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Work-in-Progress: Applying Backwards Design Principles to Redesign a Summer Research Experience for Undergraduates

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Abstract

This work-in-progress paper describes the pedagogical redesign of a summer research experience for undergraduates (REU). The summer REU that we have examined has functioned as a research apprenticeship program for over 20 years delivering numerous professional development opportunities to undergraduate researchers. The apprenticeship part of the program focuses on experience in a laboratory, conducting experiments or simulations. We have applied backward-course design principles to enhance the structure of the program. Backwards design is a way of designing curriculum by starting with the end goal in mind. This means identifying desired results (learning objectives) followed by acceptable evidence of learning (assessment) before developing instructional activities (instruction). Although backward-course design has been applied to course-based undergraduate research experiences (CUREs), to our knowledge, these principles have not explicitly been applied to a traditional apprenticeship model.

Introduction

Undergraduate research experiences (UREs) have become a popular program at many institutions to bridge the gap between theory and practice (Ahmad, 2022), engage students in a discipline (Drake, 2024), encourage students to pursue advanced degrees (Ahmad, 2022; Drake, 2024), and inform students about research career pathways (Ahmad, 2022; Drake, 2024; Siby 2024). UREs come in different formats such as course-based undergraduate research experiences (CUREs), a traditional research apprenticeship, or some unique hybridization of a CURE and an apprenticeship (Ahmad, 2022; Drake, 2024).

In this study, we focus on the redesign of a summer research apprenticeship program using backwards design principles (Hansen, 2011) which aid in constructive alignment (Biggs, 1996). Backwards design principles originate from outcome-based course design but to our knowledge, have not been explicitly applied to summer research apprenticeships in a peer-reviewed publication or at least the details of such a design has not been published in a peer-reviewed setting. Additionally, we acknowledge that backwards design principles have likely been implemented in practice to some degree, but this implementation may not have been published or explicitly stated. Consequently, our aim is to explicit backwards design practices to the design of URE apprenticeships.

Our program has required certain deliverables in the past such as a technical paper and presentation at a research program. However, the ideas that students are taking away from the program were not directly assessed. Instead, faculty & laboratories provide students with feedback on their technical paper and judges provide students feedback on their research presentation. Their technical communication ability is well assessed, but other research, laboratory, and conceptual knowledge is not directly assessed.

We aim to promote greater conceptual understanding and develop more focused assessments by using backwards design. Here, we present a work-in-progress form of the program design.

While the learning objectives and assessments portions are complete, the mini conference (learning activity portion) is not yet complete.

Literature Review

In this section, we discuss course-based undergraduate research experiences (CUREs) to give context on the application of backwards design for UREs. CUREs are courses that embed research practices into its pedagogy (Ahmad, 2022). CURES are common in natural sciences like biology and chemistry so laboratory components with cutting-edge techniques are used frequently.

In course design, we found some discussion in the URE community that calls for more rigorous research and the incorporation of learning sciences into CUREs (Linn, 2015). Since this call in 2015, only one study has explicitly mentioned backwards course design study for a CURE format (Hills, 2020). Additionally, start to finish CURE designs are uncommon in the literature (Hills, 2020). The uncommon nature of CURE design publication inspired us to apply backwards design principles to a URE like (Hills,2020)

The novelty is that our URE is an apprenticeship model not a CURE. The "traditional" apprenticeship model, where students will work on a specific research project under the mentorship of a laboratory (Ahmad, 2022; Drake, 2024; Siby, 2024). Unlike the CURE model, the apprenticeship model can offer more "hands-on experience" and one-on-one mentoring (Ahmad, 2022). Notably, this model can offer student greater autonomy than a CURE format (Ahmad, 2022). Conversely, the challenges that apprenticeship-models face are smaller improvements in theoretical knowledge when compared with CUREs, limited student participation, and greater competition for participation (Ahmad, 2022).

The distinction between the CUREs and apprenticeships is that CUREs are a course designed around a research question and discovery-based approach (Ahmad, 2024; Hills,2020). While a research apprenticeship is a research experience designed around a mentored research project. Despite the distinction, hybridization between a CURE and apprenticeship model has been done a few times (Drake, 2024; Siby, 2024).

These hybrid programs have been called a course-bases apprenticeship (Drake, 2024). We consider the program that we are designing a course-based apprenticeship, because we are supplement the lab apprenticeship experience with learning activities. The aim of course-based apprenticeships are to obtain the benefits of CURES and apprenticeships while avoiding their individual pitfalls.

Theoretical Framework: Backwards Design

In this section, we discuss the theoretical framework for the redesign of our Summer REU. Backwards course design is a way of designing curriculum by starting with the end goal in mind (Hansen, 2011). This means identifying desired results (learning objectives) followed by acceptable evidence of learning (assessment) before developing instructional activities (instruction). The benefits of backwards course design are that 1) it focuses on the big picture of what student should learn, 2) it provides detailed criteria of quality performance upfront, 3) designs are built around authentic performance tasks, 4) formative assessment shifts the instructor role towards that of a coach, and 5) activities are structured to overcome barriers to critical thinking (Hansen, 2011).

Backwards design principles lend themselves well to other design principles (Hills, 2020), which further increases the redesign benefits. Constructive alignment is a constructivist approach to course design that aligns learning, objectives, assessment, and instruction with one another to help students construct the desired knowledge (Biggs, 2020). We apply constructive alignment during the during the backwards design process. The benefits of constructive alignment are 1) students can focus on the learning goals that were set, 2) assessment can become fairer and more reliable, 3) critical thinking and the depth of student work can improve, 4) greater transparency allows for designs that are more transferable to other contexts, and 5) programs become more coherent (Biggs, 2020). We hope to leverage the benefits of both backwards design and constructive alignment in our apprenticeship program redesign.

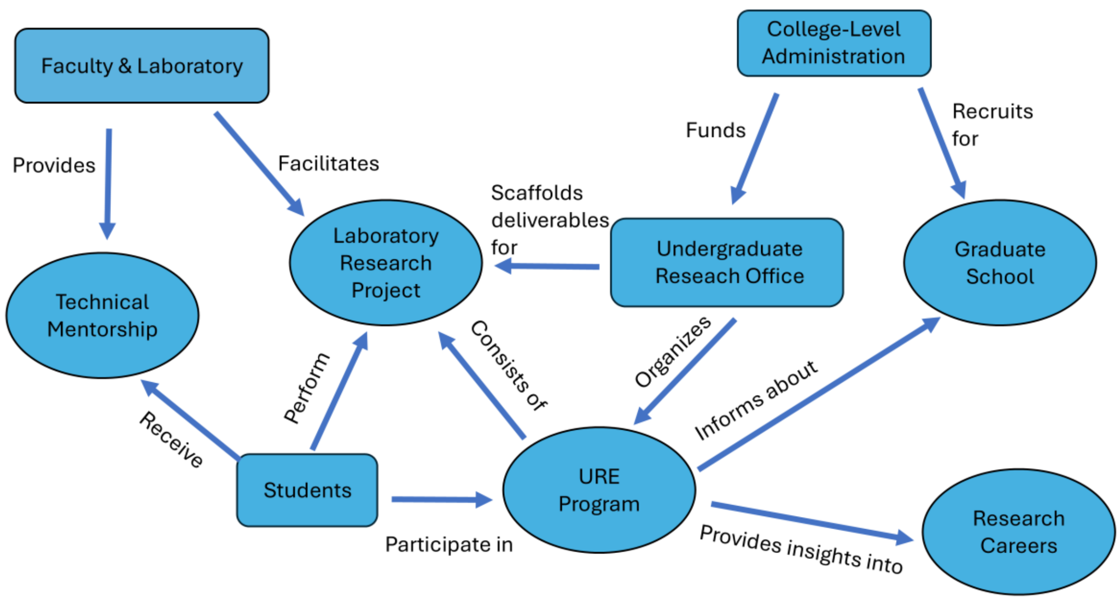

Figure 1: A concept map of the program with respect to the stakeholders.

Stakeholders & Program Goals

In this section, we elaborate the background of the program in the context of who the stakeholders are and how this has led to the program goals. The program goals served as the foundation that we built the rest of our summer research program upon. The summer research program initially started as a college-level initiative to create a summer traditional research apprenticeship over 20 years ago. The initial goal of the program was to provide students with a dedicated laboratory experience that provided hands-on and research-related learning.

A secondary related goal was that a dedicated laboratory experience would encourage students to pursue research careers and graduate level education. The secondary goal led to the incorporation of speakers and tours to certain lab facilities to help inform students. The addition of these elements to the apprenticeship started at least 10 years ago.

These two goals remain strong values within the administration, so we had to keep them in mind for our design. Furthermore, we consider the opinions of the faculty and laboratories as they are our partners in the program. In Figure 1, we provide a concept map that denotes the relationship between the stakeholders and the key aspects of the program.

On the right, the college-level administration funds undergraduate research initiatives like the program that we are redesigning. Additionally, the administration hopes that undergraduate research experiences will persuade students to apply for graduate school. The undergraduate research office functions as an administrator and organizer of the URE program. Our program consists of a laboratory research project, aims to inform participants about graduate school, and aims to provide insights into research careers.

Our partners are listed as faculty and laboratory, but we also include the university research centers in this category. About a dozen university research centers host or co-host projects via our program. Faculty and laboratories facilitate the laboratory project and provide technical mentorship to the students via the apprenticeship part of our program.

The program goals that have emerged from the relations between the program and the stakeholders are that students should have research-based lab experience (Hsieh, 2013; Youssef, 2016), students should learn about graduate school and research careers (Hsieh, 2013), and students should learn how to communicate their research (Hsieh, 2013; Youssef, 2016). The last part about communicating research comes from the intrinsic value of technical communication, especially given that the program consists of more than 300 students with unique technical backgrounds.

Learning Objective Design

To construct the learning objectives for our program, we start by formulating the enduring understanding (Hansen, 2011). To formulate the enduring understandings, we started with a review of the program goals for the previous year's offering. With the program goals in mind, we incorporated some of the feedback from the previous year's offering, new initiatives from the administration, and narrowed our focus. We produced the three enduring understandings shown in Table 1.

Then, we constructed the learning objectives by asking ourselves what students should be able to do with these enduring understandings. Next, we extrapolated performance tasks to assess the students' progress towards the enduring understandings. The performance tasks are further detailed in the assessment design section. Finally, we wrote the learning objectives using an action verb from Bloom's Taxonomy (Bloom, 1956) followed by a specific description of the activity. Our focus was to make the learning objectives specific, action-oriented, and measurable. Consequently, we avoided vague action verbs like appreciate, understand, learn, etc. which are difficult to measure. The final learning objectives are listed below in Table 1.

Enduring Understandings	Learning Objectives
EO-1: Research is a cyclical and iterative process for generating new knowledge from a foundation of community knowledge.	**LO-1**: Appraise a scholarly publication related to the research project
	LO-2: Summarize one of the scholarly publications as the background information for your research project.
	LO-3: Execute a project to help investigate a research question.
EO-2: Research careers can have diverse pathways in multiple employment sectors with graduate school as a gateway to more advanced career paths.	**LO-4**: Identify the types of laboratory roles.
	LO-5: Identify how a research program can be funded by a university or other external entities.
	LO-6: Explain the differences between doctorate and masters degrees.
EO-3: The way a research story is told changes with the audience.	**LO-7**: Write in a technical voice.
	LO-8: Develop a presentation of the project for a general scientific audience.
	LO-9: Create graphical representations of concepts and/or data that is well labeled.

Table 1: The enduring understandings are shown on the left with their corresponding learning objectives shown on the right.

Each enduring understanding led to three learning objectives focused on performance tasks that would be manageable for even first-time researchers within the 11-week period in which the program takes place. We chose to make it manageable for first-time researchers because our program has a large diversity of participants. Participants in our program include international students, first-time researchers, rising sophomores, rising juniors, and rising seniors. Thus, we want to make this design of the program manageable for any student in our program. We are also considering another design in the future for an "honor" version of the program for more advanced students.

Assessment Worksheet for LOs 1-4			
Learning Objective	Evidence of Learning	Acceptable Performance	Tasks
LO-1: Appraise a scholarly publication related to the research project.	Learning is implied by the ability to parse an academic publication for features that support its quality, judge these features for their validity, and evaluate their implications for the student's research questions.	The student will produce clear documentation outlining the key points of the academic publication, how the key points are relevant to the student research questions, and the evaluation of the publication quality.	Complete an annotated literature review using the provided template.
LO-2: Summarize one of the scholarly publications as the background information for your research project.	Learning is implied by the ability to distil information from scholarly publications into the background for a research project with a level of detail sufficient for a given audience.	The student will produce background summaries for a general scientific audience and technical audience backed by scholarly publications. Additionally, students will show that the final summaries consider feedback from their mentors.	Annotated Literature Review Technical Paper Presentation
LO-3: Execute one or a series of experiment(s)/simulations(s) to investigate a research question.	Learning is implied by the ability to create documents that incorporate a methodology to guide their experiments, provide results as outputs of their experiment, and align their methodology and results with their research question.	Documentation outlining a research project with inputs, actions, and outputs.	Presentation Technical Paper
LO-4: Identify the types of laboratory roles.	Learning is implied by the ability to recall the common roles in an academic laboratory.	The students will produce documentation that outlines the laboratory roles of undergraduate researcher, masters student, PhD student, Postdoctoral researcher, and principal investigator.	Summer Development Plan Mini-Conference Reflections.

Table 2: Assessment Worksheet for learning objectives 1-4.

Assessment Design

To design the assessments, we focused on the constructive alignment between the learning objectives and the proposed assessment. Meaning, the assessment is a measurable activity that allows students to complete the learning objective. Additionally, we gear our assessments of learning objectives 1-3 and learning objectives 7-9 as authentic performance tasks i.e. tasks that a researcher may do in real-life.

To aid us, we use assessment worksheets as a tool to align the assessments with their corresponding learning objective(s). On the assessment worksheet, we list the evidence of learning for that learning objective, what constitutes acceptable performance, and task that we will use to measure progress towards that learning objective. For example, Table 2 shows the assessment worksheet for the first learning objective.

Assessment Worksheet for LOs 5-9			
Learning Objective	Evidence of Learning	Acceptable Performance	Tasks
LO-5: Identify that a research program can be funded by a university or other external entities.	Learning is implied by the ability to identify three sources of graduate school funding.	The student will be able to identify that graduate school can be funded from fellowships, assistantships, and company tuition reimbursement. Additionally, the student will be able to explain the difference between fellowships, assistantships, and company tuition reimbursement.	Summer Development Plan Mini-Conference Reflections.
LO-6: Explain the differences between doctorate and masters degrees.	Learning is implied by the ability to define doctorate and masters degrees and explain the difference between the two.	The student will distinguish that a masters degree is about deepening a professional's knowledge, skills, and abilities in a specific field while a PhD is a research degree.	Summer Development Plan Mini-Conference Reflections.
LO-7: Write in a technical voice.	Learning is implied by the ability to write using the proper technical terms and writing style for that research community	The student will produce a technical paper that follows conference-level standards, considers feedback from mentors, and meets the approval of their lab mentor.	Technical Paper
LO-8: Develop a presentation of the project for a general scientific audience.	Learning is implied by the ability to the ability to distill the story of their research project into 5–10-minute presentation with a poster or PowerPoint as visual aid.	The student will produce a 5–10-minute talk on their research project that outlines the project inputs, actions, and outputs in language suitable for a general scientific audience	Presentation Draft Presentation Final
LO-9: Create graphical representations of concepts and/or data that is well labeled.	Learning is implied by the ability to create a legible graphic with labels necessary for a general scientific audience.	The student will produce at least one graphic that is legible and well-labeled in language suitable for a general scientific audience.	Graphical Visual Aid Draft Presentation

Table 3: Assessment Worksheet for learning objectives 5-9.

Rubric Design

To assess the tasks in Table 2 and Table 3, analytical rubrics will be implemented. A well-designed rubric can make the instructor standards and grading more explicit (Allen, 2006). Moreover, rubrics facilitate assessment to a more consistent standard and encourage reflective practice. We choose analytical rubrics here so that the criteria are fully detailed (Allen, 2006). It is important to provide adequate detail to rubric criteria to eliminate redundancy, inconsistent qualifiers, and limit the routes for partial credit (Goldberg, 2014).

To produce rubrics, we will focus on expanding the evidence of learning into criteria relevant to a deliverable. Then, we will develop the highest performance criterion based on the acceptable performance column of Table 2 and Table 3. Next, we will take the description of the highest performance criterion and change a couple key words to evenly develop subsequent levels of performance and their criteria (Goldberg, 2014; Kellog, 2001). In Table 4, we have developed an example rubric that works through this procedure. The example rubric below would be used to evaluate the technical paper.

Going left to right, we detail the highest performance levels first because English-speaker read left to right. We want the highest performance criterion to be the first criterion that the reader encounters as shown in Table 4.

Our program does not give grades, so the scores are categorized into acceptable and unacceptable performance as shown at the top of Table 4. If a student does not produce a deliverable with an average score of 3 or above when graded using the rubric, we will request that the student make corrections to that deliverable. To avoid correction on the final technical paper, we provide drafts where students are evaluated using the same rubric. However, drafts will not be resubmitted no matter what score students receive.

To facilitate the fairness of scoring, evaluators using our rubrics will be invited to a meeting to discuss the rubrics. Rubrics are improved by including the evaluators in the design of the rubric or including them in rubric training (Kellog, 2001). We will implement this principle so that our evaluation of students can be as consistent as possible using rubrics. However, we may have to redesign our rubrics during the summer according to feedback from the evaluators.

LO-7	Acceptable Performance		Unacceptable Performance		
Criteria\Quality	Excellent (4)	Good (3)	Emerging (2)	Needs Improvement (1)	No Attempt (0)
Use of technical terms	Technical terms appear in all the appropriate locations	Technical terms appear in expected locations	Technical terms mostly appear in expected locations	Technical terms appear in inappropriate locations	No Submission
Use of the literature to corroborate	Well-formatted in-text citations and references support the arguments of the paper.	Acceptable in-text citations and references support the arguments of the paper.	Acceptable in-text citations and references are included in the paper.	In-text citations and references are not included in the paper	No Submission
Structures writing into sections	Paper includes introduction, methods, results, and a conclusion section	Paper is missing one section: introduction, methods, results, or a conclusion section	Paper is missing two sections: introduction, methods, results, or a conclusion section	Paper is missing three or more sections: introduction, methods, results, or a conclusion section	No Submission
Grammar & Spelling	Writes with impeccable mechanics	Writes with smooth mechanics	Writes with acceptable mechanics	Writes with incomprehensible mechanics	No Submission

Table 4: An example of the analytical rubric with a section for comments.

Mini-conference Design

Our program originally started as a traditional research apprenticeship. The addition of activities and the deliverables have shifted the classification of our program to a Course Apprenticeship-based URE (Drake, 2024). Lecture/seminar activities that we call mini conferences were added to supplement the program apprenticeship. Mini-conferences consist of two one-hour sessions, each with three different speakers. Over the 11-week program, we administer four mini-conferences.

We have considered doing learning activities other than mini conferences. However, faculty mentors and the administration suggested that we restrict ourselves to mini conferences so that students have enough lab time to complete their projects. We complied with this suggestion because students do experience some pressure to finish their projects within the 11-week period.

In lieu of additional activities, we plan to incorporate various STEM teaching techniques (Felder, 2016) to improve the mini-conference session. Notably, most mini-conference sessions in the past had a lecture-based approach. With this redesign, we hope to incorporate more active learning techniques to engage students. However, we invite some mini-conference speakers so speakers will use their own styles that may or may not incorporate active learning to various degrees. Currently, we are working on a mini conference itinerary. Therefore, we are not able to divulge many details of what topics and active learning techniques will be used at this time.

However, we have chosen reflective writing activities to help students develop their metacognitive skills. Ryan et al. (Ryan, 2013) define reflection as "(1) making sense of experience in relation to self, others and contextual conditions; and importantly, (2) reimagining and/or planning future experience for personal and social benefit." One of the features of STEM experts is that they reflect on their cognitive decisions and make real-time adjustments (Felder, 2016). While expertise takes years to acquire, we can help students foster their metacognitive skills by incorporating activities that attend to multiple levels of reflection (Felder, 2016; Ryan 2013). Donald Schön notes in *The Reflective Practitioner: How Professionals Think in Action* (Schon, 1983) that the benefits of reflective writing activities include: 1) "Helping students identify their tacit knowledge as well as gaps in that knowledge", 2) "Brings to the surface rhetorical and writing process decisions that can focus subsequent revision or learning", and 3) "Encourages growth as a working professional".

Each reflective writing activity for the mini conferences will use questions based on the five Rs outlined by (Ryan, 2013): reporting, responding, relating, reasoning, and reconstructing. Reporting and responding are the lowest cognitive level of reflection (Ryan, 2013). Reporting and responding recounts the experience and reactions to that experience for the purpose of identifying critical incidents (Ryan, 2013). Relating corresponds to how reflection incorporates one's knowledge, skills, ability, beliefs, and broader identity (Ryan, 2013). Reasoning is the part of the reflective process where one draws on evidence to make conclusions (Ryan, 2013). Reconstructing is the highest cognitive level of reflection that uses the prior levels of reflection to transfer knowledge to other contexts (Ryan, 2013).

Challenges

Our program faces three main challenges that impacted this design. The challenges were alignment with stakeholder values, gearing the program towards the students, and being limited to a certain number of mini conferences as our learning activities. We were able to overcome these challenges in theory. Once we run the program in the summer, we will see how well our implementation satisfied our challenges. Inevitably, we will have to make changes to future editions of the program.

The stakeholders are the research centers that co-host students with us, the administrative offices of the college that support us, and the faculty that host the student projects over the summer. Each group values different things so we had to take these values into consideration during our redesign. To overcome these challenges, we took the opportunity to get approval from the administration on our learning objectives in the Fall. Additionally, we are coordinating with the research centers, and we have kept the faculty feedback in mind.

As we mentioned in the learning objective section, the students come with various backgrounds and levels of research experience. The broad variation makes it difficult to develop specific learning objectives and activities that will be valuable to a wide variety of students. Our solution was to gear the program such that first-time researchers could be successful. We aim for our program to help students learn the fundamentals of research. For some advanced and senior students, the program design may not be as challenging, so we are considering the creation of another program design for more advanced students.

Even without the diverse cohort of students, we were limited to four mini conferences as our learning activities. We find that it is more difficult to help the student practice the material without more opportunities for learning activities. The conference session during last year's offering was just sufficient to cover all the topics. Nevertheless, we decided to add in reflections and a summer development plan to help students explore the material without adding more conference sessions. Ideally, we will also incorporate more active learning into the sessions to fully leverage the mini conferences.

Long-Term Goals

The goal of this project was to redesign our summer course-based apprenticeship URE using backwards design and constructive alignment principles. Our vision is to become a leader in undergraduate research programs by incorporating scholarship and research into our program design. Backwards design and constructive alignment are effective tools in outcome-based education that we viewed as transferable to the context of our program.

Our previous program designs incorporate some ideas of outcome-based education such as learning objectives. However, the learning objectives were not written with the best practices in mind. The learning objectives did not use an action verb, the learning objectives were not specific, and the learning objectives were difficult to measure. Even with some knowledge of outcome-based education, there were still some misconceptions, or missing knowledge present in our previous designs. We aim to use this publication to bring attention to careful incorporation of scholarship and research into a URE design.

In a future study, we aim to conduct a case study of student pairs to assess the effectiveness of our 2025 design. Each pair will be in the same lab, but only one student of the pairs will be enrolled in our summer program. We aim to compare student experiences with our program vs student experiences for those who participate in summer research via other means

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