heat pulse. None of the required reagents are premade by instructional staff.

Data Analysis

Inevitably the teams have something go wrong in at least one of the steps required to complete the project. Teams must work together to determine where things went wrong and determine what additional steps are needed to correct the error or overcome an obstacle. Instructors meet with each team weekly for project updates and to discuss potential directions of inquiry to identify issues. Teams are required to review available resources to determine an appropriate means of expressing transformation efficiency and use that approach with their data. Teams submit their results as a short report. Each team provides a short presentation to the class including a Question and Answer portion.

Discussion

Results obtained are compared to published reports and differences are noted and discussed. Opportunities for improving transformation efficiency are noted. Discussion of protocols where high efficiency transformation is required and protocols and approaches where high efficiencies are not necessary are encouraged.

Materials-A

Tissue culture facility with biosafety cabinet(s), incubator(s), cell lines, inverted light microscopes, fluorescent dyes, fluorescence microscope with image capture system.

Materials-B

General microbial growth media, chemicals required for buffers, incubators, water baths, electrophoresis equipment, spectrophotometry analysis (e.g., nanodrop) equipment, access to autoclaves or autoclave service.

Notes for the Instructor

One of the most difficult changes in approach is to provide learners with the opportunity to completely fail their attempts without intervening. This is essential (barring an obvious safety hazard requiring immediate intervention) to allow them to internalize that they must take responsibility for their own actions and approaches. Team meetings with instructors must be learner-led with instructors acting as research coaches to help learners ask themselves the right questions to discover where they may have gone wrong rather than serving as the "all-knowing" answer guru.

For Example-B, a key component of this exercise is not only obtaining the specific skill of DNA purification and transformation, but also, skills of problem solving, teamwork, and learning that failing an attempt is common and a valuable resource for learning something new and building resilience. We have learners self-score their perceived levels (1 through 7) for each of the facets of research of the RSD Framework both at the start of the exercise, and as a reflective activity after completion of the exercise. An in-class discussion follows in which surprising changes in attitudes are shared.

Cited References

Auchincloss, LC, Laursen SL, Branchaw JL, Eagan K, Graham M, Hanauer DI, Lawrie G, McLinn CM, Pelaez N, Rowland S, Towns M, Trautmann NM, Varma-Nelson P, Weston, TJ, and Dolan, EL. 2014. Assessment of course-based undergraduate research experiences: A meeting report. CBE-Life Sciences Education, 13: 29-40.

Sun E, Graves ML, and Oliver DC. 2020a. Propelling a course-based undergraduate research experience using an open-access online undergraduate research journal. Frontiers in Microbiology 11: 2980.

Sun E, Graves ML, and Oliver DC. 2020b. The Lay of the land: an overview of Canada's undergraduate research opportunities within the life sciences. SPUR 4(1): 63-71. doi: https://dx.doi.org/10.18833/spur/4/1/16

Willison J; O'Regan K; and Kuhn SK., RSD7: Researcher skill development framework (US English Edition) (2018). Open Educational Resources. 5. https://commons.und.edu/oers/5

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About the Authors

Dawn Giesbrecht has been a lab coordinator at the University of Saskatchewan since 1998 where she teaches labs in microbiology, molecular biology, biochemistry, and tissue culture to second- and third- year students and is a member of the CURE research lab instructional team.

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Dawn, Harold, and Sheryl, in addition to these initiatives, have collaborated on a series of blog posts that explain the CURE approach: **https://vpresearch.usask.ca/students/undergraduate/undergraduate-research-blog/undergraduate-research-blog.php**

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