A CURE for everyone: A guide to implementing Course-based Undergraduate Research Experiences

A CURE FOR EVERYONE: A GUIDE TO IMPLEMENTING COURSE-BASED UNDERGRADUATE RESEARCH EXPERIENCES

Best practices and advice from the primary literature

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CONTENTS

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EXECUTIVE SUMMARY

There have been numerous reviews of the nature, benefits, structure, and design of Course-based Undergraduate Research Experiences (CUREs). The goal of this pressbook is to draw on these efforts and expand on them to provide guidance for instructors at the Ohio State University and beyond in designing and implementing CUREs. This pressbook is not a prescriptive set of guidelines for the development of a particular model of CUREs. Instead, it is a set of ideas, recommendations, and best practices based on published evidence. Instructors may develop different models of CUREs than those suggested herein.

CUREs promote student learning, foster students' identity as scholars, build community, and shape professional futures. They do so by actively engaging students in an original research or creative contribution project within a course and lead to a deliverable accessible to stakeholders. The primary characteristic of a CURE is that it involves all students of a class who are primarily working during class time. In a CURE, students engage in multiple research practices to investigate a novel question whose outcome is unknown. Such research is associated with an inherent risk of generating "messy" data and involves collaboration among students as well as with the instructional team.

CUREs differ from traditional course projects by the explicit relevance of the research to the scholarly community and their integration with an instructor's research program (or a national research program), which guides the direction of the project and questions. CUREs have been implemented in STEM (Science Technology Engineering and Math), social science, and humanities courses. CUREs are used in introductory, upper division, and non-major courses.

By opening research opportunities to all students as part of the regular curriculum for a degree, regardless of the individual circumstances of students, CUREs help level the playing field of high-impact practices. They give everyone the opportunity to engage in research and thus can spark interests in research careers, contributing to changing the demographic and identity make-up of the research community. CUREs themselves lead to increased engagement in research, and persistence in STEM. The integration of research into the regular course load of students and the concentration of the work associated with the research project into the class time (or in replacement of regular homework) helps overcome many obstacles encountered by research internships in diversifying the research community including awareness of research opportunities, awareness of benefits of research experiences, unconscious societal bias, financial constraints, and personal barriers.

Student gains in CUREs meet or exceed those observed in summer internship and mentored student research experience models and are higher than those experienced by students in traditional labs. Benefits of CUREs for students include gains in content knowledge and technical skills, gains in broadly applicable skills, changes in attitudes towards and understanding of research, gains in confidence and self-efficacy, and changes in professional/career paths.

CUREs also benefit instructors with opportunities to perfect the crafts of teaching and research including for postdoctoral scientists and graduate students, the chance to engage in a meaningful research-driven teaching practice, and increased research productivity.

There are three possible paths to designing a CURE: (1) implementing a researcher-independent CURE for which there is a pre-existing structure available through national programs, (2) developing a new researcher-independent CURE, or (3) designing a unique researcher-driven CURE. When designing a new CURE, instructors should adopt a backward-design approach, which requires first the identification of the outcomes desired from the CURE, then the determination of the acceptable evidence that these outcomes have been met, and only afterwards, the planning of the learning experiences and instruction (Cooper et al., 2017). A successful CURE:

- **Is part of the curriculum:** It is critical to determine the audience of the course, the level of preparation and prior knowledge instructors can expect from students, the duration of the CURE, the scope and intent of the research, and the needs to integrate program requirements.
- **Considers intellectual responsibility and ownership of the research:** Student ownership of the CURE project positively impacts student benefits and their experience of the course. Instructors should allow students to make decisions throughout the design and implementation of the research protocols. Instructors

should also give students opportunities to develop their own claims and hypotheses.

- **Integrates the research process:** CUREs should integrate responsible and ethical conduct of research. Consider the use of published data, online databases, citizen-science projects, and data collected by previous iterations of CUREs or collaborators. Set-up checks and balances for student-collected data. Formally training students in the reading and analysis of the primary literature is critical to their engagement with scholarship. Build room in the course structure for failure and iteration.
- **Balances research progress with student learning and development:** Mini-workshops and activities on subsets of the dataset analyzed or published data can help students understand critical concepts that cannot be authentically explored because of time. Students can benefit from intellectual or data exchanges with other members of the research team, including graduate students, postdocs, and undergraduates in mentored research experiences.
- **Structures the research learning tasks to foster students' development as scientists:** The incorporation of a carefully thought-through scaffold that includes a series of activities and assignments is critical. Each assignment should itself be scaffolded. Writing-to-learn activities can facilitate student learning and development as writers. Information literacy should be fostered through reflective work as well as activities promoting metacognition.
- **Leads students to communicates their research results:** It is important to consider the appropriate mode(s) of dissemination of the CURE's findings, the division of labor among students in preparing the deliverable, and authorship rules. Different deliverable formats are not necessarily mutually exclusive. Communicating the results of the CURE should reflect authentic scholarly communication in the field.

CUREs can be evaluated through a suite of tools aimed at assessing learning, attitudes changes, and skills. Many published tools involve pre-post comparisons of students engaged in CUREs and can be easily implemented by instructors without prior experience in discipline-based education research.

Designing and implementing a CURE is a challenge but also an immensely rewarding experience. Many of the obstacles to the development and implementation of CUREs can be overcome with careful design and by leveraging institutional and professional resources. In an effort to contribute to facilitating the development of CUREs, several class activities and document templates are provided along with an extensive literature cited section providing many models of CUREs, example assignments, and best practices.

Original data from a survey of a small number of instructors at Ohio State are presented as part of an overview of the structure, benefits, and challenges of teaching CUREs.

INTRODUCTION

Course-based Undergraduate Research Experiences (CUREs) have become popular pedagogical tools to enhance the learning experience of undergraduate students (Buchanan & Fisher, 2022). Their rise in the natural sciences, particularly biology and chemistry, has given way to a broader application across the college curriculum, and beyond. The increased use of CUREs across disciplines has led to numerous analyses and meta-analyses of the effectiveness of this teaching approach. There have also been numerous reviews of the nature and development process of CUREs (e.g., Dolan, 2016) and several discipline-focused guides on CURE design aimed at instructors (e.g., Bakshi et al., 2016; Govindan et al., 2020; Provost, 2022). The goal of this pressbook is to draw on these efforts and expand on them to provide guidance for instructors at the Ohio State University and beyond in designing and implementing CUREs.

Part I of this pressbook is primarily aimed at instructors at the Ohio State University and places CUREs within the framework of the Ohio State curriculum. Part II presents ideas, recommendations, and best practices from the primary and secondary literature to guide the development and implementation of your own course, wherever you teach. References are made in this second part of the pressbook to courses and curriculum elements of the Ohio State University, but they are relevant to a wide audience. Although not explicitly designed as a workbook, the purpose of this pressbook is indeed to encourage your reflection and active engagement in course development as you read. To this end, the core of this pressbook is structured around a series of questions that prompt you to think about both the research and teaching aspects of your CURE. I hope that this guide will help make the challenge of developing a CURE easier, thus enabling you to experience the incredible joy, professional satisfaction, and intellectual development that CUREs bring to the classroom.

CUREs are a model of undergraduate research experiences that actively engage students in an original research, inquiry project, or creative contribution to the discipline that is an integral component of their education and leads to a deliverable accessible to stakeholders (reviewed in Auchincloss et al., 2014). Thus, CUREs exemplify research as an iterative, ongoing, and collaborative process addressing unresolved problems or unanswered questions (ACRL). Different definitions of CUREs have emerged, and different institutions emphasize different components of the experience students engage in (e.g., University of Florida, University of Colorado, Brown University). The primary characteristic of a CURE is that it involves all students of a class; these students are primarily working during class time (Auchincloss et al., 2014). Some characteristics of CUREs are found in other models of student research (including inquiry activities and mentored research apprenticeships), but the combination of characteristics below distinguishes make CUREs a unique model of research training (Auchincloss et al., 2014; CUREnet):

- Students engage in multiple [research or inquiry] practices
- The purpose of the investigation is usually integrated with the instructor's ongoing research
- The outcome of the research is unknown
- The findings are novel
- The students' work is relevant beyond the course and may provide opportunities for action
- The research work involves collaboration among students as well as with the instructor and teaching assistants
- The instructor's role in the experience is to guide and mentor the students
- The research is associated with an inherent risk of generating "messy" data
- The research process often involves iteration

In these regards, CUREs differ from inquiry instructions by the explicit relevance of the research to the scholarly community and their integration with the research program of the supervising researcher, which guides the direction of the project and questions (CUREnet).

CUREs have predominantly been implemented in STEM (Science Technology Engineering and Math) courses, particularly in biological sciences (Buchanan & Fisher, 2022; Dolan, 2016; Elgin et al., 2021). However, there are also instances of CUREs developed in other disciplines including in discipline-based education research (Cooper & Brownell, 2018; Mohammed et al., 2021), psychology (Hernandez-Ruiz & Dvorak, 2020; Mesmer and Gaudier-Diaz, 2022; Wilson, 2022), anthropology (Ruth et al., 2021), linguistics (Bjorndahl & Gibson, 2022), business

(Sternquist et al., 2018), criminal justice (Kruis et al., 2022; McLean et al., 2021), human resource development (Hwang & Franklin, 2022), as well as writing and composition (Kao et al., 2020; Parsons et al., 2021). There is no intrinsic reason why CUREs cannot be developed across a wide range of disciplines.

All forms of authentic inquiry and scholarship can be integrated in CUREs. CUREs in STEM fields have often been centered around laboratory experiments (e.g., Chaari et al., 2020; Sarmah et al., 2016), but there are also field-based CUREs (Gonzales & Semken, 2009; Stanfield et al., 2022; Thompson et al., 2016; Tomasik et al., 2014), and museum collection based CUREs (https://bceenetwork.org/; Hiller et al., 2017). Some models of CUREs have also been developed that do not require in-person lab/recitation time (Bennett et al., 2021; Hernandez-Ruiz et al., 2022; Karlsson et al., 2022; Sweeney et al., 2022; Waddell et al., 2021; Werth et al., 2022; Zelaya et al., 2022). In the social sciences, projects have been based on interviews (e.g., Ruth et al., 2021), surveys (e.g., McLean et al., 2021), neuroscience data (Wilson, 2022), and artefact analysis (Ruth et al., 2021). In the humanities, CURES have incorporated oral history (Parsons et al., 2021), writing projects (Kao et al., 2020), and archival work (https://reclaimingourhistories.org/about; https://ohiojewishhistory.com/).

CUREs have been put into effect across higher education institutions including community colleges (Genet, 2021; Hanauer et al., 2022; Hewlett, 2018; Kortz & van der Hoeven Kraft, 2016; Silvestri, 2018; Wolkow et al., 2014), primarily undergraduate institutions (e.g., Alaimo et al., 2014; Harrison et al., 2011; Ward et al., 2014; Wiley & Stover, 2014), minority serving institutions (Hanauer et al., 2022; Ing et al., 2021; Malotky et al., 2020; Martin et al., 2021; Pavlova et al., 2021; Ramírez-Lugo et al., 2021; Shuster et al., 2019; Siritunga et al., 2011), and research universities (e.g., Boltax et al., 2015; Brownell et al., 2012; Burnette & Wessler, 2013; Chen et al., 2005; Clark et al., 2016; Drew & Triplett, 2008; Gin et al., 2018; Harvey et al., 2014; Jones & Lerner, 2019; Kloser et al., 2011; Shapiro et al., 2015; Williams & Reddish, 2018; Winkelmann et al., 2015). Some CUREs have also been integrated into K-12 education (Bascom-Slack et al., 2012; Hatfull et al., 2006). The same CURE can even be implemented across institution categories (Bucklin & Mauger, 2022; Lopatto et al., 2020; Stoeckman et al., 2019). CUREs can also be collaboratively implemented by partner two-year and four-year institutions (Matyas et al., 2022). CUREs are used in both introductory and upper division courses (e.g., Buchanan & Fisher, 2022) and efforts have been made to implement CUREs in non-major courses as well (Ballen et al., 2017; Caruso et al., 2009; Smith et al., 2022). Although class size is often presented as a challenge to implementing a CURE, successful courses have been implemented in very large classes (e.g., Freeman et al., 2023; Merrell et al., 2022). Several CUREs have been taught at the Ohio State University (e.g., Clark et al., 2016; CLSE).

CUREs can represent small or large portions of the curriculum. Some CUREs are run over several classes concurrently or across semesters (e.g., Bucklin & Mauger, 2022; Sarmah et al., 2016) whereas others only represent a small portion of a given class (**Table 1**).

Number of credits of the class including the CURE (N=17)	
1	1
2	2
3	9
4	4
5+	1
Percentage of the class time dedicated to research (N=19)	
<15%	2
15-25%	7
25-35%	2
35-50%	3
50-75%	4
>75%	1

Table 1. Data from instructor survey showing the portions of the curriculum devoted to a random sample across disciplines of CURES developed at the Ohio State University. Numbers showed are frequencies of classes in each category.

PART I

PART I: COURSE-BASED UNDERGRADUATE RESEARCH EXPERIENCES AT THE OHIO STATE UNIVERSITY

A) RESEARCH, INQUIRY, AND SCHOLARSHIP IN THE GE AT OHIO STATE

The new general education (GE) requirements of the Ohio State University frame the experience of students at Ohio state around foundation courses, theme courses, and bookends of the four-year degree. One element of this framework explicitly offers the opportunity for instructors to weave in undergraduate research. Indeed, as part of the GE, students can take a single 4+ credit course in their sophomore or junior year (instead of two 3 credit courses in two different disciplines) to satisfy the GE Theme requirement on the condition that this course be recognized as high-impact (GE implementation committee report). One of these high-impact practices is research and creative inquiry. The GE identifies three broad learning goals for classes implementing undergraduate research (Research and creative inquiry courses description):

- Provide students with training in the tools and methodology of the discipline
- Are designed to scaffold undergraduate research and creative experiences, such that early curricular experiences provide students with the transferable skills to subsequently undertake appropriately advanced, scholarly projects
- Impress upon students the value of understanding methods and research results, noting that students undertaking scholarly work must be prepared to read and interpret primary literature

Each course that is submitted to qualify for the high-impact designation will be evaluated using an integrative practices inventory (Research and creative inquiry course inventory). This inventory articulates the following requirements of courses implementing high-impact student research experiences:

1. Performance expectations set at appropriately high levels (e.g., students investigate their own questions or develop their own creative projects)
2. Significant investment of time and effort by students over an extended period of time (e.g., scaffolded scientific or creative processes building across the term, including, e.g., reviewing literature, developing methods, collecting data, interpreting or developing a concept or idea into a full-fledged production or artistic work)
3. Interactions with faculty and peers about substantive matters including regular, meaningful faculty mentoring and peer support.
4. Students will get frequent, timely, and constructive feedback on their work, iteratively scaffolding research or creative skills in curriculum to build over time
5. Periodic, structured opportunities to reflect and integrate learning in which students interpret findings or reflect on creative work
6. Opportunities to discover relevance of learning through real-world applications (e.g., mechanism for allowing students to see their focused research question or creative project as part of a larger conceptual framework)
7. Public demonstration of competence, such as a significant public communication of research or display of creative work, or a community scholarship celebration
8. Experiences with diversity wherein students demonstrate intercultural competence and empathy with people and worldview frameworks that may differ from their own
9. Explicit and intentional efforts to promote inclusivity and a sense of belonging and safety for students, (e.g. universal design for learning principles, culturally responsible pedagogy)
10. Clear plan to market this course to get a wider enrollment of typically underserved populations.

One model of implementation of high-impact research in undergraduate classes are Course-based Undergraduate Research Experiences (CUREs).

B) HOW DO CURES SATISFY GE REQUIREMENTS?

A CURE is a high-impact practice and represents a transformative experience for students because it:

1. Leads students through an authentic experience that reflects the work of professional scholars and meaningfully contribute to society.
2. Guides students through the creation of novel content, not merely the consumption of existing knowledge.
3. Provides the opportunity to demonstrate competence and creativity to peers and the world.
4. Fosters the development of widely applicable skills and metacognition.
5. Engages students in working collaboratively with a diverse group of peers and professionals.
6. Helps reduce the equity gap and open professional opportunities to all.

CUREs enable the implementation of research projects for an entire class. Additionally their features correspond to the expectations of high-impact research course at Ohio State articulated in the research and creative inquiry (RCI) inventory (**Figure 1**). CUREs are therefore well-suited to Theme courses with a research and creative inquiry component; they are also appropriate for other elements of the curriculum, including within the majors, that seek to bring scholarship to a greater number of undergraduate students.

Two elements (9-10) of the RCI inventory that are not included in **Figure 1** deserve attention. They are both associated with the importance of an inclusive curriculum that explicitly seeks to address the equity gap. By opening research opportunities to all students as part of the regular curriculum for a degree, regardless of the individual circumstances of students, CUREs help level the playing field of high-impact practices. They give large numbers of students the opportunity to engage in research

(Ahmad & Al-Thani, 2022; Gentile et al., 2017); something only a few students, and disproportionately not students from underrepresented minorities, otherwise benefit from through limited numbers of research internships (Bell et al., 2017; Desai et al., 2008; Gin et al., 2022; Haeger et al., 2015; Jayabalan et al., 2021; Jones & Lerner, 2019; Mahatmya et al., 2017; McLean et al., 2021; Shanahan, 2018; Stoeckman et al., 2019). By introducing a diverse body of students to research and its benefits, CUREs can spark interests in research careers, change students' identity, and contribute to changing the demographic and identity make-up of the research community over the longer term (Bangera & Brownell, 2014; Newell & Ulrich, 2022; Villarejo et al., 2008; Wilczek et al., 2022). Research experiences have been identified as one of the critical predictors of the persistence of underrepresented students in the sciences (Schultz et al., 2011; Villarejo et al., 2008). CUREs themselves have been showed to lead to increased engagement in research, and persistence in STEM (Bascom-Slack et al., 2012; Harrison et al., 2011; Harvey et al., 2014). The integration of research into the regular course load of students and the concentration of the work associated with the research project into the class time (or in replacement of regular homework) helps overcome many obstacles encountered by research internships in diversifying the research community including awareness of research opportunities, awareness of benefits of research experiences, unconscious societal bias, financial constraints, and personal barriers (Longmire-Avital 2018; Bangera & Brownell, 2014; Shanahan, 2018; Villarejo et al., 2008). In fact, CUREs have sometimes been showed to positively impact student groups traditionally underrepresented in the sciences specifically (Hanauer et al., 2022). CUREs have also been called the most complete intervention possible to address the hidden curriculum (Jayabalan et al., 2021). As such, they have the potential to participate in creating inclusive college classrooms, reduce the equity gap, and stem the leaks of underrepresented scholars (Handelsman et al., 2022).

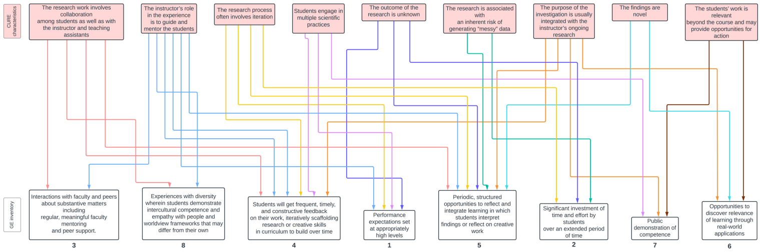

Figure 1. Relationship between the CURE characteristics from CUREnet and the integrative practices of the inventory for research and creative inquiry of the new GE at Ohio State. Numbers correspond to the list in section A.

PART II

PART II: WHY AND HOW? DEVELOPING YOUR OWN CURE

C) WHY IMPLEMENT A CURE IN YOUR CLASS

High-impact practices are associated with learning gains for students and benefits to the university community that include gains in GPA, increased student retention, improved student-instructor interactions, and more supportive campus environments (Kuh, 2008). Research experiences specifically have been demonstrated to benefit students' knowledge gains, skill acquisition, motivation, identity as researchers, comfort, and engagement (e.g., Follmer et al., 2017; Hanauer et al., 2017; Hunter et al., 2007; Landrum & Nelsen, 2002; Lopatto, 2007; Newell & Ulrich, 2022), including, and sometimes particularly, for students from underrepresented minorities (Daniels et al., 2016; Genet, 2021; Hanauer et al., 2017, 2022; Lopatto, 2007; Malotky et al., 2020; Martin et al., 2021; Matyas et al., 2022; Rodenbusch et al., 2016; Shuster et al., 2019), contributing to reducing the equity gap (Shapiro et al., 2015). CUREs are one tool that contributes to implementing a more equitable model of education moving forward (Elgin et al., 2021).

There is an extensive literature on the benefits of research experiences and CUREs, particularly for students. However, much of this literature is composed of studies that do not control for student-level characteristics, which could explain differences between groups (e.g., GPA, level of preparedness, enrollment preferences, prior research experience). In fact, many studies consist of pre-post comparisons of single groups and do not include comparison groups. Additionally, most of the assessments (e.g., quizzes, tests, and exams) of the content knowledge that was undertaken in published studies was subject-specific, preventing comparisons across learning experiences. Finally, analyses of skill gains and personal development overwhelmingly rely on self-reporting by students (Linn et al., 2015). In addition to cultural and identity issues associated with self-reporting and confidence, it can be difficult to determine whether students have indeed improved in a particular skill through the experience or merely became more confident about their skills (Dolan, 2016). Because CUREs are demonstrated to benefit self-efficacy (Martin et al., 2021), this type of data should be considered with care.

1. **Benefits to students and learning gains**

CUREs are widely recognized to benefit students. Most of the research is based on pre-post comparisons of self-reported levels of confidence, but numerous studies also include knowledge assessments using quizzes, comparisons with traditional laboratory or recitations sections employing "cookbook" labs and activities, and comparisons with mentored research experiences. There are some analyses that fail to identify strong signals of improved skills (e.g., Brownell et al., 2015), but for many aspects of the research experience, student gains in CUREs meet or exceed those observed in summer internship and mentored student research experience models (Bixby & Miliauskas, 2022; Evans et al., 2021; Frantz et al., 2006; Hanauer et al., 2012; Jordan et al., 2014; Lopatto et al., 2008; Overath et al., 2016; Shaffer et al., 2010; Shapiro et al., 2015; Smith et al., 2021). Student gains in CUREs are higher than those experienced by students in traditional labs (Blumling et al., 2022; Brownell et al., 2012; Evans et al., 2021; Hanauer et al., 2017; Jordan et al., 2014; Lopatto et al., 2008; Newell & Ulrich, 2022; Pavlova et al., 2021; Pontrello, 2015; Wolkow et al., 2014; Wu & Wu, 2022). Analyses of CUREs across institutions, disciplines, and course levels show that the greatest gains are found in CUREs that are implemented over the course of an entire semester, allow for student input in the research process, and focus on novel research with outcomes unknown to both instructors and students (DeChenne-Peters et al. 2023; Mader et al., 2017). Additionally, students enrolling in a course-sequence including more than one CURE see additional gains (Corwin et al., 2022). There have also been reports that student gains are higher or more critical in CUREs at the introductory level than the upper level (Hanauer et al., 2017; Handelsman et al., 2022; Ruttledge, 1998).

Broadly speaking, the impacts of CUREs on students can be assigned to five categories:

1. Gains in content knowledge and technical skills
2. Gains in broadly applicable skills
3. Changes in attitudes towards and understanding of research
4. Gains in confidence and self-efficacy

5. Changes in professional/career paths

Gains in content knowledge and technical skills

One of the strongest gains experienced by students in CUREs is an improved content knowledge. This impact is observed across disciplines including CUREs in molecular biology (Harvey et al., 2014; Makarevitch et al., 2015), plant biology (Ward et al., 2014), ecology (Valliere, 2022a, 2022b), microbiology (DeHaven et al., 2022), geosciences (Gonzales & Semken, 2009; Kortz & van der Hoeven Kraft, 2016), genomics (Drew & Triplett, 2008), ecology (Genet, 2021), and cell biology as well as genetics (Makarevitch et al., 2015; Siritunga et al., 2011). This increased content knowledge can translate to improved grades through time or compared to non-CURE course sections (Blumling et al., 2022; Ing et al., 2021; Jordan et al., 2014; Olimpo et al., 2016; Shaffer et al., 2010; Waynant et al., 2022; Winkelmann et al., 2015). It may also participate in increasing student retention within courses (Blumling et al., 2022) as well as between first and second years (Jordan et al., 2014). Importantly, the time-constraints of CUREs on content coverage does not have a detrimental effect on students' understanding of biological concepts beyond the focus of the CURE (Jordan et al., 2014) or overall content knowledge in the discipline (Wolkow et al., 2014). Several assessments of CUREs across disciplines have also found strong gains in students' technical skills (Kortz & van der Hoeven Kraft, 2016) including in computer modelling, software program use, and general computer use (Drew & Triplett, 2008; Pavlova et al., 2021; Williams & Reddish, 2018), enhanced statistical knowledge (Olimpo et al., 2018; Pavlova et al., 2021; Ward et al., 2014), and laboratory techniques (Bixby & Miliauskas, 2022; Evans et al., 2021; Jordan et al., 2014; Large et al., 2022; Siritunga et al., 2011; Stoeckman et al., 2019). CUREs also improve students' ability and confidence in their ability to design experiments and interpret data (Bixby & Miliauskas, 2022; Blumling et al., 2022; Brownell et al., 2012; Genet, 2021; Kloser et al., 2013; Large et al., 2022; Martin et al., 2021; Pavlova et al., 2021; Shaffer et al., 2014).

Gains in broadly applicable skills

Students also widely report great gains in soft skills. Those skills are applicable to courses and experiences through the student's academic career and beyond in their professional careers; they are not limited to the discipline associated with the CURE. Thus, students indicate a greater familiarity with the structure of scholarly papers and a greater ability to engage with the primary literature following engagement in a CURE (e.g., DeHaven et al., 2022; Drew & Triplett, 2008; Evans et al., 2021; Jordan et al., 2014; Martin et al., 2021; Shelby, 2019; Valliere, 2022b). Several studies also report improved written and oral communication, including the graphical representation of data and the presentation of both the research process and research findings (DeHaven et al., 2022; Genet, 2021; Jordan et al., 2014; Large et al., 2022; Makarevitch et al., 2015; Shaffer et al., 2014; Shelby, 2019; Stoeckman et al., 2019; Valliere, 2022a, 2022b; Ward et al., 2014; Wiley & Stover, 2014; Williams & Reddish, 2018). This improved ability to communicate is associated with increased willingness and confidence in communicating research (e.g., Kloser et al., 2013; Valliere, 2022a). There is also evidence that CUREs lead to improved time management and organization skills (Kortz & van der Hoeven Kraft, 2016) as well as increased problem-solving skills (Olimpo et al., 2016; Wu & Wu, 2022). Students engaged in CUREs gain an appreciation for the obstacles and challenges of research (Drew & Triplett, 2008). In fact, a major impact of CUREs is their ability to increase tolerance for obstacles in students (Corwin et al., 2022; Evans et al., 2021; Jordan et al., 2014; Large et al., 2022; Stoeckman et al., 2019; Williams & Reddish, 2018; Wu & Wu, 2022). Students report valuing the ability to learn from their mistakes in the CURE (Harrison et al., 2011). Even when research goals are not met, students engaged in CUREs increase their ability to navigate research obstacles (Gin et al., 2018). CUREs lead students to become more active learners who can better think independently, are motivated to learn, and better able to think in new ways (Evans et al., 2021; Harrison et al., 2011; Kortz & van der Hoeven Kraft, 2016; Shaffer et al., 2010). Research has also showed that students value the potential for publication of the research they engage in as part of the CURE (Wiley & Stover, 2014); these publications may facilitate future admission into graduate and professional programs.

Changes in attitudes towards and understanding of research

CUREs are an enjoyable experience for students (Carr et al., 2018; Drew & Triplett, 2008; Harvey et al., 2014; LaForge & Martin, 2022; Pontrello, 2015). Students like the experience of exploring an open-ended question with no known outcome (Brownell et al., 2012; Hanauer et al., 2012; Harrison et al., 2011; Williams & Reddish, 2018), making decisions in their work (Hanauer et al., 2012; Harrison et al., 2011), and the relevance of their work to the scholarly community and the world (Drew & Triplett, 2008; Hanauer et al., 2012; Jordan et al., 2014; LaForge & Martin, 2022; Tomasik et al., 2013). Students often find CUREs to be community-building (e.g., Kulesza et al., 2022; Large et al., 2022; Hanauer et al., 2017; Werth et al., 2022) and recognize the positive impact of CUREs on their professional paths (e.g., Amir et al., 2022). CUREs also contribute to a better understanding of and confidence in the research process and science (Bascom-Slack et al., 2012; Bixby & Miliauskas, 2022; Evans et al., 2021; Freeman et al., 2023; Hanauer et al., 2012; Harrison et al., 2011; Jordan et al., 2014; Kulesza et al., 2022; LaForge & Martin, 2022; Large et al., 2022; Shaffer et al., 2014; Stoeckman et al., 2019). Harrison et al. (2011) reported increased interests in science and research in students who took a CURE. Valliere (2022a) documented a significant increase in students' perception that they can personally relate to a scientist. Kortz and van der Hoeven Kraft (2016) found an increased general appreciation for science and scientists in students engaged in CUREs. This positive attitude towards research is retained for years (Harvey et al., 2014). CUREs also lead students to identify as researchers or as members of the scholarly community and not merely students more than they do after traditional courses (Hanauer et al., 2017; Mraz-Craig et al., 2018). Additionally, students involved in a CURE were found to have developed a better understanding of the distinctions between hypotheses and theories as well as a deeper grasp of the importance of creativity in research compared to students who completed a traditional lab course (Russell & Weaver, 2011). Interestingly, Dewey et al. (2022) found that different CURE models lead students to perceive scientific research in different ways and identify different elements as central to the culture of research in the discipline. Designing an inclusive CURE experience is therefore critical to the experience of the students and their view of research.

Gains in confidence and self-efficacy

Because of the nature of the data collection undertaken in evaluating many CUREs, much of the information collected on the benefits of CUREs concerns the confidence of students with specific tasks and general self-efficacy. Kortz and van der Hoeven Kraft (2016) reported increased student confidence in talking with other people and more open minds in students. In fact, an increased willingness and ability to engage in conversations and collaborations is a common outcome of CUREs (Brownell et al., 2012; Jordan et al., 2014; Martin et al., 2021; Stoeckman et al., 2019; Vater et al., 2021). Yet, CUREs also promote the ability to work independently (Stoeckman et al., 2019; Jordan et al., 2014). More broadly, students report greater confidence with their ability to conduct research (Fendos et al., 2022; Jordan et al., 2014; Siritunga et al., 2011, Wu & Wu, 2022) and self-efficacy in general (e.g., Hanauer et al., 2017).

Changes in professional/career paths

CUREs have a significant effect on students' identity as scholars, particularly in the sciences, boosting their intention to pursue a career in STEM (Newell & Ulrich, 2022). In fact, for many students, CUREs help clarify their career path (Jordan et al., 2014; Shaffer et al., 2014; Stoeckman et al., 2019). CUREs increase the matriculation in STEM majors (Rodenbusch et al., 2016). They also directly or indirectly lead to increased graduation rates (Rodenbusch et al., 2016; Waynant et al., 2022). Additionally, several studies have found that engagement in a CURE leads to increased interest in conducting research in other settings following the course (Bascom-Slack et al., 2012; Brownell et al., 2012; Carr et al., 2018; Fendos et al., 2022; Harvey et al., 2014; Overath et al., 2016; Shaffer et al., 2014; Ward et al., 2014). Students also mention feeling better prepared to undertake research projects following their engagement in a CURE (Bascom-Slack et al., 2012; Drew & Triplett, 2008; Jordan et al., 2014; Newell & Ulrich, 2022; Stoeckman et al., 2019; Williams & Reddish, 2018). This leads to greater engagement in traditional research experiences (Harvey et al., 2014). This interest in research also translates to changes in career paths with increased interests and matriculation in graduate school and medical school (Harrison et al., 2011; Bascom-Slack et al., 2012; Shaffer et al., 2014). Many years later, CUREs lead to increased retention in scientific careers (Harvey et al., 2014; Shaffer et al., 2014).

2. **Benefits to instructors**

CUREs provide instructors with opportunities to improve student learning, help undergraduates develop a portfolio of works that help them reach their career goals, and foster chances for students to gain skills (Desai et al., 2008; Lopatto et al., 2014; see also section C1 above). As such, CUREs enable instructors, postdoctoral researchers, and graduate teaching assistants to pursue the mission of their institution as well as their own educational goals.

CURE instructors may be faculty members, instructors, postdoctoral researchers, or graduate student assistants (Goodwin et al., 2021; Heim & Holt, 2019). Cascella & Jez (2018) presented the argument that CUREs represent a great opportunity to train postdoctoral researchers and graduate students in the roles of instructors and principal investigator. They specifically argue that CUREs provide the opportunity to develop instructional materials, practice active learning methods of teaching, and build an identity and practice as a teacher beyond merely assisting in grading and delivering content (Cascella & Jez, 2018). The nature of CUREs also provides a platform for trainees to become familiar with the functioning and management of large research projects that involve personnel, deadlines, and a budget (see also Desai et al., 2008 for a similar argument in a learning community context). Because of the potential for publication of the results of the original research undertaken in CUREs, trainees also maintain or increase their productivity (in the form of presentations, publications, or the generation of data that can feed into proposals or manuscripts). Little research has been undertaken assessing the experience of graduate teaching assistants (GTAs) in CUREs. Heim and Holt (2019) provided limited data that support the conclusion that GTAs value the experience of mentoring undergraduate research, but many report the experience being very challenging. Goodwin et al. (2021) similarly found that graduate student instructors almost universally recognize the pedagogical value and benefits of CUREs (for both students and GTA), but that many report high costs to teaching CUREs, including time and emotional investment. In fact, in an important link between benefits to undergraduates and benefits to instructors in training, research shows that the individual experiences of students across course sections taught by different GTAs vary widely (Goodwin et al., 2022, 2023). These experiences appear to be affected by the beliefs, motivation, interests, training, and attitude of the GTAs more than their research and teaching experiences (Goodwin et al., 2022, 2023). Specifically, the ability of GTAs to provide support necessary for undergraduate students to persevere through failures and repeat their work is likely an important predictor of the quality of the students' research experience (Goodwin et al., 2022). The motivation of undergraduate students taking the CURE, in particular, appears to be highly affected by GTA training and practice (Goodwin et al., 2023). Support from instructors of record, peers, and undergraduate teaching assistants is therefore critical to the success of GTAs teaching a CURE as well as the success of their students (Goodwin et al., 2021, 2022, 2023). Kern and Olimpo (2022) have developed an effective training program to help GTA facilitate CUREs.

There are also many benefits of teaching a CURE for principal investigators and lecturers. A survey of 16 instructors across disciplines at the Ohio State University who have implemented a CURE shows a range of positive impacts. The open answers of the instructors were categorized in each of eight categories. Instructors were able to identify more than one benefit of teaching a CURE resulting in 24 coded impacts (**Table 2**). Three instructors did not identify a benefit (responding "unclear" or "not sure").

Benefit	N
Increased research productivity	4
Growth of research group	2
Personal satisfaction and fulfillement	5
Increased university community engagement	2
Increased student engagement and enjoyment	5
Increased recruitment/retention of students in major/program	2
Personal learning	1
Pedagogical development	3

Table 2. Benefits of implementing a CURE identified by 13 instructors at the Ohio State University.
N is the frequency of instructors for each category.

Below, I focus on the benefits of CUREs to instructors that positively impact the career of instructors and are best characterized as self-interests (Desai et al., 2008). Although much less research has been undertaken on instructor gains than students', CUREs have widely been recognized to benefit instructors. Instructor impacts can be divided into three categories:

1. Engaging in a meaningful research-driven teaching practice
2. Boosting engagement in research and increasing productivity
3. Gaining access to resources and developing a network of colleagues

Engaging in a meaningful research-driven teaching practice

CUREs provide the opportunity for instructors to integrate their research and teaching missions (Fukami, 2013; Shortlidge & Brownell, 2016). This includes the pursuit of one's research program as well as the chance to go into new directions and satisfy one's intellectual curiosity (Desai et al., 2008; Roberts and Shell, 2023; Shortlidge et al., 2016). As such, CUREs are more enjoyable to teach than traditional labs (Shortlidge et al., 2016; DeChenne-Peters & Scheuermann, 2022) and enable instructors to meaningfully engage students in the discipline without the barrier of content-coverage (Elgin et al., 2021). Instructors report that CUREs enable them to improve their pedagogical knowledge and develop an interest in the formal assessment of their own teaching (Craig, 2017). CUREs also enable instructors to teach in a way that promotes student enthusiasm and motivation (Lopatto et al., 2014). Some instructors report that CUREs improve their relationships with students (Shortlidge et al., 2016). Others report that CUREs improve their job satisfaction (Shortlidge et al., 2017). CUREs can be components of broader impacts of grant proposals and thus support the success of both research and teaching in one more way (see Shortlidge et al., 2016).

Boosting engagement in research and increasing productivity

For instructors at primarily undergraduate institutions and lecturers at research universities whose faculty model involves high teaching loads, CUREs offer the opportunity to remain involved in research endeavors (Hewlett, 2018; DeChenne-Peters & Scheuermann, 2022) and provide research opportunities to students when uncommitted time available for mentored research experiences is lacking (Gentile et al., 2017). Instructors benefit from the opportunity to keep up with the field of research and the literature (Lopatto et al., 2014). CUREs also increase the confidence of some faculty members in their own research (Shaffer et al., 2010). Because CUREs enable instructors to explore significant research questions that are broadly relevant to the scholarly community, they can be beneficial in generating data for faculty research (Shortlidge et al., 2016). In fact, the significance of the research itself has been found to be a motivator for many instructors (Lopatto et al., 2014), just like for students. Numerous faculty members have reported productivity benefits from CUREs, particularly co-authorship on publications (Lopatto et al., 2014, Shortlidge et al., 2016). Publication is an important outcome and motivator of engagement in the development and implementation of CUREs for both faculty members and students (e.g., Hatfull et al., 2006; Jordan et al., 2014; Ward et al., 2014). For some researchers, CUREs also offer the opportunity to identify and recruit trained and motivated students for mentored research internships (Overath, 2016; Shortlidge et al., 2016; Stoeckman et al., 2019; Ott et al., 2020; Elgin et al., 2021), or even prepare students for mentored research experiences (Fendos et al. 2022). The many research and teaching gains of CUREs lead some instructors to report increased prestige or improved reputation (Lopatto et al., 2014; Shaffer et al., 2010). CUREs are influential for promotion and tenure (Shortlidge et al., 2016).

Gaining access to resources and developing a network of colleagues

Surveys of instructors who have implemented CUREs show their impacts go beyond direct career benefits. CURE instructors value the chance to gain access to new technology on campus and beyond (Shaffer et al., 2010). Involvements in CUREs, particularly when instructors join national collaborative efforts like the Genomics Education Partnership (Lopatto et al., 2008), the Biological Collections in Ecology and Evolution Network (https://bceenetwork.org/), the Malate Dehydrogenase CURE Community (Provost 2022), or the Science Education Alliance Phage Hunters Advancing Genomics and Evolutionary Science (SEA-PHAGES; Jordan et al., 2014) also enable instructors to gain colleagues, grow their network of collaborators, and connect to a larger research and teaching community (Lopatto et al., 2014; Shaffer et al., 2010; DeChenne-Peters & Scheuermann, 2022). Instructors involved in CUREs report professional growth from the experience (Lopatto et al., 2014).

3. **Benefits to the institution**

Many of the benefits of CUREs to the institution are encapsulated in the benefits to instructors and students. Institutions benefit from higher student retention and graduation rates, training a more diverse workforce, and developing a more inclusive learning environment. They also gain from having happier instructors with higher research outputs and potentially higher tenure rates, who are less likely to leave their positions (Elgin et al., 2021; Shortlidge et al., 2017). CUREs can in fact contribute to increased enrollment (Bell et al., 2017). Similarly to service-learning courses, CUREs can provide institutions the opportunity to partner with business and community organizations (Elgin et al., 2021; Malotky et al., 2020; Silvestri, 2018) and provide actionable information for the students' community (Smith et al., 2022; Valliere, 2022a) or partners around the world (Kay et al., 2023). CUREs have also been showed to inspire faculty members to seek grant support for research and education (Shaffer et al., 2010), which can bring the institution additional funds through indirect-cost recovery. The CUREs themselves or the outputs from these CUREs can also participate in increasing the prestige of the institution with an increased number of publications, presentations, and awards (e.g., Ahmad & Al-Thani, 2022; Shaffer et al., 2010; Overath, 2016; Bell et al., 2017). Recent calls for institutions to support the development and implementation of CUREs have emphasized their importance in overcoming the opportunity gap in college (e.g., Handelsman et al., 2022).

D) DESIGNING A SUCCESSFUL CURE: THE BASICS

Although CUREs share several characteristics (see Introduction), there exists a diversity of CURE designs and models. Shuster et al. (2019) proposed a taxonomy of CUREs with two main categories: researcher-independent CUREs and researcher-driven CUREs. The former category includes many discovery-based CUREs. Researcher-independent CUREs are not tied to the expertise or research interests of the instructor. As such, they can be supervised by different instructors, may have a greater lifespan, and can potentially foster student-driven questions (Shuster et al., 2019). However, these CUREs are supervised by non-expert researchers who may not be confident in the project and require training (Shuster et al., 2019). Researcher-independent discovery-based CUREs can be replicated across institutions and lead to national programs (e.g., Genné-Bacon & Bascom-Slack, 2018; Jordan et al., 2014; Shaffer et al., 2014). Some of those national programs have common research goals. For example, the Genomics Education Partnership (GEP) is annotating the genome of *Drosophila* (Shaffer et al., 2010; 2014). Instructors can apply to join these programs and receive centralized training, benefit from the support system put in place by these project's networks, and exchange with the associated communities of instructors and researchers. One advantage of such programs is the potential time savings made by instructors in developing and initiating a CURE (Gentile et al., 2017). There are also national programs that have been developed to support students and their instructors in undertaking their own research projects. Examples of these programs include The Genome Consortium for Active Teaching (GCAT; Campbell et al., 2007; Walker et al., 2008) and its sister program, GCAT-SEEK (Buonaccorsi et al., 2014; Buonaccorsi et al., 2011) as well as the Ecological Research as Education Network. Both GEP and GCAT have been extensively analyzed for their ability to support CUREs (Lopatto et al., 2014). Malotky et al. (2020) present yet another model of researcher-independent CURE in their CEL-CURE. This CURE involves

"Community-Engaged Learning"; the research questions investigated by the students each semester stem from conversations with community partners in an original combination of service-learning and research (Malotky et al., 2020). Similarly, Adkins-Jablonsky et al. (2020) developed a series of CUREs centered around environmental justice in an effort to increase community-engagement as well as science efficacy and identity.

Researcher-driven CUREs are experiences in which the students contribute to the research program of the instructor. Researcher-driven CUREs are mentored by experts who are invested in the success of the CURE and its dissemination to the research community (Shuster et al., 2019). These CUREs are likely to be hypothesis-driven and lead to publication (Fukami, 2013; Shuster et al., 2019). There are some opportunities for researcher-driven CUREs to benefit from the support of national programs–the Keck Geology Consortium provides such an opportunity (De Wet et al., 2009)–but these opportunities are rare and often support small numbers of students (six to nine students in the case of the Keck Consortium). Because of the inherent integration of their teaching and research missions in researcher-driven CUREs, faculty members at research institutions may be more likely to be invested in the development and success of such CUREs as opposed to researcher-independent ones, whereas faculty members at community colleges and institutions with little support for the course development efforts associated with creating a CURE, and limited research funding, can benefit from joining national programs that provide a framework for implementing CUREs.

Thus, there are three possible paths to designing a CURE:

1. Implementing a researcher-independent CURE for which there is a pre-existing structure available through national programs or the peer-reviewed discipline-based education research (DBER) literature
2. Developing a new researcher-independent CURE
3. Designing a unique researcher-driven CURE

When designing a new CURE, just like any other course, instructors should adopt a backward-design approach (Dolan, 2016; Graff, 2011; Hills et al., 2020; Shapiro et al., 2015; Wiggins & McTighe, 1998). This approach requires instructors to first identify the outcomes desired from the CURE, then determine the acceptable evidence that these outcomes have been met, and only afterwards, plan the learning experiences and instruction (Cooper et al., 2017). One important caveat to this structure when designing a researcher-driven CURE is the need to integrate the research goals of the researcher with the learning outcomes for the students. Such integration can and should follow a backward-design approach for the research component as well (Cooper et al., 2017: Table 1). It may be necessary to adjust the research project to meet the desired learning outcomes or revise the learning outcomes of the CURE to match the limitations of the research project (Cooper et al., 2017). The instruction and mentorship of the research experience itself will need to consider several critical issues (e.g., Cooper & Brownell, 2018; Kloser et al., 2011; Shaffer et al., 2014; Zelaya et al., 2020) presented in **Table 3**.

Logistical issues	Duration of the experience
	Equipment and supply needs including IT resources, lab equipment, and reagents
	Class size and space availability
	Staff and teaching assistant support
Research issues	Technical expertise of the students and the data collection/analytical needs of the research project
	Expertise of the instructor with the study system
	Availability and logistics (including permitting) of specimens, resources, or organisms for the data collection
	Size and complexity of the dataset, the number of variables, as well as the diversity of hypotheses and questions the students will be able to explore
	Setup of checks and balances for student-collected data
Pedagogical issues	Integration of program requirements
	Scaffolding of the process of research
	Feedback structure including instructor-feedback and peer-reviews
	Format of the final deliverable and presentation of the findings
	Accessibility and inclusivity

Table 3. Critical issues to consider in developing a CURE.

The issues of **Table 3** can be rephrased as framing questions (questions

1-2, 4-5, 7-8, and 10 from Dolan, 2016) to guide the development of a CURE:

1. *How will the CURE be integrated into the curriculum?* Identifying the target audience of the course, the nature of the course, and its place within the curriculum as well as the CURE's research goals.
2. *To what extent will students have intellectual responsibility and [ownership] of the research?* Determining the role the students will have in developing, implementing, and communicating the research.
3. *Which components of the research process will be integrated into the CURE?* Defining the research experience of the students and guiding them through the literature, data collection, and data analysis.
4. *How will research progress be balanced with student learning and development?* Designing an inclusive experience that includes peer-reviews and addresses the limitations imposed by the course structure.
5. *How will the research learning tasks be structured to foster students' development as [scholars]?* Scaffolding the CURE and individual assignments, fostering reflection, and promoting successful group work.
6. *How will students communicate the results of their research?* Choosing the appropriate mode of communication to reflect authentic scholarship and ensure equity.
7. *How will [the progress and experience of students] be assessed?* Adopting a mode of grading that is true to the research process as well as transparent and inclusive for all students.
8. *How will research learning tasks change as discoveries are made and initial research questions are answered?* Including iteration within the course and ensuring the success of a CURE over the long term.
9. *What are the logistical obstacles and solutions for the different steps of the CURE?* Overcoming problems accessing and analyzing data and funding a CURE.
10. *What are the roles of instructional [and support] staff?* Transforming instructors into mentors to support students and teaching assistants.
11. *How will the success of the CURE be assessed?* Assessing the usefulness of the scaffold of the CURE and its individual activities and evaluating the success of the research and the students.

1. **Successful CUREs across disciplines**

Many successful CUREs have been developed across institutions, course-levels, and disciplines. **Table 4** presents a selection of CUREs, sorted by discipline, focusing on examples that provide templates or curriculum elements for the replication of the experience or its implementation in a different context. These examples can be used to start reflecting on the questions presented above.

Examples of CUREs across disciplines and topic

References for CUREs at the introductory and/or upper level in Anthropology, Biology, Business, Chemistry, Criminal Justice, Engineering, Forensic Science, Geosciences, Human Resource Development, Information security, Linguistics, Mathematics, Psychology, Physics, as well as Writing and Composition.

Discipline	Level	Topic	Reference
Anthropology	Both	Equity, Health, Obesity, etc.	Ruth et al., 2021
Biology	Both	Botany	Ward et al., 2014
Biology	Both	Conservation Biology	Sorensen et al., 2018
Biology	Both	DBER	Cooper & Brownell, 2018
Biology	Both	DBER	Mohammed et al., 2021
Biology	Both	Ecology	Russell et al., 2015
Biology	Both	Genomics – GEP	Lopatto et al., 2008
Biology	Both	Genomics – GEP	Shaffer et al., 2010
Biology	Both	Genomics – GEP	Shaffer et al., 2014
Biology	Both	Microbiology	Adkins-Jablonsky et al., 2020
Biology	Both	Microbiology	Lyles & Oli, 2022
Biology	Both	Microbiology	Zelaya et al., 2020
Biology	Both	Molecular Biology	Russell et al., 2015
Biology	Both	Molecular Biology/ Ecology...	Poole et al., 2022
Biology	Both	Public Health	Malotky et al., 2020
Biology	Intro	Developmental Biology	Sarmah et al., 2016

Discipline	Level	Topic	Reference
Biology	Intro	Ecological Genetics	Bucklin & Mauger, 2022
Biology	Introductory	Botany	Murren et al., 2019
Biology	Introductory	Ecology	Brownell et al., 2012
Biology	Introductory	Ecology	Fukami, 2013
Biology	Introductory	Ecology	Genet, 2021
Biology	Introductory	Ecology	Kloser et al., 2011
Biology	Introductory	Ecology	Kloser et al., 2013
Biology	Introductory	Ecology	Young et al., 2021
Biology	Introductory	Field Ecology	Stanfield et al., 2022
Biology	Introductory	Field Ecology	Thompson et al., 2016
Biology	Introductory	Genetics	Brownell et al., 2015
Biology	Introductory	Genetics	Mills et al., 2021
Biology	Introductory	Genetics/ Ecology/ Evolution…	Bakshi et al., 2016
Biology	Introductory	Genomics	Bowling et al., 2016
Biology	Introductory	Genomics	Burnette & Wessler, 2013
Biology	Introductory	Genomics	Chen et al., 2005
Biology	Introductory	Genomics	Evans et al., 2021
Biology	Introductory	Genomics	Hatfull et al., 2006
Biology	Introductory	Genomics	Makarevitch et al., 2015
Biology	Introductory	Genomics	Wiley & Stover, 2014
Biology	Introductory	Genomics	Wolkow et al., 2014

Discipline	**Level**	**Topic**	**Reference**
Biology	Introductory	Genomics – SEA- PHAGES	Harrison et al., 2011
Biology	Introductory	Microbiology	Peyton & Skorupa, 2021
Biology	Introductory	Molecular Biology	Hekmat-Scafe et al., 2017
Biology	Introductory	Neuroscience	Waddell et al., 2021
Biology	Upper	Cell Biology	Shapiro et al., 2015
Biology	Upper	Cell Biology	Siritunga et al., 2011
Biology	Upper	Conservation Biology	Gastreich, 2020
Biology	Upper	Ecology	Shapiro et al., 2015
Biology	Upper	Genetics	Delventhal & Steinhauer, 2020
Biology	Upper	Genetics	Li et al., 2016
Biology	Upper	Genetics	McDonough et al., 2017
Biology	Upper	Genomics	Drew & Triplett, 2008
Biology	Upper	Genomics	Dunne et al., 2014
Biology	Upper	Genomics	Harvey et al., 2014
Biology	Upper	Genomics	Martin et al., 2020
Biology	Upper	Immunology	Cooper et al., 2019
Biology	Upper	Metagenomics	Baker et al., 2021
Biology	Upper	Microbiology	DeHaven et al., 2022
Biology	Upper	Microbiology	Jurgensen et al., 2021
Biology	Upper	Microbiology	Pedwell et al., 2018
Biology	Upper	Microbiology	Petrie, 2020

Discipline	Level	Topic	Reference
Biology	Upper	Microbiology	Sewall et al., 2020
Biology	Upper	Microbiology	Shapiro et al., 2015
Biology	Upper	Microbiology	Zelaya et al., 2020
Biology	Upper	Molecular Biology	Shanle et al., 2016
Biology	Upper	Molecular Biology	Shapiro et al., 2015
Biology	Upper	Molecular Biology	Shuster et al., 2019
Biology	Upper	Molecular Biology	Siritunga et al., 2011
Biology	Upper	Physiological Ecology	Ramírez-Lugo et al., 2021
Biology	Upper	Physiology	Rennhack et al., 2020
Biology	Upper	Restoration Ecology	Valliere et al., 2022b
Biology	Upper	Urban Ecology	Valliere et al., 2022a
Biology	Upper	Virology	Shapiro et al., 2015
Biology*	Introductory	Genomics – SEA- PHAGES	Jordan et al., 2014
Biology*	Introductory	Microbiology	Genné-Bacon & Bascom-Slack, 2018
Biology*	Introductory	Plant Microbiome	Bascom-Slack et al., 2012
Biology†	Introductory	Molecular Biology	Boltax et al., 2015
Biology†	Introductory	Molecular Biology	Rowland et al., 2012
Biology†	Introductory	Organismal Biomechanics	Full et al., 2015
Business	Upper	Retail	Sternquist et al., 2018

Discipline	Level	Topic	Reference
Chemistry	Both	Biochemistry	Roberts et al., 2019
Chemistry	Both	Biochemistry	Shelby, 2019
Chemistry	Both	Biochemistry	Vater et al., 2021
Chemistry	Introductory	Analytical Chemistry	Silvestri, 2018
Chemistry	Introductory	Biochemistry	Bell, 2011
Chemistry	Introductory	Biochemistry	Chaari et al., 2020
Chemistry	Introductory	Biochemistry	Knutson et al., 2010
Chemistry	Introductory	Bioremediation	Silsby et al., 2022
Chemistry	Introductory	General Chemistry	Blumling et al., 2022
Chemistry	Introductory	General Chemistry	Miller et al., 2022
Chemistry	Introductory	General Chemistry	Tomasik et al., 2013
Chemistry	Introductory	General Chemistry	Weaver et al., 2006
Chemistry	Introductory	General Chemistry	Winkelmann et al., 2015
Chemistry	Introductory	Organic Chemistry	Alaimo et al., 2014
Chemistry	Introductory	Organic Chemistry	Carr et al., 2018
Chemistry	Introductory	Organic Chemistry	Cruz et al., 2020
Chemistry	Introductory	Organic Chemistry	Pontrello, 2015
Chemistry	Introductory	Organic Chemistry	Ruttledge, 1998
Chemistry	Introductory	Organic Chemistry	Silverberg et al., 2018

Discipline	**Level**	**Topic**	**Reference**
Chemistry	Introductory	Organic Chemistry	Weaver et al., 2006
Chemistry	Introductory	Organic Chemistry	Wilczek et al., 2022
Chemistry	Upper	Analytical Chemistry	Tomasik et al., 2014
Chemistry	Upper	Biochemistry	Ayella & Beck, 2018
Chemistry	Upper	Biochemistry	Colabroy, 2011
Chemistry	Upper	Biochemistry	Large et al., 2022
Chemistry	Upper	Biochemistry	Satusky et al., 2022
Chemistry	Upper	Biophysical Chemistry	Hati & Bhattacharyya, 2018
Chemistry	Upper	Medicinal Chemistry	Williams & Reddish, 2018
Chemistry	Upper	Polymer Chemistry	Karlsson et al., 2022
Chemistry*	Introductory	General Chemistry	Clark et al., 2016
Chemistry†	Introductory	Biochemistry	Rowland et al., 2012
Chemistry†	Introductory	Organic Chemistry	Boltax et al., 2015
Criminal Justice	Introductory	Crime statistics	Kruis et al., 2022
Criminal Justice	Introductory	Crime statistics	McLean et al., 2021
Engineering	Introductory	Biofluid Mechanics	Clyne et al., 2019
Engineering	Upper	Software Development	Abler et al., 2011
Engineering†	Introductory	Organismal Biomechanics	Full et al., 2015
Forensic Science	Upper	Next Generation Sequencing	Elkins & Zeller, 2020

Discipline	**Level**	**Topic**	**Reference**
Geosciences	Introductory	DBER	Kortz & van der Hoeven Kraft, 2016
Geosciences	Upper	Field Geomorphology	May et al., 2009
Geosciences	Upper	Field Glaciology	Connor, 2009
Geosciences	Upper	Field Petrology	Gonzales & Semken, 2009
Human Resource Development	Upper	Any	Hwang & Franklin, 2022
Information Security	Upper	Vulnerability Scanning	Xu et al., 2022
Linguistics	Introductory	Phonetics and Phonology	Bjorndahl & Gibson, 2022
Mathematics	Both	Any	Deka et al., 2022
Physics	Introductory	Solar Physics	Werth et al., 2022
Psychology	Upper	Cognitive Neuroscience	Wilson, 2022
Psychology	Upper	Music Psychology	Hernandez-Ruiz & Dvorak, 2020
Writing & Composition	Introductory	Oral History	Parsons et al., 2021
Writing & Composition	Introductory	Writing Pedagogy	Kao et al., 2020

Table 4. Examples of CUREs across disciplines and topic. * CURE implemented at the Ohio State University, † Interdisciplinary CURE

In addition to the many published CUREs, there are also several CUREs that have been developed across the campuses of Ohio State in STEM, social sciences, and humanities. **Table 5** provides examples of these courses at the time of writing including the instructor or contact person who may be able to provide documents from their course and/or insights into their experience developing and implementing the CURE.

Examples of unpublished CUREs across disciplines and topic at the Ohio State University

Information for select CUREs in STEM, Social sciences, and Humanities

Discipline	Course	Topic	
Microbiology	Micro 2100	Yeasts and Fermentation	Steven Ca
Evolutionary Biology	EEOB 4220	Mammal Ecology and Evolution	Ryan No
Comparative Studies	CS 5189-S	Field Ethnography	Katherine Waugh-Q
Women's, Gender, and Sexuality Studies	WGSST 2550	History of Feminist Thought	Mytheli S
History	HIST 2475	History of the Holocaust	Robin Ju
English	ENG 4523	Renaissance London: Literature, Culture, and Place, 1540-1660	Chris Hig

Table 5. Examples of unpublished CUREs across disciplines and topic at the Ohio State University.

2. **Expected learning outcomes of CUREs**

CUREs can help foster student success in different components of the curriculum. They can be implemented at the introductory level as well as in upper classes (**Table 3**) and even in first-year seminars (Vater et al., 2019); they can lead to thesis projects and fulfill other writing requirements; they can also involve extensive laboratory work (e.g., Pontrello, 2015), field work (e.g., Gonzales & Semken, 2009; Messager et al., 2022; Thompson et al., 2016), or community-based interventions (e.g., Malotky et al., 2020). As such, CUREs may be appropriate as entire classes or elements of classes in foundation courses, theme courses, honors classes, non-major courses, required introductory courses for the major, or upper-level electives.

The first step in the design of a CURE is to identify the desired pedagogical goals for the course. Keep in mind that pedagogical goals, or learning goals, describe what you as instructor, and your program, aim for with the CURE. They give students a general idea of what they will gain from the CURE. Expected learning outcomes (ELOs) describe what students are able to do at the outset of the CURE. ELOs are specific statements that use action verbs to state what student should achieve; they should be measurable and realistic.

There are three important categories of learning goals to consider. The first one concerns discipline-specific knowledge and skills, including technical skills. The second one is concerned with soft skills, including broadly applicable competences in communication and habits that promote success, like the ability to work well as part of a team. The third category of learning goals that is worth including in the framework of a CURE is personal goals. Encouraging students to develop their own learning goals for the CURE can be a powerful way to increase buy-in and ownership of the project (see [**Activity 1**]). It has also been linked to more positive impacts of the course for students (Lopatto et al., 2022). Whichever of these three categories they belong to, the goals should be aligned with appropriate expected learning outcomes.

Discipline-specific goals can be sourced from program guidelines and department resources. In the case of courses redesigned into CUREs, the learning goals articulated for the non-CURE format of the class should also be considered. Learning goals adapted to CUREs, particularly learning goals that incorporate technical skills, can be found in the CURE literature (e.g., Connor et al., 2022; Hanauer et al., 2017; Mishra et al., 2022; **Table 4**) and select dedicated publications (e.g., Irby et al., 2018). An additional source of learning goals may be found in the discipline-based education research literature, particularly concept inventories. Concept inventories and concept assessments, more than lists of discipline-specific learning goals, enable the evaluation of student learning through validated sets of multiple-choice questions (Libarkin, 2008). There exists concept inventories for a large number of disciplines and topics, particularly in STEM (Libarkin, 2008; **Table 6**); there are also databases of learning objectives for some disciplines (e.g., Bioliteracy; Chemistry, Life, the Universe, and Everything).

Discipline/Topic	Reference
Biology	
Natural selection	Anderson et al., 2002
Homeostasis	McFarland et al., 2017
Meiosis	Kalas et al., 2013
Genetics	Smith et al., 2008
Molecular biology	Couch et al., 2015
Genetic drift	Price et al., 2014
Evo-devo	Hiatt et al., 2013; Perez et al., 2013
Dominance in genetics	Abraham et al., 2014
Microbiology	Paustian et al., 2017
Microbiology for health sciences	Seitz et al., 2017
Biological experimental design	Deane et al., 2014
Population dynamics	Q4B Project
Speciation	Q4B Project
Translation and Transcription	Q4B Project
Statistical reasoning in biology	Deane et al., 2016
Host Pathogen Interactions	Marbach-Ad et al., 2009
Earth Sciences	
Meteorology	Davenport & French, 2020
Oceanography	Arthurs et al., 2015
Mineralogy	Scribner & Harris, 2020
Climate change	Jarrett et al., 2012
Physics	
Thermal physics	Yeo & Zadnik, 2001
Newtonian gravity	Williamson et al., 2013
Psychology	
Research methods and statistics	Veilleux & Chapman, 2017
Astronomy	
Planet formation	Simon et al., 2019
Chemistry	
Redox	Brandriet & Bretz, 2014
Enzyme-substrate interactions	Bretz & Linenberger, 2012

Table 6. Examples of published concept inventories

Learning outcomes can be drawn from program requirements and general education curriculum expectations. At the Ohio State University, competencies and skills that are not discipline-specific are articulated in the expected learning outcomes of the foundations, themes, integrative practices, and embedded literacies of the general education curriculum (Ohio State GE Program). Like at many other institutions, additional expected learning outcomes exist for the Honors program (Honors Program Goals).

Foundations courses enable students to gain a well-rounded education across academic disciplines and modes of inquiry. At Ohio State, students are required to take a course in each of seven fields of study (GE Program Structure), each associated with five to eight ELOs. Theme courses have their own sets of ELOs based on the theme they fall under. Theme courses are particularly appropriate for CUREs because the implementation of a CURE in a theme course enables it to qualify as a high impact practice course. The integrative practice inventory itself dictates ten expectations for these courses; they should be carefully considered at the time of design. Within a major, courses at the introductory or upper level can be valuable contexts to develop CUREs. Courses within the major are driven in part by the ELOs of the embedded literacies. Honors courses should satisfy ELOs from the Honors program.

Instructors should select learning outcomes from the appropriate list based on the nature of the course being developed (see question 1 starting on p. 51). Based on the discipline of the course, a subset of the ELOS for the foundation courses, theme courses, or embedded literacies are relevant. Once the ELOs for the course have been selected, they should be translated to specific outcomes for the CURE being developed. Specific learning outcomes should be center ed around students. All statements should start with "Student will be able to ..." This statement should be followed by an action verb appropriate for the goal (see Verb wheel for examples). Each CURE outcome should also be associated with specific assignments that will enable the instructor to assess whether students have met the desired course outcome; in application of the backward-design approach (see p. 32). Examples of such alignment efforts are shown below for select learning outcomes. Instructors developing their own CUREs can contact the Office of Academic Enrichment (https://osas.osu.edu/oae/) as well as the Office of Undergraduate Research and Creative Inquiry (https://ugresearch.osu.edu/) for assistance in translating the learning outcomes of university-wide programs into course-specific ELOs. Best practices in writing and using learning goals are reviewed in Orr et al. (2022) at http://lse.ascb.org/learning-objectives/.

For each of the four curricular context identified above for Ohio State, **tables 7-10** show the alignment between select ELOs, their translation for different example CURES in different disciplinary contexts (STEM, social sciences, and humanities or any), and a proposed assignment enabling the evaluation of the ELO. The assessment of learning outcome competency is critical and should be integrated in the design process of the course (see Mishra et al., 2022 for an example).

Examples of ELO alignments for Foundation courses

Select Expected Learning Outcomes for Foundation courses associated with exampl

Expected Learning Outcome	Translation to specific CUREs
Generate ideas and informed responses incorporating diverse perspectives and information from a range of sources, as appropriate to the communication situation	Compare results of analyses to published findings
	Integrate perspectives from different actors to explain social interactions
	Organize raw narrative data into usable research data
Draw appropriate inferences from data based on quantitative analysis and/or logical reasoning	Interpret results of statistical analyses of phenotypic data in light of ecology
	Correlate quantitative demographic data and questionnaire responses to test specific hypotheses
	Analyze word-frequency data to identify linguistic changes
Analyze and interpret significant works of visual, spatial, literary and/or performing arts and design	Integrate historical context and iconographic analysis to critically assess the representation of past events
Use historical sources and methods to construct an integrated perspective on at least one historical period, event or idea that influences human perceptions, beliefs, and behaviors	Combine the writings of different authors representing opposite interest groups to understand historical upheavals

Expected Learning Outcome	Translation to specific CUREs
Employ the processes of science through exploration, discovery, and collaboration to interact directly with the natural world when feasible, using appropriate tools, models, and analysis of data	As a group, assemble a database from field specimens that will enable novel analyses
Critically evaluate and responsibly use information from the social and behavioral sciences	Assess the value of published data and the context in which these were collected
Explain how categories including race, ethnic and gender diversity continue to function within complex systems of power to impact individual lived experiences and broader societal issues	Associate personal narratives with patterns in socioeconomic data

Table 7. Examples of ELO alignments for Foundation courses

Examples of ELO alignments for Theme courses

Select Expected Learning Outcomes for Theme courses associated with examples of tr

Expected Learning Outcome	Translation to specific CUREs	
Identify, reflect on and apply the knowledge, skills and dispositions required for intercultural competence as a global citizen	Evaluate the component skills of intercultural competence	Ref inte
Demonstrate a developing sense of self as a learner through reflection, self-assessment and creative work, building on prior experiences to respond to new and challenging contexts	Assess changes in metacognition over the course of the CURE	Ref
Engage in an advanced, in-depth, scholarly exploration of the topic or idea of sustainability	Summarize the state of the research on the management of natural resources	Co stu
	Analyze the roles of different stakeholders in the adoption of sustainability policies and commitments worldwide	Cri dec
	Synthesize the historical perspective of the concept of sustainability	Wri mo
Explore and analyze health and well-being from theoretical, socio-economic, scientific, historical, cultural, technological, policy and/or personal perspectives	Synthesize health outcome data from multiple fields of study	Int mo chr
	Evaluate how mental attitudes affects health efforts	Tes sign
	Summarize historical data on population health	Co tim

Table 8. Examples of ELO alignments for Theme courses

Examples of ELO alignments for Embedded literacies

Select Expected Learning Outcomes for Embedded literacies associated with examples of proposed assessments

Expected Learning Outcome	**Translation to specific CUREs**	**Proposed as**
Apply methods needed to analyze and critically evaluate statistical arguments	Re-analyze published data to evaluate the validity of proposed paradigms	Graphic of t associated su analyzed sup
		Critical evalu of three selec
		Use network Religions Pa
Interpret the results of qualitative data analysis to answer research question(s)	Use visual analysis of rock samples to determine lithology in the field	Lithological geological m
	Employ questionnaires to investigate major cultural anthropology questions	Survey immi area to shed of people ma
	Explain the role of theatre reviews in the dramatic arts	Synthesize re characterize
Develop scholarly, creative, or professional products that are meaningful to them and their audience	Cooperatively develop a publication-quality manuscript in a given journal format	Manuscript peer-reflectio
Recognize how technologies emerge and change	Articulate the significance of a recent technological advancement for future research in chemical engineering	Group Pech involving mi chemical eng
	Appreciate the importance of technological exchanges across the world	Create a map led to the de
	Explain the role of historical advancements in technology on human societies	Essay on the printing pres in Europe du

Table 9. Examples of ELO alignments for Embedded Literacies

Examples of ELO alignments for Honors courses

Select Expected Learning Outcomes for Honors courses associated with examples of tran

Expected Learning Outcome	**Translation to specific CUREs**
Reflect on ways in which their learning furthered their aspirations	Identify professional skills improved through the CURE
Identify, assess, and compare how scholars from a diversity of perspectives in different fields and disciplines approach their most challenging problems	Integrate knowledge from different subfields relevant to your research project
	Contrast the policy solutions proposed by academics from different leanings
	Undertake a comparative analysis of a topic treated by different writing modes
Take on a variety of roles within groups	Use appropriate language and communication skills to fulfill a given role within a group
Communicate using modalities that are effective and inclusive relative to the intended audience	Model inclusive interactions during group activities
Articulate what success looks like for them in both personal and professional contexts	Develop three personalized learning goals for the semester
Demonstrate a growth mindset to integrate new information and ways of thinking	Evaluate self-efficacy and acquisition of new skills

Table 10. Examples of ELO alignments for Honors courses

E) STRUCTURING YOUR CURE

Designing a CURE is a complex endeavor that requires coordination with staff members, administration, and other instructors. Fortunately, there is now an extensive literature on CUREs that enables the identification of best practices and recommendations for an effective experience. The elements identified in **Table 11** should be revisited throughout the process of designing a CURE.

Topic and Focus	Topic is appealing Research is publishable / significant to others
	Project ownership is encouraged
	Instructor leverages their expertise to foster high-level research interactions
Research Design	Research only requires minimal background and is conceptually simple
	Appropriate technical expertise is required to collect data, especially in initial stages
	Study system involves enough variables to allow for a variety of questions A common database of variables enables authentic research and peer-discussions
Pedagogical Design	Project information is regularly and appropriately provided
	Scaffolding of research activities guides students through the process
	There are frequent deadlines
	Multiple achievement milestones are built into the schedule of activities
	Everyday strategies implemented in the classroom explicitly align with ELOs
Communication	Communication between student and instructors as well as among students
	The frequent feedback structure incorporates peer-reviews and leads to revisions
	Specific guidelines and expectations for communication and inclusivity are explained
Reflection	The course structure provides opportunities for reflection on the research process as well as the specific project
	The course structure includes a reflection on personal learning and gains
	Course assessment mirrors authentic scholarly communication

Table 11. Elements of a successful CURE (modified from Dolan, 2016; Hanauer et al., 2022; Kortz & van der Hoeven Kraft, 2016; Wiley & Stover, 2014; Turner et al., 2021; Kloser et al., 2011; Hatfull et al. 2006)

The goal of this section is to use the framing questions presented above (p. 33-34) to guide prospective CURE instructors through the development of the research experience. These questions are not just prompts for reflection; together, they also form a worksheet for the design process.

- For each question, the "Overview" provides an overview of the critical design elements that are identified and developed in this section of the worksheet.
- The "starts here" units guide you through these elements of design. Although the pedagogy-centered issues are presented before the research-centered ones, they are better thought of as parallel tracks.
- The "research and education together" section combines the elements of design from both aspects of the CURE. This is an opportunity to identify and resolve conflicts.
- The "boxes" help remind instructors of the important elements of the question and critical points of contact across (and beyond) campus.

1. How will the CURE be integrated into the curriculum?

Overview: Despite the desire to design the CURE solely around learning goals and research questions, reality requires first the consideration of the place of the CURE in the students' slate of courses. This section enables you to determine:

1. The audience of your course
2. The level of preparation and prior knowledge you can expect from students
3. The duration of the experience
4. The integration of program requirements into the course
5. The scope and intent of the research

Education starts here: Many of the questions below are best answered in communication with the chair of the undergraduate curriculum committee of your department or unit.

- Will the CURE be a new course or integrated into an existing course?
- If developing a new course:
    - Will this course be aimed at majors or non-majors?
    - Will this course be an upper-level class with prerequisites or open to freshmen and sophomores?
    - Will this course become a requirement for any minor or certificate?
    - How many course credits will the CURE represent? Are there constraints on this number? How many hours of contact hours does this correspond to? How will they be divided between lectures, recitations, and labs? What is the total time commitment you can expect from students including homework?
    - Will this course be taught as a summer course? A half-semester course? Through two courses over an entire academic year?
    - What is the expected enrollment for the course?
    - Will this course become a requirement for other courses or be an elective?
        - If becoming a requirement:
            - What is the knowledge base and skillset that students need to master to continue with the next course?
        - If an elective:
            - What are the goals and expected learning outcomes of electives in your department, college, or unit? More broadly, what are expectations in your field and related professional avenues?
- If revising an existing course:
    - What is the place of this course in the curriculum? The major? Minors or certificates?
    - Will the CURE be replacing traditional labs or are you also integrating the lectures and/or recitations into the experience?
    - What are the expected learning outcomes of the current version of the course? Are they being revised?
    - What is the current enrollment in the course?
    - How does the course fit into the curriculum and how does it prepare students for the next steps in their education and

career?

Scholarship starts here: When developing a researcher-driven CURE, this element of design is led by the researcher and his team. When developing a researcher-independent CURE, this element of design is driven by the CURE program goals that you are joining.

- What discipline/field of research does the research topic fall under?
- Is the research project novel? What is already known about the possible outcome(s) of the research?
- Are you planning on focusing on a single question/goal or will the class tackle several research questions?
- Is this research hypothesis-driven or exploratory?
- What is the current stage of the research?
- Who are the stakeholders of the research that should be involved? Any collaborators?
- How does the research align with the topic, scope, and knowledge goals of the class (particularly if revising a pre-existing course)?

Research and Education together: Any incompatibility between research and education goals at this point of the development process, including incompatibilities between research goals and class enrollment or number of contact hours, may be fatal. Although revisions to the focus of the research or learning goals of the course are sometimes possible without compromising the student experience and learning, the nature of the course and the scope of the research must come together for the CURE to be possible.

Box 1: Important points

- Contact the chair of the undergraduate curriculum

committee of your department or unit.
- Verify the guidelines and requirements of the course approval process when proposing new courses.
- Engage colleagues (staff or faculty) involved in the implementation of existing courses if you are revising them.
- Identify the relevant expected learning outcomes of the department, program, major, minor, or certificate.
- Do not forget the research stakeholders. How can postdocs, graduate students, and undergraduate students in your lab contribute to and benefit from the CURE?

2. To what extent will students have intellectual responsibility and ownership of the research?

Overview: Research shows that student ownership of the research project undertaken as part of the CURE positively impacts their experience of the course and their learning gains (Hanauer et al., 2012; Harrison et al., 2011; Hatfull et al., 2006). Project ownership is a central component of the role of CURE instructors (Hanauer et al., 2022). Different degrees of project ownership may be possible depending on the scope, depth, and conditions of the CURE. They are intimately associated with the level of inquiry that students engage in.

Several levels of inquiry have been defined in the context of laboratory courses (Buck et al., 2008) and revised to fit the framework of CUREs (Brownell & Kloser, 2015). Because CUREs require the investigation of novel questions with no-known outcomes and the communication of the research results, they may only fall under some of these categories (**Table 12**). The degree of responsibility of the students in the design of the research project is associated with the degree of inquiry desired by the instructor and should be guided by the expected learning outcomes of the course. Together, they will open a range of opportunities for the student's ownership of their research.

Characteristic	Structured Inquiry	Guided Inquiry	Open Inquiry	Authentic Inquiry
Problem/Question	Provided	Provided	Provided	Not provided
Theory/Background	Provided	Provided	Not provided	Not provided
Procedures/Design	Provided	Not provided	Not provided	Not provided
Results analysis	Not provided	Not provided	Not provided	Not provided
Communication	Not provided	Not provided	Not provided	Not provided
Conclusions	Not provided	Not provided	Not provided	Not provided
Known answer?	Yes/No	Yes/No	No	No

Table 12. Levels of inquiry in undergraduate courses (modified from Buck et al., 2008 and Brownell & Kloser, 2015). It is entirely possible to imagine hybrid situations in which for example only parts of the research protocol are provided to students.

This section enables you to determine:

1. The level of inquiry you are aiming for in the CURE.
2. The choice between students exploring researcher-chosen questions/hypotheses and student-driven questions/hypotheses
3. The amount of input students will have on the design of the research project
4. The ability of students to communicate the research upon its completion

Education starts here: The ELOs for the course are critical in determining everything from the nature of the research activities included in the experience to the scope of the research questions. They should be referenced throughout the course design process.

- What level of inquiry is dictated by the ELOs?
    - Are students expected/able to develop original questions directly from observations? Will students be choosing from a range of predetermined questions and topics?
    - How will you foster peer discussions and class-wide activities if several questions/hypotheses will be studied by different groups or individuals?
    - Will you be giving students an introduction to the existing knowledge on their research topic or are they expected to collect this information directly from the published literature? If the latter, how will you guide this work and/or assess it?
    - Are students allowed/capable of collecting their own data based on permitting requirements (e.g., IRB) and ethical best practices?
    - Will appropriate analytical procedures be suggested to students or should they propose particular approaches based on their reading of the literature?
- Is the level of inquiry selected compatible with the amount of time given to students?
- Is the level of inquiry selected compatible with the expertise of the students?
    - What is the efficacy of students with reading the primary literature? Will you be providing training on this topic?
    - What is the familiarity of students with the field of research chosen for the CURE? How much background information is necessary to be able to comfortably initiate the research process?
    - Can you expect the students to understand and implement the analytical procedures likely to be involved in the research? Will you be providing the necessary knowledge as part of the class?
    - What are the computational skills of the students? Does the analytical protocol require coding skills or can it be implemented in a software program with a GUI?
    - In what prior classes or context would the students have acquired the required expertise/competence for the CURE?
- If students will explore their own questions:
    - Will you be placing constraints of the breadth and depth of the questions chosen by students?
        - What is too narrow a question?
        - What is too broad a question?

        - Can you mentor the diversity of questions and datasets entailed by this structure?
        - Are there topics that could be emotionally difficult for some students? Will these students have the opportunity to work on a different projects or will these projects simply not be validated by the instructor?
    - How will students select their hypothesis/question from all possible options?
        - What is the process by which a student question/ hypothesis is approved for the CURE?
        - Can a mock panel (for example composed of the instructor, graduate student researchers, and colleagues) review student proposals?
    - If students will be working in groups, how will you balance the group structure with individual questions?
- If students will be exploring researcher-chosen questions:
    - Will the questions be prescriptive, or will there be an opportunity for students to refine their question, narrow it, or define a question from a broad topic?
    - Is the question chosen compatible with the time frame of the CURE and the skill level of the students?

Scholarship starts here: It is important to recognize that there are constraints on scholarship stemming from regulatory and ethical requirements. Additionally, and no less important to the success of the CURE, its place within the broader research project it is part of, may drive the nature of the deliverable, the breadth and depth of the work, and the level of prescription imposed by the instructor(s).

- What are the existing constraints on the project from other stakeholders (e.g., other lab members, external collaborators, and national programs or networks)?
- What are the existing constraints on the project from existing data, commitments to funding agencies, museum collections, permitting agencies, university rules (including EHS and IRB), formal and informal agreements, and ethical concerns?
- How do these different types of constraints narrow the nature, breadth, and depth, of the questions that can be investigated by the students? How about the analytical protocols?

- If the CURE is researcher-driven:
    - What question are you interested in exploring?
    - What question/topics are you comfortable/uncomfortable mentoring?
    - How much of the research process are you comfortable leaving up to the students?
    - What is the deliverable you are hoping for upon completion of the CURE?
    - How critical is the success of the research (i.e. the obtention of the deliverable defined above) to you?
    - How much time will you be dedicating to the CURE outside of contact hours?
    - Is the research goal of the CURE compatible with the time and means given to students?
- Does the CURE represent a standalone project publishable upon its completion or a portion of a bigger project? How does this impact the format of research communication upon completion of the CURE (i.e. does the end product represent a manuscript? A poster presentation? An element of a grant proposal?)

Research and Education together: Legal, ethical, and professional requirements dictated by the field of research, necessary resources for the project, and the research program context of the CURE are the starting point for the level of inquiry that is possible for the CURE. However, there are several existing strategies to increase student engagement and ownership of the project that should be considered:

- Hanauer et al. (2022) presented a model of CURE mentoring that includes a project ownership strategy centered around fostering personal responsibility starting with teaching a scientific protocol and includes promoting research ethics, facilitating peer collaboration, encouraging independence, encouraging engagement and enthusiasm, creating opportunities for presentations, and fostering future educational and career opportunities.
- Students who collect their own data are more invested in the research project and display a greater research identity than students working with pre-existing datasets they did not collect (Cooper et al., 2020a).
- Undergraduate students can work with graduate students or undergraduate researchers who have benefited from mentored

research experience or previous iterations of the CURE to contribute to the research questions and methods within a framework (Hanauer et al., 2012).

- Emphasizing to students the significance of the research to the broader community of scholars in the field is important (Hanauer et al., 2012). Research shows that broadly relevant novel research leads to higher ownership of the project by students (Cooper et al., 2019).
- It is sometimes possible to pursue research questions relevant to the community or the students themselves (e.g., Malotky et al., 2020; Silvestri, 2018; Valliere 2022a). Students enjoy the opportunity to choose their own research topic (Amir et al., 2022) and those who are given opportunities to investigate questions relevant to themselves or their community show increased ownership of the research (Hanauer et al., 2012).
- Incorporating meetings that mimic research group meetings in the discipline and poster presentations can promote project ownership (Satusky et al., 2022).
- A CURE design that creates intellectual challenge and encourages problem solving deepens the engagement of students and the significance of the research experience (Hanauer et al., 2012). Challenges and iterations are critical to increasing the ability of students to navigate research obstacles (Gin et al., 2018; Light et al., 2020). In fact, students report valuing the ability to learn from their mistakes (Harrison et al., 2011) and view challenges and iterations as more representative of a real research experience (Goodwin et al., 2021). CUREs should deliberately incorporate iteration and discussions about the importance of iteration in research as part of student development (Light et al., 2020). Iteration enables the development of adaptive strategies by students that benefit them beyond the course (Cooper et al., 2022). A review of the best practices to engage students in problem solving is provided by Frey et al. (2022) and at https://lse.ascb.org/evidence-based-teaching-guides/problem-solving/.
- The CURE should be challenging without being overwhelming; this level of difficulty, paired with instructor support, has previously be showed to foster motivation (Dolan, 2016).
- If students will be developing their own questions, they should be guided through the process of identifying their own research question including the following critical issues:

    - What questions have already been asked?
    - What is the existing knowledge on the topic?
    - What questions have not yet been answered or even asked?
    - What are the gaps in the conversation?
    - What questions are relevant to the field of research?
- An activity leading students through the process of identifying scholarly significant questions can be followed up with an activity helping them narrow big research questions into manageable CURE projects (see [**Activity 2**]).

Box 2: Important points

- Students should tackle questions and test hypotheses relevant to the broader (research) community.
- Students should be allowed to make decisions throughout the design and implementation of the research protocols.
- Instructors should rethink their place in the classroom to that of mentors and not merely supervisors.
- There should be multiple opportunities for students to develop their own hypotheses and defend them with evidence from the literature and their own work.

3. Which components of the research process will be integrated into the cure?

Overview: The traditional view of the scientific method involves a series of steps starting with observation and the formulation of a hypothesis followed by the test of this hypothesis and the dissemination of the findings (Voit, 2019). In the social sciences, qualitative, quantitative, and mixed approaches may be adopted to probe questions pertaining to human beings and their societies, but the overall process of inquiry remains the same (Creswell, 2014). The nature of the data collection process and data analyses differs in the humanities, but the scholarly endeavor is still the "evidence-based exploration of a question or hypothesis that is important to those in the discipline in which the work is being done" (University of Washington English Department). Thus, across disciplines, the research process requires the identification of an appropriate research question, whether it be from direct observation or a review of the primary literature, the collection of data, their analysis, the interpretation of outputs, and the communication of the knowledge gained from the research. It is critical to identify which of these elements of the research process will be included in the CURE while considering the constraints of the undergraduate classroom. This section enables you to determine:

1. Your approach in defining research to students and framing their experience as scholars
2. The background information that needs to be provided to the students
3. The role of students in the data collection process
4. The engagement of students with the primary literature
5. The role of students in the data analysis process
6. The role of iteration and impact of failure on the CURE

Education starts here:

- How would your students define "research"?

  - What does the research process look like to them?
  - What is their understanding of the concept of "Research as Inquiry?"
  - What is your understanding of the students' view of research?
- What information is necessary to understand the basis of the question(s) the students will investigate?
  - Are there recently published reviews of the field/topics that students will be researching? Are there other sources of information that can help draw students into the literature (including secondary and tertiary literature, videos, and journalistic writings)?
  - Are there important conflicts or controversies in the field that students should know about? What is the current paradigm and are we on the edge of a new one?
  - Will you provide a brief introduction to the study system in class drawing upon your knowledge, past iterations of the CURE, and ongoing research on campus (and beyond)?
- Will students be collecting the entire dataset they will analyze? Alternatively, will they be working from pre-existing datasets in whole or in part?
  - Are there pilot or example datasets that enable students to visualize their objective while collecting most of the data they will analyze?
  - Will specific data collection protocols be enforced by permitting requirements (e.g., IRB) or ethical best practices?
  - Are there professional, legal, or ethical training requirements for students to collect data? Consult and analyze data?
    - How can you incorporate responsible and ethical conduct of research training into the course to satisfy needs and train reflective and responsible professionals?
- Will students be required to read certain publications or a minimum number of freely chosen publications? At what stages of the research process will engagement with the literature be suggested/enforced?
  - How will you guide students towards relevant publications and/or vet their choice of readings?
  - How will you make sure that students engage with a variety of sources and read the work of multiple authors representing different points of view?
  - Students should be prompted to reflect upon questions like: (1)

How does the source contribute to the scholarly conversation? (2) How do others in the field perceive the value of the source? (3) How does the source guide or support my work?

- Will specific analyses be required of students in the form of a detailed protocol or as a list of milestones? If not, how will students choose the analyses they will use? How will they be guided through this process?
    - What is the role of published studies as models for the students' work?
- Will students identify analyses that will be run by scholars with greater computational skills or are they able to run some or all of these analyses themselves?
- How would experimental failure or faulty data collection impact the learning process?
    - Are there backup datasets?
    - Are there alternative protocols and analyses?
    - What is the relevance/significance of null results or a failed protocol to the scholarly community?
- Is there enough time in the CURE to implement alternative protocols? Revise the data collection? Add to the dataset? Repeat an analysis?

Scholarship starts here:

- Is there a need for a formal review of the field of study the students will engage with?
    - Can the CURE be the impetus to publish a peer-reviewed review of a topic?
    - Would a more accessible summary benefit audiences beyond the CURE including undergraduates starting mentored research experiences in the lab or the general public?
- Is the CURE an opportunity for the instructor/researcher to engage or reengage with specific aspects of the primary literature?
- What is an appropriate sample (including quantity and quality parameters) to address the question of the CURE?
- Will student-collected data represent the entire set of relevant data for this project or are there other elements of the research project they will not engage in?
- Does the use of preexisting data dictate a specific data collection

protocol to enable comparisons/integrations?
- What work is necessary ahead of the CURE to make data collection by students possible?
- What checks and balances will be implemented to validate the quality of the student-collected data?
    - Do those checks and balances involve peer-review? Instructor review? Outside researcher review?
- Are there analyses that are standard/expected in the field?
    - Are some of these analyses computationally too demanding for the CURE?
    - Do some of these analyses require coding or statistical training beyond what can reasonably be expected of students?
- Are there critical failure points in the research protocol? Are there data or analyses whose failure would hobble or interrupt research progress?
- What would be the consequence of failure (of a specific analysis, experiment, or data collection) on proposal submissions, publication completions, and professional advancements (including promotion and tenure)?
- What is the role of the CURE in the development of the research program/project(s) of the researcher/instructors/collaborators/ graduate students/mentored undergraduate researchers/ etc.?

Research and Education together:

- Do not underestimate the importance of framing the entire CURE experience with a conversation about the nature of research. Students may not always recognize research as information creation and inquiry. "Research as Inquiry" is a core concept underlying the practice of research. Defining research as inquiry means explaining to students that research is an open-ended and messy exploration process focused on information gaps, unanswered questions or problems, involving multiple sources and the interpretation of information, often with no clear right answer, leading to new questions, generating ambiguity, and requiring an open mind, persistence, and flexibility (e.g., [**Activity 3**]). Research shows that engaging in this type of conversation about the nature of research can lead to higher student outcomes (Lopatto et al., 2022).
- CUREs are designed as authentic engagements in research and as

such should incorporate responsible conduct of research (RCR) training to form conscientious professionals (Diaz-Martinez et al., 2021). Many institutions and organizations require ethical conduct of research training. At Ohio State, RCR training is provided through the Collaborative Institutional Training Institute (CITI) course, which can be assigned as homework.

- Discipline-specific best practices in ethical conduct of research should also be implemented as part of the CURE (e.g., Hills and Light 2022). They can be integrated in the grading scheme for the course.
- Consider using mind-mapping exercises to help students identify the existing knowledge of the topic of the CURE and the current debates and controversies in the field of study [**Activity 4**].
- Established databases provide sources of data that can be used in CUREs (e.g., Gastreich, 2020). Those include museum databases, citizen science databases, and professional databases (**Table 13**).

Examples of databases that can be leveraged for research projects in CUREs

Research databases across disciplines including Art History, Biology, Earth Sciences, Machine Learning, Physics and Astronomy, as well as Political and Social Sciences

Name	**URL**
Art History	
Index of Medieval Art	https://theindex.princeton.edu/
Wax collection of Islamic art	https://minicomp.github.io/wax/collection/
Biology	
AntMaps	https://antmaps.org/
AntWeb	https://www.antweb.org/
Arctos	https://arctos.database.museum/
CalFlora	https://www.calflora.org
CalPhotos	https://calphotos.berkeley.edu/
COSMIC	https://cancer.sanger.ac.uk/cosmic
Diatoms of North America	https://diatoms.org/
eBird	https://ebird.org/home
featherbase	https://www.featherbase.info/en/home
iNaturalist	https://www.inaturalist.org/
Madagascar Terrestrial Camera Survey	doi/10.1002/ecy.3687
Movebank	https://www.movebank.org/cms/movebank-main
NEON	https://www.neonscience.org/
NEOTOMA	https://www.neotomadb.org/
NOW	https://nowdatabase.org/
Paleobiology Database	https://paleobiodb.org/
Protein Data Bank	https://www.rcsb.org/
VertNet	http://vertnet.org/

Name	URL
Earth Sciences	
Macrostrat	https://macrostrat.org/
Soil grids	https://soilgrids.org/
WorldClim	https://www.worldclim.org/
USGS Current Water Data	https://waterdata.usgs.gov/nwis/rt
LAGOS	https://lagoslakes.org
EarthData	https://search.earthdata.nasa.gov/search
Stone Lab Algal and Water Quality Laboratory	https://ohioseagrant.osu.edu/research/live/water
Mauna Loa Trends in Atmospheric CO2	https://gml.noaa.gov/ccgg/trends/data.html
NASA GISS Surface Temperature Analysis	https://data.giss.nasa.gov/gistemp/station_data_v4_globe/
North Temperate Lakes LTER	https://lter.limnology.wisc.edu/data
Machine Learning	
Machine Learning Repository	https://archive.ics.uci.edu/ml/index.php
Physics and Astronomy	
SIMBAD	http://simbad.u-strasbg.fr/simbad/
Astrophysics Data System	https://ui.adsabs.harvard.edu/
Political and Social Sciences	
ICPSR	https://www.icpsr.umich.edu/web/pages/
Various	
Smithsonian Open Access	https://www.si.edu/openaccess
Hathi Trust Digital Library	https://www.hathitrust.org/datasets
GeoPlatform	https://www.geoplatform.gov/
Omeka Project Directory	https://omeka.org/classic/directory/

Table 13. Examples of databases that can be leveraged for research projects in CUREs.

- Iterative CUREs enable students to access data from previous years and other lab groups and as such the opportunity to analyze realistic sample sizes that may be difficult or impossible to gather in the time of a CURE (Kloser et al., 2011; see Satusky et al., 2022 and Sun et al., 2020 for examples). The assembly of large datasets also enables long-term outlooks (e.g., Potter et al., 2009).
- It is important to define "Scholarships as Conversation" for students. Scholars and researchers engage in ongoing conversations in which new ideas and research findings are continually being discussed (ACRL) (e.g., [**Activities 5-6**]).
    - Being part of the scholarly conversation is an expectation of academic research and is integral to research and therefore of a CURE.
    - The scholarly conversation takes place in the peer-review literature, including books and journal articles.
    - Scholarly conversations also take place at conferences.
    - The classroom is an environment for scholarly conversations.
- There is an extensive literature on teaching the primary literature. There also exists multiple activities and exercises that enable instructors to introduce the primary literature to undergraduate students. Examples can be found in [**Activity 7**], Beck (2019), Hammons (2021), Howard et al. (2021), Chen (2018), Carson & Miller (2013), Hartman et al. (2017), Mitra & Wagner (2021), and Smith (2001) as well as the C.R.E.A.T.E. strategy (https://teachcreate.org/roadmaps/) and the science education resource center at Carleton College (Egger; Mogk). The collaborative reading and annotating of articles from the primary literature by students can also be helpful (Cafferty, 2021).
- Providing guidelines and help on exploring the primary literature through formal (or informal) bibliography exercises (e.g., [**Activity 8**]) helps students find additional resources on their own (e.g., [**Activity 9**]).
- Encourage students to identify the consensus that have developed, but also competing perspectives and approaches, and how new voices and evidence emerge (e.g., [**Activities 9-11**]).
- Do not overlook the importance of explaining to students how to

evaluate and select sources as well as how to provide citations. Many students are not familiar with the process of searching for references (video).

- You should also engage students to reflect upon best practices of literature review, including:
    - Using existing research to guide one's own work (including on the issue of "tracing the scholarly conversation" [**Activity 9**]).
    - Considering context when evaluating sources. One may not be able to understand the value of a particular piece of scholarship unless they consider the broader conversation (see [**Activity 10**]).
    - Providing attributions.
    - Needing to learn the "language" of the conversation before being able to fully participate.
    - Acknowledging that joining in the conversation confers both rights and responsibilities.
    - Recognizing that one is most likely entering into an ongoing conversation and not a finished one
- Are there freeware programs or programs with user-friendly GUIs that can be used by students to engage in the data analysis process without the need for extensive coding or other computationally difficult tasks (see Acuna et al., 2020 for an example; Zelaya et al., 2022 for an example in a CURE context)? An extensive collection of freeware programs for data visualization and analysis, network analysis, mapping, text analysis, etc. is available at https://guides.osu.edu/DH/digitalhumanities (see also **Table 14**).

Examples of freeware programs and programs with user-friendly GUIs that can help engage students in analyses

Select freeware programs enabling image analyses, statistical analyses, concept mapping, and visualization of data

Program name	**URL**	**Type of analyses**
ImageJ	https://imagej.net/software/fiji/	Image analyses
PAST	https://www.nhm.uio.no/english/research/infrastructure/past/	Statistical, time-series, and spatial analyses
jamovi	https://www.jamovi.org/	Statistical analyses
VUE	https://vue.tufts.edu/	Concept mapping
Google Jamboard	https://jamboard.google.com/	Concept mapping / Interactive whiteboard
SwissADME	http://www.swissadme.ch/	Drug discovery
UCSF Chimera	https://www.cgl.ucsf.edu/chimera/	Visualization and analysis of molecular structures

Table 14. Examples of freeware programs and programs with user-friendly GUIs
that can help engage students in analyses.

- It is important to reflect on the role of the CURE in the development of the research program of the researcher(s). CUREs can help enable the research program of a research group (see figure 2 in Sun et al., 2020), but careful planning and circumscribing of the role(s) of the CURE(s) are critical.

Box 3: Important points

- CUREs should integrate responsible and ethical conduct of research into the student training.
- Consider the use of published data, museum and research databases, data collected by collaborators, and data collected by previous iterations of CUREs.
- Set-up checks and balances for student-collected data.
- Formally training students in the reading and analysis of the primary literature is critical to their engagement with scholarship.
- Build room in the course structure for failure and iteration; they are important elements of the learning process.

4. How will research progress be balanced with student learning and development?

Overview: The strength of CUREs is their combination of research and teaching in a unique pedagogical experience for both students and researcher-instructors; it is also an important source of challenges. The ideal CURE would involve a steady progress of the research process that is accompanied by student gains and learning. These pedagogical goals can sometimes conflict with the research advancing at a necessary pace. Similarly, the required validation and repetition steps of many research protocols may not be needed to fulfill many learning goals. The structure of a course itself with the associated time-constraints can place limits on repeating experiments, increasing sample size, and even fully exploring a particular dataset or question.

This section enables you to determine:

1. The pace of the research process
2. The appropriateness of lessons on replication and statistical power to address the limitations of time in a CURE
3. The possibility to assign some analyses and research tasks to outside researchers
4. The role of peer-review as a combination of the scholarship review process and a pedagogical feedback
5. Inclusivity issues to consider alongside research progress and student development

Education starts here:

- How will you make explicit to students the pace of the CURE?
    - Will there be class meetings dedicated to specific data collection efforts, analyses, group brainstorming, peer-discussions, instructor conferences, etc.?
    - What activities will be assigned to students as homework?
    - What is the schedule of writing of the different sections of the deliverable?
    - Can you identify weekly goals for the project?
    - When will students be prompted to reflect upon their work? When will they be asked to discuss their work with peers or mentors? When will they be asked to formally review and critique their work or the work of others?
- What are the elements of the research process that will not be authentically included in the CURE?
    - Can any of those elements be modeled on smaller datasets by the students?
    - Can any of those elements be modelled on a different dataset of the same nature (published or not) as part of a class activity?
    - Can some complex analyses demanding high computational skills be demonstrated by the instructor or guests (e.g., a graduate student working on this type of analysis)?
    - Are there elements of the research that can be outsourced to the instructor or other researchers and merely explained or showed to students?
- What activities and requirements could represent obstacles to the engagement of all?
    - Are some specific lab tasks, field work, data collection protocols,

    etc. in conflict with student accommodations?
    - Are there activities that take place outside of the normal class time but need to happen on a specific day or time (e.g., attending to something in the lab, recording field observations at specific events)?
    - Is the literature that students need to consult to complete the work accessible and affordable to them?
    - Are there graphical representations of data or media used as part of the research that are not accessible to all?
    - Are the tools and support necessary for the success of all available on campus, including IT resources?
- How can you develop a supporting environment in which students explore research, manage their work, and fail safely?

Scholarship starts here:

- Are there specific deadlines associated with the research project including proposal deadlines, abstract deadlines, theses deadlines, manuscript deadlines, and commitments to collaborators or research students (graduate or undergraduate)?
    - Is the CURE work necessary for another step of the research process outside of the classroom?
    - Is the CURE work integrated with the research of a graduate student or mentored undergraduate student?
- Does the work that students will undertake in the CURE represent the work necessary to complete the research deliverable chosen? Alternatively, is the CURE research only one component of the deliverable?
- What analyses, if any, typically reported in supplementary information, are necessary for validation but cannot be fully incorporated in the CURE?
- Can the research questions and/or tasks be easily divided among groups or students?
- Can you collect the literature relevant to the project (or a representative subset of it) ahead of the CURE to share with students?
    - Can you share with students during the CURE examples of papers being published that are relevant to the research?
- What are important research concepts and analyses for the CURE

that may require some explanation? Have you completed [**Activity 1**] yourself?

Research and Education together:

- The milestones of the CURE should mimic the different elements of the process of scholarly work from inception to presentation/ publication. Thus, students should produce deliverables that are equivalent (at least in format) to the deliverables of professional scholars (e.g., Bakshi et al., 2016; Gastreich, 2020; Ramírez-Lugo et al., 2021).
- Peer-review and instructor feedback are models for the scholarly review process. Consider using the review framework of a prominent journal in your field or alternative rubrics (see [**Activities 12A and 12B**]) to guide students through this process and make peer-reviews valuable educational experiences.
- A consistent structure helps instructor and students keep track of the research and learning processes. One such structure is presented in [**Appendix 1**]. The structure is designed in eight different pedagogical steps that lead to a research deliverable as an integration of the two aspects of the CURE. Other examples of course structures are presented in the published literature (Bakshi et al., 2016; Bell, 2011; Bowling et al., 2016; Carr et al., 2018; Chen, 2018; Colabroy, 2011; DeHaven et al., 2022; Hekmat-Scafe et al., 2017; Mills et al., 2021; Murren et al., 2019; Ramírez-Lugo et al., 2021; Satusky et al., 2022; Sewall et al., 2020; Sweat et al., 2018; Thompson et al., 2016; Waddell et al., 2021; Wilczek et al., 2022; Zelaya et al., 2020).
- Dedicating class time to tutorials associated with formative assessments and/or discussions enables instructor(s) to verify that students are ready to undertake the homework and activities of the CURE.
- Dedicating class time to group meetings enables the instructor(s) to check in on all students/groups of students and address concerns and difficulties. Such meetings should be structured and scaffolded to promote constructive conversations. An example of the possible structure for one of these meetings is presented in [**Activity 13**].
- Field work can sometimes be implemented through asynchronous self-led field trips to overcome logistical obstacles (Washko, 2021).
- Lessons and interventions on specific topics, including replication

and statistical power, may help students understand issues and concepts in research that cannot be undertaken in the CURE itself and overcome misconceptions (Schwartz et al., 2004).
- Conversations with staff members in the Office of Academic Enrichment, Disability Services, the University Libraries, and the Teaching and Learning Center (Drake Institute at the Ohio State University) can help instructors find compromise and solutions to the challenges of implementing research in the classroom.
- The TILT framework (Winkelmes et al., 2016) enables instructors to increase transparency in assignments. Including explicit links between assignments and tasks as part of the purpose of the assignment helps make explicit the progress through the scholarly process. An introduction to the TILT framework is available here.
- Transparency in the assignments can also be improved by working with students through "understanding assignments" activities. Such activities can be done individually or as a group and enable students to make sure they are meeting the expectations of the instructor without being impeded by jargon. It encourages students to think about what it is they are expected to do (examples of assignments available at UNC Chapel Hill).
- Universal Design for Learning (UDL) is a framework that helps design teaching products and structures that can be used by all without the need for accommodations. UDL is a proactive approach to adaptation in the classroom and benefits all regardless of their needs for specialized designs. UDL enables instructors to meet the diversity of their classroom. It includes several key components reviewed in Burgstahler, 2013. UDL includes the implementation of different media, additional scaffolds, technology, etc. (Burgstahler, 2009; Griful-Freixenet et al., 2017), but also expands to other issues. Consider how you can equitably support students through flexibility in deadlines, meetings, and schedules. This can include letting students set their own work hours or provide students the opportunity to attend remotely certain meetings. Learn what users need by conducting check-ins for group access needs during lab meetings and surveying users about the overall accessibility of the course experience. Consult with accommodation services staff to determine how you can optimize research and teaching practices and spaces and how to make them more inclusive for individuals with disabilities and specialized needs. Advocate on behalf of students

with disabilities by communicating with accommodation services staff and encourage students to reach out to those services to get the support they need and deserve.
- Mentorship structure can involve peer-researchers and graduate students.
- Any mentorship structure can benefit from direct feedback from students. Communication is key to the success of the CURE.

Box 4: Important points

- Mini-workshops and group or class-wide activities on subsets of the dataset analyzed or published data comparable to those studied by the students can help students understand critical concepts that cannot be authentically explored in the CURE because of time.
- CURE students are integral members of the research team and can benefit from intellectual or data exchanges with other members of the research team, including graduate students, postdocs, and undergraduates in mentored research experiences.
- Consider presenting to students the trajectory of a research project from inception to publication, including the role of formal and informal peer-reviews of ideas, presentation conferences, and manuscripts.
- Consider how universal design for learning can be implemented in the CURE to facilitate the engagement of all students in the experience.
- Implement a mentorship model of the CURE students that fosters a safe environment for self-exploration and self-management (Palmer et al., 2015).

5. How will the research learning tasks be structured to foster students' development as scholars?

Overview: The design of a CURE requires the incorporation of a carefully thought-through scaffold that enables students to engage with an intellectual challenge that is often beyond any they have encountered before. Well-constructed scaffolds are critical to the success of CUREs because they enable students to tackle appropriately challenging tasks (Lopatto et al., 2020) and support students through failures, leading to greater perseverance (Corwin et al., 2022) . Scaffolds are relevant to the design of the entire CURE, which should include a series of activities and assignments that guide students through the entire project (e.g., Bakshi et al., 2016; Delventhal & Steinhauer, 2020; Hills et al., 2020; Makarevitch et al., 2015; Peyton & Skorupa, 2021; Rennhack et al., 2020). They are also relevant to the design of individual assignments because they help guide students through the tasks of research. This section enables you to determine:

1. The appropriate framework for the CURE assignments
2. The structure of CURE tasks as individual or group assignments
3. The activities that require detailed tutorials or mini workshops
4. The teaching interventions and writing assignments necessary to guide student learning
5. The role of reflective activities in the development of student deliverables
6. How the learning activities will foster an inclusive experience

Education starts here:

- What are the knowledge/skill bottlenecks students will encounter during the CURE? What tasks or expectations might represent obstacles?

- What does group work contribute to this activity? Which activities require group work?
    - Is the amount of work simply too much for a single person?
    - Is the interaction among students necessary to generate answers?
- How does students' ability to work well with others factor into the goals of the CURE?
- What does an authentic research team structure resemble in the field of research associated with the CURE? How can the CURE mimic this?
- How will you design groups whose structure promotes inclusivity and constructive intellectual exchanges?
- Are there activities that require tutorial or workshops to be explained?
    - Can students perform all necessary analyses for the CURE without particular training?
    - Will students need to be introduced to a particular software program to collect or analyze data? To construct figures or tables?
    - Can you feasibly guide individual students/groups of students through the experimental components of the CURE without prior training on a smaller/published/example dataset?
- How are you introducing the expectations for graded assignments and deliverables to students? How do they know what is expected of them?
- What are the necessary or helpful intermediate steps to completing all deliverables and graded assignments? What steps do you go through to complete these activities yourself? What about a graduate student? How would you guide a mentored undergraduate researchers outside of the course through this activity? Based on all of this information, ask yourself: "What would a novice do?"
- How can reflection help students develop better deliverables? What is the role of reflection in the development of student deliverables?
- Can a think-pair-share structure facilitate progress or foster the development of deliverables?
- How can you design learning activities that foster an inclusive experience?

Scholarship starts here:

- What are the different steps of the research process that students will be going through? What numbered elements of **Figure 2** are necessary or, instead, need to be edited?
- What foundational skills and knowledge of the field of research should be incorporated in the CURE? Does that include skills or knowledge that may not in fact be strictly necessary for the specific research question/hypotheses tested in the CURE?
- Which of the CURE tasks is typically achieved by individuals in a research setting? By groups of people?
- Are certain elements of reflection or of the scaffolding of the research project typically shared through publication (for example as appendices) in professional deliverables?

Research and Education together:

- Instructors often do not consciously realize that the process of research relies upon underlying concepts and practices. Researchers familiar with the research process skip over some of these foundations in their daily engagement in scholarship. Instructors can help students become researchers by explaining the critical concepts underlying the practice of research ([**Activity 3**]).
- Engaging in research can be daunting for students. Reflection workbooks and journaling can help students overcome the challenge of the research process, reduce their anxiety, increase their appreciation of research, and facilitate exchanges between students and instructors (Apgar, 2022). Research shows that training significantly improves students' reflection skills (Devi et al., 2017).
- The entire course would benefit from a scaffold that guides students (and instructors) through the learning process. Sabel (2020) provides an example of a framework to develop the scaffold of a course. Another example is showed by the Decoding the Disciplines framework (https://decodingthedisciplines.org/) introduced here. [**Appendix 1**] shows yet another example in which students, for each element of the CURE (e.g., searching the literature, data collection, data analysis, writing the material and methods) engage in a series of activities that lead them to produce a research deliverable (**Fig. 2**).
- Group meeting agendas can help students prepare the meetings they will have with their teammates during class time. Example of

questions and guidelines to prepare various group meetings are provided in **[Activity 14]**.

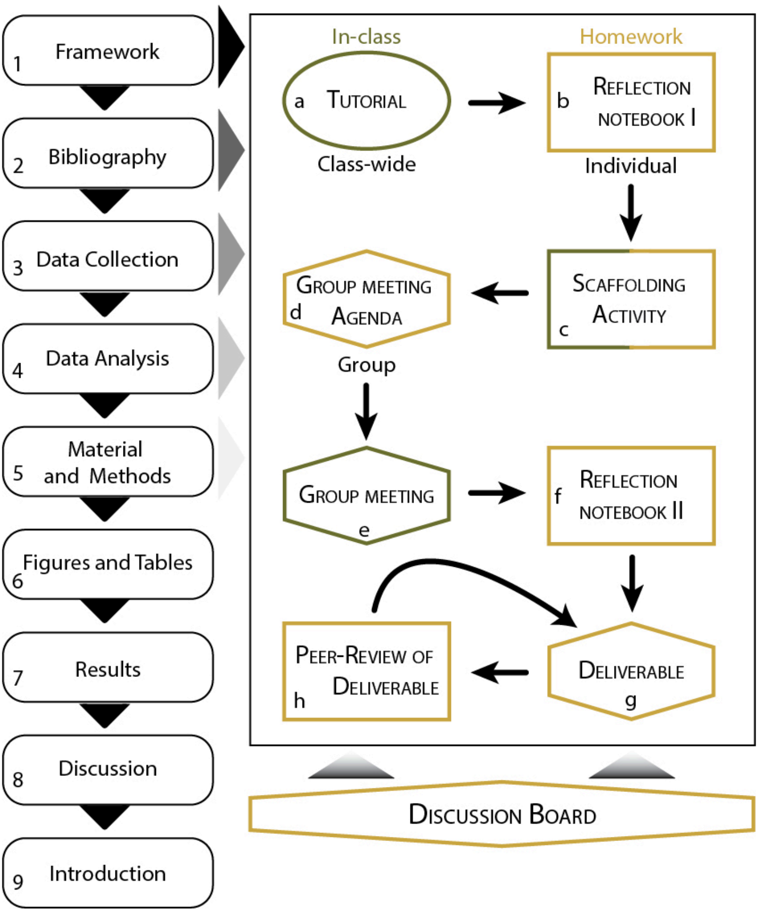

Figure 2. Possible CURE scaffold. The colors denote the location of the work, the shape of the boxes whether the work is undertaken individually, as part of the research group, or class wide. Arrows show the flow of work through deliverables for which prompts are provided in [Activities 15-17].

- There is an extensive literature on the design of groups emphasizing the need to carefully consider the group composition as well as the framing of the group work by the instructor(s). Best practices for group work are summarized in Wilson et al. (2018) and at https://lse.ascb.org/evidence-based-teaching-guides/group-work/

- Consider carefully the size of the groups (Heller & Hollabaugh, 1992).
- Consider carefully the gender and ethnic minority status of students in the composition of the groups (Adams et al., 2002; Micari & Drane, 2011).
- Assigning specific roles to students is helpful to encouraging and structuring the conversation (Heller & Hollabaugh, 1992). Enforcing a rotation between the roles of the students, if possible, can be helpful. There are several strategies for distributing roles presented in the literature (e.g., Olimpo et al., 2016; Winkelmann et al., 2015).
- Including discussions of the nature of intelligence, academic failure, systemic biases, as well as fostering a growth-mindset in students can greatly help students overcome social-comparison concerns (Micari & Pazos, 2014).
- Setting group goals can also be helpful (Werth et al., 2022) and strategies for effective group work are important (Washington University in St. Louis). In addition to assigning specific roles, instructors should consider using group contracts [**Activity 18**], and peer evaluations (see [**Activity 19**], which have been showed to encourage student participation (Chang & Brickman, 2018), can facilitate the assessment of the contract compliance, and make easier the identification of conflicts and problems leading to a more rapid resolution. Group contracts and peer evaluations can be used as part of the grading scheme to determine individual contributions.
- The Peer Assessment Factor is a quantitative assessment of the students by themselves and peers that can be used as a formative assessment and a guide for interventions.
- Examples of other activities, and interventions are provided in the PETS Process Manual.

- Frameworks for mini-workshops are presented in the primary literature for many tools and protocols. Some are specifically aimed at CUREs. A statistical workshop is presented by Olimpo et al. (2018). Sewall et al. (2020) presents several mini-workshops on computational tools (R and QIIME2). Alternatively, published protocols might be sufficient to guide students through an experiment or research task without the need for a prior tutorial or workshop (Acuna et al., 2020; Buser et al., 2020; Chen, 2018; Craig, 2017; Goeltz & Cuevas, 2021). Several published CUREs include within the supplementary information files useful protocols and tutorials (e.g., Bucklin & Mauger, 2022; Jurgensen et al., 2021; Poole et al., 2022; Roberts et al., 2019; Zelaya et al., 2022).

- There are numerous published strategies to help scaffold inquiry activities such as authentic research. Several are summarized in a TLRC teaching topic. Additional information on scaffolding is provided in Killpack et al. (2020).
- Writing-to-Learn (WTL) activities can help students build their understanding of the existing literature on the CURE topic, work through their project, and complete their deliverables (Balgopal et al., 2018; Bangert-Drowns et al., 2004; Fry & Villagomez, 2012). Many examples of WTL activities are available online (see in particular the Center for the Study and Teaching of Writinghttps://cstw.osu.edu/writing-learn-critical-thinking-activities-any-classroom). A selection of scaffolding activities derived from WTL concepts that can be implemented in a CURE are presented here, including an activity guiding students through the process of deciding on their data analysis protocol [**Activity 20**], an activity helping students summarize the existing literature [**Activity 21**], two sister activities helping students compare their findings to data from the primary literature [**Activities 22-23**], and an activity meant to help students prepare the discussion section of their paper **[Activity 24]**.
- Tutorials for writing can be developed for each section of the deliverable, including the elements of an IMRaD paper (Introduction, Methods, Results, and Discussion). An example of the structure of such tutorials are showed in **[Activity 16]**. An example activity to develop students' graphical skills is showed in **[Activity 25]**.
- Other activities can be designed to scaffold the students' work including activities encouraging students to predict their results and represent them graphically or activities comparing the introduction and discussion from a single publication to emphasize their roles as bookends of the deliverable.
- **Figure 2** shows a possible framework by which reflection can be

incorporated in the scaffolding of the course to enable students to build their metacognition while they engage in scholarship (see Denke et al., 2020). Student reflection can be guided by a set of questions and an information literacy framework. An example of such guide is provided in **[Activity 26]**.

- Best practices to build student metacognition are reviewed in Stanton et al. (2021) and at https://lse.ascb.org/evidence-based-teaching-guides/student-metacognition/.
- Think-Pair-Share activities, whereby students first reflect upon their work and then discuss their thoughts with group members before to engage with the rest of the class and the instructor(s), may be helpful in promoting reflection as well as conversations among students; they can also be used as formative assessments by the instructor(s) to improve student performance (Akhtar & Saeed, 2020). Best practices for this active-learning activity have recently been reviewed in Cooper et al. (2021) and Prahl (2017).
- The TILT framework (Winkelmes et al., 2016) enables instructors to increase transparency in the assignments by providing clear descriptions of the purpose, tasks, and evaluation criteria for each activity the students engage in. Examples of applications of this framework are provided at: https://tilthighered.com/tiltexamplesandresources.
- There are numerous sets of best practices and recommendations (e.g., Cooper et al., 2020b; Faulkner et al., 2021; Linder et al., 2015; see question 10 on p. 104) that have been developed to promote an inclusive classroom environment (whether in a CURE or not). Miller et al. (2022) presented a framework to incorporate "antiracist, just, equitable, diverse, and inclusive principles" in the design of a CURE. Best practices for inclusive teaching are presented in Dewsbury and Brame (2019) and at https://lse.ascb.org/evidence-based-teaching-guides/inclusive-teaching/.

Box 5: Important points

- The prior knowledge of the students informs the first rungs of the learning scaffold.
- The ELOs for the course provide the framework for the endpoint of the scaffold.
- Group work should be intentionally designed, supervised, and assessed to lead to accountability and personal learning milestones.
- The scaffold adopted should provide students all required background information, guide them through challenging tasks in an accessible context, provide opportunities for reflection, and enable students to repeat or expand on their work to advance the research process.
- Writing-to-learn activities can facilitate student learning and development as writers.
- Information literacy is critical to student success and can be fostered through reflective work as well as activities promoting metacognition.
- The Transparency framework of TILT enables instructors to articulate the purpose, tasks, and criteria for evaluations of each activity to students, thereby promoting metacognition and reflection.

6. How will students communicate the results of their research?

Overview: The communication of research findings is critical to the process of scholarship, including undergraduate-led research (Spronken-Smith et al., 2013). It is also an important element of CUREs. Many traditional outlets of professional scholars are also appropriate for student research derived from CURE. Thus, presenting research findings at conferences has been showed to greatly benefit undergraduate students (Little, 2020). Publishing the findings of a CURE on a database used by researchers has been demonstrated to lead to increased student motivation (Wiley & Stover, 2014). Finally, publications resulting from CUREs have been associated with both personal and professional benefits for students (Turner et al., 2021). In all forms of deliverables, it is important to consider how the contributions of all members of the CURE will be recognized. Research has showed that there exists a gap between what an instructor or professional researcher might consider necessary for authorship *versus* what students consider necessary (Turner et al., 2021). This section enables you to determine:

1. The appropriate mode(s) of dissemination of the CURE's findings
2. The division of labor among students in preparing the deliverable
3. Authorship rules

Education starts here:

- What is an appropriate expectation in terms of deliverable given the time constraints of the CURE?
- Would a specific deliverable be more motivating for students? Have you asked students?
- Is one format of deliverable going to benefit students professionally more than another?
- Which mode of dissemination would be appropriate for a professional scholar at this point in the research? Would that be any different for a student participating in a mentored research experience?
- Will the deliverable be evaluated for a grade?
- Will each student be expected to produce a final document (be it a dataset, poster, manuscript, or proposal) or will the deliverable be prepared by a group of students?
    - Will each student prepare one section of the deliverable? Alternatively, will all students be contributing to all sections of the document?

    - Will all students in the group be evaluated as a group with a single grade for the document applying to all students? Alternatively, will the students receive an individualized grade?
    - If students will be individually graded, what criteria will be retained to differentiate between group members? Are those going to impact authorship order?
- How will the intellectual and practical contributions of the students participating in the CURE be recognized in products of the project?

Scholarship starts here:

- What deliverable are you expecting/hoping for at this stage of the research?
    - Are the students completing a project leading to a publication manuscript? Will the students produce a version of the manuscript near-ready for submission or will there be large amounts of work undertaken after the conclusion of the course to bring the manuscript to a submittable form? Who will undertake this work?
    - Are the students helping start a new project, developing preliminary results for a proposal or contribute to a database?
- Will the findings of the CURE be appropriate for a conference presentation?
- What are the standards for manuscript authorship in your field? At your institution? In your research group? Alternatively, when are contributors merely acknowledged?
- How will the contributions of instructors and outside researchers be considered for authorship?

Research and Education together:

- Different deliverable formats are not mutually exclusive.
- The format of the CURE deliverable should reflect the authentic mode of delivery of research findings in the field (Kloser et al., 2011).
- Students enjoy the opportunity to present the results of their research at conferences and/or publish their work (Amir et al. 2022).
- Participation in research conferences has been showed to benefit students both by helping students develop their communication and research skills, but also by positively impacting their career and

engagement in other activities (Little, 2020).

- The opportunity to publish the findings of the CURE enhances student motivation (Wiley & Stover, 2014).
- Publications can be powerful deliverable for a CURE because:
    - They can act as scaffold with the different sections of a manuscript corresponding to elements of the research process
    - They represent the scholarly endeavor and can help students gain an appreciation for the process of research.
    - They can help build the students' identity as researchers through co-authorship of a published document.
    - They positively impact the careers of students (Turner et al., 2021).
    - They can be motivating and thus increase student engagement in the CURE.
    - They provide a tool for accountability among students and with the instructor.
- Consider how the participation in a national or university-wide CURE program may dictate the deliverable if the CURE is not researcher-driven.
- Undergraduate research symposia can be great venues for the students to present the results of the CURE. Many colleges and universities as well as some departments at larger institutions organize symposia at least once a year (Presentation Opportunities).
- There are also numerous national conferences dedicated to student research (e.g., SigmaXi; Council on Undergraduate Research).
- In addition to discipline-specific publication venues and journals aimed at professional scholars, there are also open-access online undergraduate research journals (Sun et al., 2020) that may be appropriate outlets for the CURE's findings.
- The Knowledge Bank of Ohio State (https://library.osu.edu/kb) enables the archiving of intellectual outputs of the university community in an accessible digital format. Other digital repository, some discipline-specific, may also be appropriate (e.g., the Environmental Data Initiative)
- There are online repositories of research products that are citable and can be appropriate for the results of CUREs (e.g., https://figshare.com/).
- Digital and artefactual exhibits can also appropriate venues for the presentation of archival and object or specimen-based research (e.g.,

Donegan et al., 2022; ENG5612 at Ohio State).

- Multiple online scholarly projects and databases (**Table 13**) may be appropriate venues for student contributions (e.g., Map of Early Modern London).
- Establishing clear authorship guidelines is critical to a smooth and rewarding experience:
    - Students should buy into the rules. It is important to explain the rationale for authorship rules to students.
    - Students may also have valuable input on the rules. Consider developing authorship rules specific to the CURE, with the students, that incorporate guidelines and recommendations from relevant institutions as well as best practices in the CURE's field of research.
- Many universities and colleges have developed authorship guidelines including The Ohio State University (Authorship Guidelines) and other institutions (e.g., Harvard University, University of Michigan, Yale University).
- Many professional societies have also developed best practices documents relating to authorship (e.g., American Physical Society, American Psychological Association, British Sociological Association).
- Some journals and publishers also have rules for authorship (e.g., Nature, British Medical Journal, Taylor & Francis).
- If other instructors or researchers (e.g., graduate students, peer teaching assistants, research collaborators at other universities) will be involved in the project, they should be part of the conversation and agreement on the authorship rules. Consider the authorship rules you employ in your research group.
- There are several published sets of guidelines for authorship that can also be used. The CRediT taxonomy (Honoré et al., 2020), which has been adopted by PLOS journals (PLOS Authorship Guidelines), can provide a starting point to develop guidelines specific to your CURE.
- The copyright services department of the Libraries (https://library.osu.edu/copyright) can help with issues of students' intellectual property rights.
- In the case of CURE-specific requirements for authorship, consider whether or not it is appropriate to tie authorship to course requirements and achievements (e.g., fulfilling the contract if

contract grading, obtaining a certain minimum grade on the deliverable).
- Students should be offered the opportunity to approve the final version of the manuscript they co-author, even after completion of the course.

Box 6: Important points

- Different deliverable formats are not necessarily mutually exclusive.
- Establishing clear guidelines and requirements for authorship is critical.
- Communicating the results of the CURE should reflect authentic scholarly communication in the field.
- Publication manuscripts can serve as scaffold, provide motivation, ensure accountability, and shape student identity.

7. How will the progress and experience of students be assessed?

Overview: The assessment of the students' work in a CURE enables the instructor and the entire class to stay up to date on the research progress, including the findings of the project and the setbacks. Well-designed assessments also enable students to reflect on their learning, help them identify their difficulties, and provides tools for overcoming obstacles. Because CUREs are elements of formal courses, it is also often necessary to evaluate the students' work qualitatively and quantitatively for the purpose of a grade. This section enables you to determine:

1. The goals of assessing the CURE work
2. The mode of grading to adopt in the CURE
3. The proportion of the evaluation represented by group work and individual work
4. The proportions of formative assessments and summative assessments
5. The roles of instructors, peers, and self in evaluation.
6. The nature of the assignments graded
7. The need for specific rubrics and grading criteria
8. The importance of an inclusive mode of grading

Education starts here:

- Does all evaluation work have to translate to a grade?
    - Can some assignments be evaluated simply for completion/genuine participation?
    - Can some scaffolding assignments be reviewed to provide feedbacks without associating the work with a grade?
- What are the goals of the grading in the CURE?
    - Will it be used to determine authorship eligibility?
    - How will the grading be aligned with the expected learning outcomes (ELOs) for the CURE?
- Which assignments will be graded?
    - When you assess student performance, what are you rewarding? Is the grading based on the mastery of the ELOs or on other criteria? Are those criteria made explicit to students?
    - Are students given a chance to revise their work and correct their mistakes?
    - How do you give students practice with and feedback on performance items that you are rewarding on the final assignment?
    - Do you give students the opportunity to reflect on what they are learning or how they are growing?
- What percentage of the class grade will be represented by the CURE

grade?
    - How does this compare to the time investment made by students?
- Will group assignments be graded or will only individual assignments be graded?
    - When group assignments are graded, do all members of the group get the same grade?
    - Does the mode of grading lead to increased intra-group conflicts?
- What mode of grading will be adopted in the CURE?
- What proportion of the final grade for the CURE is represented by formative assessments *versus* summative assessments?
- Are summative assessments based on the formative assessments on which the students got feedback?
- Is there room for self-evaluation in the CURE? What about peer-evaluation beyond peer-reviews of deliverables?
- Can students grade some of their own assignments with the help of a rubric as a metacognition tool? Can this exercise be combined with instructor feedback and a redo enabling students to gain missed points?
- How often will students be completing work reviewed by the instructor(s)?
    - How often do students get instructor feedback?
    - How many iterations of a given document, section of deliverable, research product will students be producing?
- Will students get rubrics for each assignment?
    - How will explicit grading criteria be provided?
    - Is it possible to hand out examples of successful products to students as models and examples of works that do not meet expectations to guide their own writing?
- What approaches can you adopt to ensure an equitable and inclusive mode of grading? How can assessments be used to reduce the equity gap?

Scholarship starts here:

- How are scholars evaluated in your field? Can this mode of evaluation be mimicked in the CURE?
- What determines the quality of a deliverable in your field and what

aspects of that document quality do students have control over?
- What is a reasonable quality standard to expect for the deliverable of choice? Is it realistic to expect the students to produce a document nearly ready for publication submission or presentation?
- How would you assess the work of a mentored research student engaged in a similar project? What expectation would you have of this student's deliverable?
- How will the success of the research impact assessment and grading?

Research and Education together:

- The nature of CUREs as authentic research may lead to failures and mistakes; in fact the novel aspect of the CURE will almost certainly lead down unpredictable paths and outcomes. Designing the assessment of the CURE to mitigate the effects of technical problems, negative results, and the steep learning curves of scholarly endeavors is critical to student engagement. The goal of assessments should be to inform students and instructors alike of the progress of students as researchers, not the success of the observations or experiments. The ability to troubleshoot, the resilience of students in the face of failures, the understanding and explanation of errors, and the repetition of tasks should be integrated in the grading scheme. Finding the solution to a problem and understanding why an experiment did not work are progress. A discussion of failure, how to approach failure with students, and the point of view of the instructor in the context of CUREs is provided in Townsend (2022).
- Backward-design requires the alignment of the assessments with the ELOs for the CURE. Instructors should rigorously verify that all ELOs for the CURE are assessed by the end of the course, but also that assessments do not evaluate expectations that are not made explicit to students. Different assessment modes are suitable for diverse learning goals (Verb wheel).
- Transparency in assessment is critical to student success and inclusive teaching. The TILT framework (Winkelmes et al., 2016) presented earlier in this document is particularly helpful: https://tilthighered.com/tiltexamplesandresources.
- Beyond traditional point-based grading, there are other modes of grading that an instructor can consider.
  - Criterion-referenced grading provides students with flexibility

in the weights of the various components of the course. It enables students to mitigate test anxiety and emphasize formative assessments; it can also be used by students to lessen the consequences of out-of-school responsibilities on their academic endeavors. In practice, you should determine bounds for the weights of the different categories of course assessments and enable students to develop their own formula for the CURE grade. Every student will be graded according to their unique formula (which can easily be setup in a spreadsheet program).

- Contract grading (Inoue, 2019) offers the opportunity to combine flexibility for students and for instructors while maintaining rigor in expectations and avoiding conflicts over grades. Contract grading is a format of grading that does not involve points or letter grades, apart from the final course grade. At the start of the semester, students choose/agree to/sign a contract that sets their path for the semester. Each contract lists the work required of the students for a particular outcome (e.g., an A, a B). If the student satisfactorily completes the work associated with their contract, they will earn that grade. Contracts are often associated with a mid-semester conference to check on progress towards the completion of the contract and reevaluate commitments if necessary. This conference is repeated at the end of the semester to assign the students' grades. The onus of tracking contract compliance may be placed on the students who are responsible for writing self-evaluations ahead of each conference in which they need to address their work, its quality, their engagement with the class, etc. You should respond to these self-assessments during the conference. You can always disagree with the student in their final assessment of their performance. Students can also be asked to keep track of their time using a labor log. An example of contract grading for writing courses is provided by Inoue (2019). Another example been published online by Cathy N. Davidson. Contracts can be more or less complex incorporating aspects of criterion-referenced grading (Hiller and Hietapelto 2001) or including specifications grading elements (Lindemann and Harbke 2011; see **Appendix 2** for a model applied to CUREs).

  - Specifications grading can help uphold academic standards and motivate students while reducing grade anxiety and cheating. In specifications grading, the assignments are graded on a pass/fail basis, a check/check minus/check plus/unsatisfactory basis, or an excellent/meets expectations/needs revisions/fragmentary basis. Instructors should provide clear specifications of what constitutes an acceptable work, what qualifies for a check (or earns a check plus), what leads one to meet (or exceed) expectations, etc. Students may also be given the opportunity to revise their work. Assignments may be assessed individually or grouped into modules that are assessed holistically. Modules can be weighed to reflect the complexity of the tasks, their relevance to learning outcomes, and/or their status as formative/summative assessments. Several models of specification grading for different fields have been published (e.g., Blackstone & Oldmixon, 2019; Carlisle, 2020; Elkins, 2016; Howitz et al., 2021).
- Group reviews can be used to assess the contributions of all members of a group to the outputs of the CURE, including specific documents. A group review template is provided in [**Activity 19**]; others exist in the literature (e.g., Bucklin & Mauger, 2022; Waddell et al., 2021).
- Self-evaluation, also called self-assessment or self-grading can be a powerful tool to promote student pacing and success, primarily as part of formative assessment (Andrade, 2019).
- Many rubrics have been published online (University of Minnesota, Chicago State University) and in the peer-reviewed literature for both writing assignments and CUREs (Bakshi et al., 2016; Kishbaugh et al., 2012; Lee & Le, 2018; Murren et al., 2019; Ramírez-Lugo et al., 2021; Sewall et al., 2020; Waddell et al., 2021).
  - An example of a rubric for discussion boards in provided in **Appendix 3.**
  - An example rubric for a manuscript-type deliverable is provided as part of the peer-review presented in **[Activity 12]**.
  - Bucklin & Mauger (2022) as well as Merrell et al. (2022) both include rubrics for a poster presentation stemming from CUREs.
  - An example rubric for a grant proposal-type deliverable is provided in Rennhack et al. (2020).

- When designing a rubric, consider the following best practices (from Bean, 2011):
  - Numbers on the rubric do not add up to 100 and do not represent directly course points.
  - The grade associated with the rubric is always presented as a letter or a check/check plus/check minus, not a number.
  - Students are explained how the rubric is used in grading.
- A good rubric should include a detailed explanation of the task students are expected to perform, the characteristics of the work that will be evaluated, the levels of mastery that will be considered, and descriptions of the characteristics for each level of expertise. Additional guidelines for the development of rubrics can be found in a number of different publications (Boston University, Brown University, and Arizona State University). You can also consider co-creating the rubric you will use with the students (University of Colorado Boulder).
- Highly structured courses with frequent low stakes assignments increase student engagement (Cavinato et al., 2021), lead to higher performance (Freeman et al., 2011), and help reduce the equity gap (Eddy & Hogan, 2014; Haak et al., 2011).
- Consider using concept inventories to test for knowledge acquisition in the field of research (**Table 6**).
- (More) authentic formative assessments can be undertaken by reviewing and grading lab notebooks, periodic research updates akin to those a research student would provide in a lab/research group meeting, conference-style abstracts, elevator speeches, or chalk board presentations.

Box 7: Important points

- Assessments should be aligned with ELOs for the CURE.
- Rubrics and clear criteria for success help communicate

the expected level of mastery to students.

- Student practice and instructor feedback on formative assessments should be aligned with summative assessments.
- Contract grading, specifications grading, peer-grading, and self-assessment are valid alternatives to traditional numerical grading by instructor.
- Frequent low-stakes assignments can help reduce the equity gap.
- Accountability for personal tasks and peer/self-review facilitate grading of group work.

8. How will research learning tasks change as discoveries are made and initial research questions are answered?

Overview: The process of research is inherently iterative and involves sequential hypothesis testing. As results emerge from observations, experiments, and analyses, new hypotheses are developed and require testing. This is often the case in CUREs. Unlike a scholar's research program, however, CUREs have strict curricular goals and involve time limits, including a comparatively small number of weekly hours of research engagement and an end to the research process imposed by the end of the instructional period be it a quarter, semester, or other. This section enables you to determine:

1. Whether to include such sequential aspect of research within a single

implementation of a CURE or across repetitions of a CURE.
2. How to bring about the transition from one hypothesis to another
3. The need to revise the scaffold and learning tasks of the CURE to fit new hypotheses and research paradigms
4. The importance of planning the research course of the CURE to offer an original experience to successive cohorts of students

Education starts here:

- Will students have time to explore only one hypothesis/question, or will they be able to at least partially engage in a second one?
- For students exploring researcher-chosen questions/hypotheses:
    - Will they be able to suggest their own follow up hypothesis/question?
    - How will you explain to them how the question/hypothesis they are investigating was developed?
- When revising or repeating a CURE:
    - What elements of the CURE are outdated? Any recommended paper or analysis no longer reflecting the knowledge or best practices in the field?
    - How will you ensure that the upcoming CURE is not merely a variation on a previous iteration, in which all novelty has been lost?
    - What should you change to make sure that the CURE does not become a "cookbook CURE", a research experience for which the approach and protocols are fully developed and the result guaranteed, leading students to engage in research novel only to them that does not significantly contribute to the field?
    - Is the new iteration of the CURE following-up on questions or hypotheses developed in previous versions of the course?
    - What advances in the field have been made since the last time the CURE was run? Should planned questions/hypotheses be revised as a consequence?
- Have new best practices in pedagogy and CURE implementation been published since the last iteration of the CURE? Do they mandate revisions to the structure, scaffold, or assessment of the CURE itself?

Scholarship starts here:

- Does the scope of the CURE represent a publishable manuscript in the field of research of the CURE? Will more than one iteration of the CURE be necessary to answer all necessary questions/test all necessary hypotheses?
- Are adjacent or related questions/hypotheses being tested by colleagues, collaborators, research students, thus limiting the scope of the work the students can follow-up on?
- When developing a new researcher-driven CURE:
    - What is the place of this CURE within the research program of the researcher(s) involved?
    - What are the natural follow-up hypotheses or questions already known?

Research and Education together:

- It is critical to introduce students to the nature of the scholarly endeavor including the fact that research generates more questions than answers and the need for researchers to critically select the questions that they will in fact explore. This discussion can take place as part of the process to select the question investigated in the CURE or not (see [**Activity 2**]). The roles of funding agencies, other scholars, institutions, and systemic biases in this selection should also be presented. Some aspects of these issues are discussed in https://opentextbc.ca/researchmethods.
- It is possible to demonstrate to students the nature of research and the succession of investigations that lead scholars to build piece-by-piece the puzzle of a particular topic without requiring students to walk these steps themselves through retrospectives and walkthroughs of the history of the current paradigms and questions they will explore.
- CUREs can build on each other over time to enable the investigation of particular topic through a series of studies (Satusky et al., 2022; Sun et al., 2020: figure 2). It is important to incorporate this history when presenting the CURE to students.
- Extensive notetaking during the design and implementation of the CURE enables an instructor to revise the CURE. There are published guides to revising courses and reflecting on pedagogy (see for example McGahan, 2018).
- Instructors teaching researcher-independent CUREs should

consider following the research advances in the field of the CURE as they do their scholarship area to maintain up-to-date knowledge of the field, active areas of research, literature reviews, and methodological developments.

Box 8: Important points

- Just like a research program, a CURE changes over time following research inquiry, progress, and setbacks.
- Showing/explaining the development of the CURE overtime to students is integral to showing/explaining the research process.
- Just like the work of students during the CURE is iterative, so is the work of (re)designing the CURE itself.
- Beware of creeping away from a CURE towards a "cookbook lab" with successive iterations.

9. What are the logistical obstacles and solutions for the different steps of the CURE?

Overview: The implementation of a CURE requires students to access the tools of the research trade. These are discipline-dependent, but may include lab space, consumables, specific technologies or equipment, library and documentary resources, research specimens, and computing facilities. Certain CUREs may also involve field experiences, which introduce their own set of logistical challenges. Planning the needs of the CURE is critical to its success and may influence the nature of the research questions investigated with students. This section enables you to determine:

1. The resources necessary for data collection
2. Alternative sources of data
3. The needs of the data analysis
4. The potential for crowd-sourcing the CURE's support
5. Possible sources of funding to support CUREs

Education starts here:

- What is the budget of the course?
- Is the CURE part of the broader impacts of a grant?
- Is the CURE part of a creative teaching or curriculum redesign effort that can receive funding or logistical support from the institution, professional societies, or funding agencies?
- What help can support staff, including lab technicians, research and teaching assistants, lab coordinators, librarians, IT staff, and museum staff, provide with data collection and analysis? What do they need to be able to help?
- Who can help me think about my CURE development process and the pedagogy of this model of research?

Scholarship starts here:

- What are the consumable needs of the CURE?
- Do loans of specimens need to be secured prior to the start of the CURE? What are the restrictions on the handling of research specimens and materials?
- What equipment, including laboratory equipment and computational resources inclusive of hardware and software programs, is necessary to not only collect and analyze the data, but also prepare deliverables? Is this equipment accessible in teaching or research facilities on campus?
- What permits, certifications, and approvals are necessary for students and instructor(s) to undertake the research?
- What existing databases and online datasets of images, observations, measurements, etc. can be leveraged to facilitate the data collection

for the CURE?
- For researcher-driven CUREs:
    - Can the CURE be integrated with other data collection efforts of the research group? What are the benefits for the research students involved in contributing their data to the CURE?
    - What is the role of research collaborators in the project?
- Are there sources of funding associated with the research ongoing in the laboratory/research group that can legitimately support the research undertaken in the CURE?

Research and Education together:

- Although the cost of a CURE has been reported to be higher than that of a traditional introductory science laboratory (Rodenbusch et al., 2016; Spell et al., 2014), it is much lower than the cost of mentored research experiences or summer research experiences (Rodenbusch et al. 2016; Smith et al., 2021). Some estimates are around $400 to $500 per student per course and many CUREs are cheaper (Poole et al., 2022) or even approach no financial costs.
- Online databases (**Table 13**) and freeware programs (**Table 14**) enable data collection and analyses at low costs.
- Collaborators and colleagues may be able to share equipment and supplies at low costs. CUREs can be departmental/institutional resources that spur enrollments and raise the profile of the teaching/research unit. Discuss with stakeholders (e.g., department chair, associate dean, and colleagues) the benefits of supporting the CURE.
- Many institutions have some equipment and resources (e.g., supercomputer, computer labs, greenhouse space, imaging facility) whose costs and access are mutualized or free for in-house projects.
- The integration of research and teaching missions of the CURE may enable different sources of funding to support the work (e.g., CUREnet). Those may include grants from professional societies, government agencies, internal competitions at the host institution, etc. (e.g., Council on Undergraduate Research). There are also calls for proposals appropriate for CUREs (NSF Division of Undergraduate Education). Some network CUREs may provide seed funding to implement the course (DeChenne-Peters & Scheuermann, 2022).
- Trainings, permits, and approvals should be secured ahead of the

CURE as much as possible. Student-specific trainings should be integrated in the course. Logistical obstacles of research are important part of the curriculum. Students learn of the realities of the process of research and the important legal and ethical regulations that are associated with it. Additionally, students who navigate through these obstacles may gain important skills in project management.

- The involvement of research group members in the CURE should be designed to benefit them in the form of co-authorship, mentoring experience, opportunities for career advancement, funding, etc.
- Teaching assistants, including graduate and undergraduate students, have been showed to be very helpful in supporting undergraduate students enrolled in CUREs (Olson et al., 2022). They should receive necessary training to learn how to teach a CURE (Kern & Olimpo, 2022)
- There are multiple offices and resources at the Ohio State University to support the development of CUREs that are summarized in **Table 15**.

Workshops and Endorsements	
Teaching Information Literacy	https://drakeinstitute.osu.edu/endorsement/teaching-information-literacy https://u.osu.edu/teachinginfolit/teaching-information-literacy-workshops/on-demand-asynchronous-workshops/
Meaningful Inquiry	https://drakeinstitute.osu.edu/endorsement/meaningful-inquiry
Teaching through Writing	https://drakeinstitute.osu.edu/endorsement/teaching-through-writing
Inclusive Teaching	https://drakeinstitute.osu.edu/endorsement/inclusive-teaching
Research Mentoring	https://drakeinstitute.osu.edu/endorsement/research-mentoring-training
Digital Humanities Pedagogy	https://drakeinstitute.osu.edu/endorsement/digital-humanities-pedagogy
Course Design Institute	
Drake Institute Course Design Institute	https://drakeinstitute.osu.edu/instructional-support/course-design-institute
Pedagogical resources	
The Teaching and Learning Resource Center	https://teaching.resources.osu.edu/
Instructor Resources at University Libraries	https://library.osu.edu/instructor-resources-at-university-libraries
Offices and Professionals	
Office of Undergraduate Research and Creative Inquiry	https://ugresearch.osu.edu/
Michael V. Drake Institute for Teaching and Learning	https://drakeinstitute.osu.edu/
Office of Academic Enrichment	https://osas.osu.edu/oae/
Honors and Scholars Center	https://honors-scholars.osu.edu/
University Libraries	https://library.osu.edu/instructor-resources-at-university-libraries
Office of Service-Learning	https://service-learning.osu.edu/

Table 15. Resources at the Ohio State University for the development of CUREs.

Box 9: Important points

- Obstacles to data collection can be overcome with research databases, citizen science data, museum databases, and online sets of images and observations or measurements.
- Campus resources including IT, the Libraries system, as well as research lab members and collaborators can help overcome data collection and analysis obstacles.
- CUREs can be integrated with mentored student research (of graduate or undergraduate students) to facilitate funding, mentoring, data collection, data analysis, and the professional development of research students.

10. What are the roles of instructional and support staff?

Overview: Although it may be tempting to think of the instructor (or instructors) as the linchpin of both the research and pedagogical processes of the CURE, the structure of CUREs is inherently student focused. As such, CUREs provide the opportunity for instructors to rethink their identity in the classroom to include a critical mentorship component built around providing a supportive environment in which students are assisted in acquiring knowledge and skills, but also learn the significance of their work (**Figure 3**).

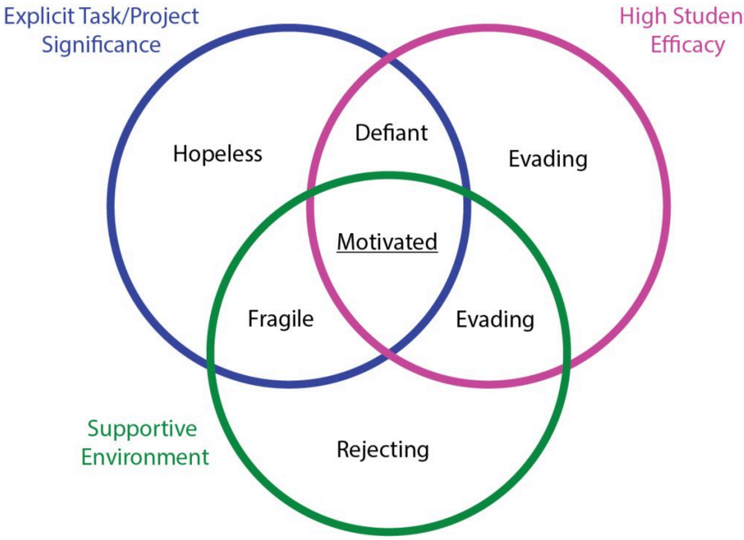

Figure 3. The three components of student attitudes that should be fostered by research mentors (redrawn and modified from Ambrose et al., 2010).

A successful CURE is easier to implement with the support of other members of the research team, educational support staff, or campus community. A researcher-independent CURE may rely on the resources and structure of a national program, but the success of the CURE will also likely involve campus members who can complete and enhance the work of the instructor. This section enables you to determine:

1. The role(s) of the instructor(s) in mentoring the CURE
2. The fostering of a supportive, motivating environment
3. The role of the instructor and other experienced scholars in the research
4. The expectation and needs of graduate or peer-teaching assistants
5. The support provided by lab managers, technicians, and other staff members

Education starts here:

- How can the experience of CURE students be improved through interactions with students who have previously completed the course, mentored undergraduate researchers, graduate students, or postdoctoral researchers?
- What challenges are students likely to encounter during the CURE?
- What are the obstacles to the mentor-mentee relationship you foresee for the CURE? Consider expert-novice gap, communication skills, and cultural differences as well as "social-distance" (Shanahan, 2018).
- What is the ability and willingness of instructors to commit time to mentoring?
- What is the prior experience of the instructor(s) in mentoring research?
- What training and support is necessary to foster the success of postdoctoral researchers, graduate student instructors, or peer undergraduate assistants as educators?
- How do the ELOs of the CURE impact the model of mentoring that instructors should approach?
- What are the expectations for postdoctoral researchers, graduate student instructors, or peer undergraduate assistants of the instructor-of-record? Of the department/college/graduate school/ HR/ etc.?
- What are the ELOs as well as professional and personal goals of postdoctoral researchers, graduate student instructors, or peer undergraduate assistants?
- How can the mentoring of postdoctoral researchers, graduate student instructors, or peer undergraduate assistants by experienced researchers and teachers help them reach their goals?
- What are the roles of the support staff and outside researchers in the CURE? Can these professionals free up instructor time for mentoring by assuming some technical responsibilities?

Scholarship starts here:

- What is the commitment (time and effort) that the instructor will dedicate to the research, particularly in class, that cannot be directed to mentoring?
- What is the responsibility of postdoctoral researchers, graduate

student instructors, or peer undergraduate assistants in the research tasks of the CURE?
- What training and support is necessary to foster the success of postdoctoral researchers, graduate student instructors, or peer undergraduate assistants as researchers?
- What mentorship model(s) do you adopt in mentored student research experiences in your own research group and how can it/they be transposed to the classroo

Research and Education together:

- CUREs require a wider vision of the role of the instructor than traditional classrooms because of the need for emotional and research support of students (Cooper et al., 2022; Goodwin et al., 2021; Linn et al., 2015; Shortlidge et al., 2016).
- Different models of the role(s) of instructors in research experiences have been developed, but the consensus is that mentorship covers five critical categories of skills: research, diversity/culture, interpersonal, psychosocial, and sponsorship (Gentile et al., 2017). These five branches of mentorship lead instructors to promote the development of adaptive attitudes in students.
- Instructors can encourage constructive attitudes through (1) framing and scaffolding (designing transparent tasks associated with an explicit awareness of both the pedagogical and research significance of the work), (2) interventions and pedagogical activities (promoting high student efficacy), and (3) explicit integrations of inclusive teaching practices (creating a supportive learning environment).
- Just like explicit expectations and relevance of CURE tasks need to be communicated to students, clear expectations and ELOs should be developed for the work of postdoctoral researchers, graduate student instructors, or peer undergraduate assistants who are engaged in the CURE. These goals should incorporate the personal and professional goals of the postdoctoral researchers, graduate student instructors, or peer undergraduate assistants (see Mabrouk, 2003).
- The TILT framework (see above) can be useful in framing both student activities and postdoctoral researchers, graduate student instructors, or peer undergraduate assistants' tasks.
- Instructors should strike a balance between "being overly

prescriptive, which inhibits creativity and agency, and being insufficiently supportive, which leads to uncertainty, frustration, and a sense of failure" (Hanauer et al., 2012:384).

- Many activities and learning exercises are helpful in engaging students in experiences that promote student efficacy, including:
    - Sharing their personal goals for the CURE and expressing their expectations for the CURE.
    - Participating in the social network of their research team through meetings, discussion boards, etc.
    - Explicitly associating elements of the research process with valuable skills and attitudes for their career aspirations.
    - Articulating hypotheses and questions in the context of the CURE's research goals.
    - Conducting experiments, collecting and organizing data.
    - Analyzing and interpreting data. Evaluating evidence. Critiquing conclusions.
    - Becoming aware of the necessity of experimental failure.
    - Understanding that sometimes discoveries emerge from iterative processes.
    - Considering the quality of evidence and their relevance to the argument.
    - Synthesizing results and drawing conclusions; planning next steps.
    - Reading the primary literature, attending relevant seminars, and discussing their work with others.
    - Presenting progress reports and comparing ideas in group setting.
    - Reflecting on how the process of critique contributes to research progress.

- Consider guiding the cognitive exploration of students by implementing these recommendations modified from Cooper et al. (2022):
    - Challenging students to check if their hypothesis is explanatory, clearly stated, and distinguishes between multiple ideas.
    - Pushing students to fully explain ideas by asking follow-up questions and asking for clarification.
    - Highlighting potential pitfalls of hypotheses and protocols encouraging student to identify the problem and its solution.

    - Asking students to explicitly articulate links between research goals, hypothesis, and experiment.
    - Encouraging students to consider alternative experimental outcomes or explanations for their predictions or results.
    - Redirecting student ideas that are unproductive by bringing student attention back to their original hypothesis/goal.
    - Reminding students to think about controls they need to consider in their experiments/analyses.
    - Providing assistance with analytical tools or protocols that are merely means to an end and not critical elements of the learning goals, to enable students to focus on course objectives.
    - Assessing the time management of the students and propose adjustments to protocol or timeline accordingly.

- Instructors can foster a supportive environment by integrating best practices developed from student focus groups (Faulkner et al., 2021) including the following:
    - Contacting students: consider emailing or connecting with students before the semester begins. This initial contact is not only meant to offer practical information, such as class time and location, it also opens the door for a connection between students and instructor. Activate your class website before the class begins. This allows you to post messages for students and gives them the opportunity to reach out with questions.
    - Learning about students: you can promote inclusivity by learning about the identities, circumstances, and concerns of your students. You can do so through get-to-know-you surveys as well as start-of-the-semester conferences. This is a good time and place to ask students their pronouns, names, and the pronunciation of the latter.
    - Setting the right tone for the class: the first day of class sets the tone for the rest of the semester. As such, it is a critical time to establish an inclusive environment. Creating an inclusive classroom necessitates that each student feels like you see them as a unique individual. It also requires the classroom environment to reflect respect and care for all students. You should set expectations for class discussions and respect of everyone's background. You also need to encourage everyone to express their ideas and learn from each other. Communicate

that you will not tolerate any discriminatory attitudes or behaviors in the classroom.

- Encouraging introductions and setting group atmosphere: creating a group atmosphere that cultivates student collaboration and support throughout the semester is essential for inclusive pedagogy. It helps students create relationships with other students in the classroom and encourage collaboration and support. You can facilitate this collaboration by having students introduce themselves and exchange contact information with the people they will work with.
- Explaining syllabus and expectations: transparency is critical to a supportive class environment. Going over the CURE in detail on the first day of class is a useful way to make students feel welcome and helps you establish course expectations.
- Self-disclosure: the classroom can feel more inclusive when you share aspects from your own life. In particular, it may help students feel less vulnerable. Students see self-disclosure both as a way to get to know you and a sign of mutual respect.
- Being approachable: see your students as the people they are by using their name and correct pronouns, treat them as capable learners, respect them, encourage them, check in on them, make them feel welcome, and do not reinforce rigid power hierarchies. Explicitly tell students how you prioritize their learning and needs as well as your desire to help and support them.
- Staying engaged: pay attention to both the verbal and nonverbal responses of students. Notice the silences and apathy as much as the participation. Hold office hours and consider requiring students to set up a five-minute meeting several times throughout the semester. Holding hybrid office hours both in-person and through online tools like Zoom or Teams can facilitate attendance.
- Providing resources: give students information about campus and community resources, not only on the first day of class, but also throughout the semester. Provide specific directions for resources including academic services, clubs, tutoring, special interest groups, as well as mental health and wellness support.
- Encourage reflection: reflect on your experience in the course, how you engage students in dialogue, how you keep

communications with students open, and how you include everyone in the class discussions. Examine your own positions of power, privilege, and vulnerabilities. Encourage your students to do the same and reflect upon their roles in the classroom environment and their interactions with others.

- Consider also the guidelines from Cramer and Prentice-Dunn (2007) for an alternative framing of the elements above into a mentorship model "caring for the whole person".
- There is an important role for peer-mentoring among students engaged in the CURE. Such mentoring mimics the interactions between researchers and, along with mentorship from more experienced researchers (instructor of record, postdoctoral researchers, graduate teaching assistant, etc.), can help mitigate the frustration inherent to the failures and setbacks of authentic research experiences (Hanauer et al., 2012).
- The expert-novice divide is well recognized across disciplines (Inglis & Alcock, 2012; National Research Council, 2000; Newman et al., 2021; Stofer, 2016) and can sometimes represent an obstacle to mentorship; it may be overcome by involving peer teaching assistants. Undergraduates with prior experience of the CURE or mentored research experience outside of the classroom may be perceived as more approachable than more senior instructor(s); they also have recent experience with the struggles and challenges associated with the knowledge and skills taught in the CURE. They can provide very valuable feedback, including on writing assignments (Cho et al., 2006). Research shows that undergraduate peer assistants are valued by students enrolled in CUREs and facilitate their success (Olson et al., 2022).
- Although peer assistants can sometimes struggle with their identity and role in the classroom (Terrion & Leonard, 2007), training and mentorship of peer assistants can help overcome these difficulties (Handelsman et al., 2005).
- Requiring members of the instructional team to schedule dedicated time to mentoring in their week leads to more successful experiences (Shanahan et al., 2015; Terrion & Leonard, 2007). This is because time scarcity is a major barrier to effective research mentorship (Gentile et al., 2017).
- Communication with postdoctoral researchers, graduate student instructors, or peer undergraduate assistants around the support they

need and the resources that would enhance their experience (in both content and format) is important in creating a successful teaching experience for them (BrckaLorenz et al., 2020).

- Goodwin et al. (2021) identified different mentorship roles for CURE graduate student instructors and provided evidence that instructors who embrace their functions as "student supporters" and "research mentors" are more likely to see value for themselves in the CURE and engage in teaching CUREs again. Goodwin et al. (2021) defined "student supporters" as mentors who "[provide] emotional support to students" and "research mentors" as instructors who "[develop] student[s'] autonomy and competence as researcher[s]" (Goodwin et al., 2021: Fig. 3).
- Good mentorship should incorporate socioemotional support, culturally relevant mentoring, and appropriate personal interest in students (Haeger & Fresquez, 2016; Robnett et al., 2018; Shanahan et al., 2015). Consider also sharing your own stories of struggles and failures with research (Jayabalan et al., 2021).
- The affective-motivational research competence model (Wessels et al., 2018) has identified six situations that mentees need support with to engage in research as well as dispositions that can be fostered to help overcome the challenges of these situations (**Table 16**). These dispositions can be brought about through interventions and scaffolding activities of the CURE aimed at fostering specific experiences and tasks that promote knowledge integration (Linn et al., 2015).

Situations	Dispositions	Experiences
Developing a research interest	Curiosity and thirst for knowledge Value-related interest in research Finding joy in conducting research	➢ Share goals for the CURE relative to personal and career aspirations ➢ Express expectations for research experience ➢ Participate in social network of research team
Making decisions	Tolerance for uncertainty Acceptance of narrowing down	➢ Articulate hypotheses and questions about the research topic ➢ Identify or formulate a question in the context of the CURE's research goals ➢ Conducts experiments, collect, and organize data ➢ Analyze and interpret data. Evaluate evidence. Critique conclusions
Enduring setbacks	Tolerance for frustration	➢ Experience experimental failure ➢ Consider how discoveries emerge from iterative processes ➢ Recognize strengths related to career aspirations
Unravelling irritations	Tolerance for complexity	➢ Consider quality of evidence and relevance to argument ➢ Synthesize experimental results ➢ Make final conclusions and plan next steps
Making use of feedback and critiques	Willingness to seek and accept feedback	➢ Read literature, attend seminars, discuss with research team ➢ Experience how process of critique contributes to research progress; share ideas as a team
Audience-appropriate communication of research	Acceptance of divergent perspectives	➢ Read literature, attend seminars, discuss with research team ➢ Present progress reports and compare ideas in group setting

Table 16. Experiences and tasks that mentors should use to foster adaptive dispositions in students that help them through (modified from Linn et al., 2015) challenging situations (modified from Wessels et al., 2018).

Box 10: Important points

- A CURE is an opportunity to move away from a model of teacher-identity centered around the delivery and assessment of knowledge to one of a mentor.
- Successful CUREs empower students to think for themselves and enable them to make mistakes in a safe and supportive environment.
- A CURE is an authentic research experience and as such can introduce students to collaboration by including outside researchers, laboratory personnel, and staff members.
- Every member of the CURE has goals, needs, and expectations. This is true of the students and instructor(s) of course, but also applies to any other member of the team. Consider carefully the help and means everyone requires to achieve their mission.

11. How will the success of the CURE be assessed?

Overview: Just like the assessment of the students' work in the CURE enables them to reflect upon their progress and make corrections, the assessment of the CURE itself provides opportunities for redesigns, corrections, and reflection by the instructor(s). Assessing students' work provides a basis for an often-necessary grade. Similarly, the evaluation of the CURE is integral to the instructor's annual evaluations, their eligibility for promotions, tenure, and awards. Because CUREs often require financial and/or logistical support, the assessment of the experience enables the demonstration of its efficacy and can facilitate the renewal or expansion of the program. When a CURE is an integral component of the curriculum, particularly as an element of introductory courses, general education requirements, or program prerequisite, its evaluation is an important part of the overall educational experience of students that may become part of program reviews, external evaluations, and validation of the course as satisfying specific certifications or endorsements. There are three overlapping components to the assessment of CUREs: course, instructor, and student outcomes (Brownell & Kloser, 2015) summarized in **Figure 4**. Section F presents a discussion of the existing approaches in evaluating all three of these elements of CUREs from a programmatic and scholarly point of view; many of these approaches are aimed at incorporating data from large number of students; several may require the involvement of education research collaborators or institutional representatives. Here, the focus is on data collection and analyses that individual instructors can engage in to reflect upon the research progress and the pedagogical framework.

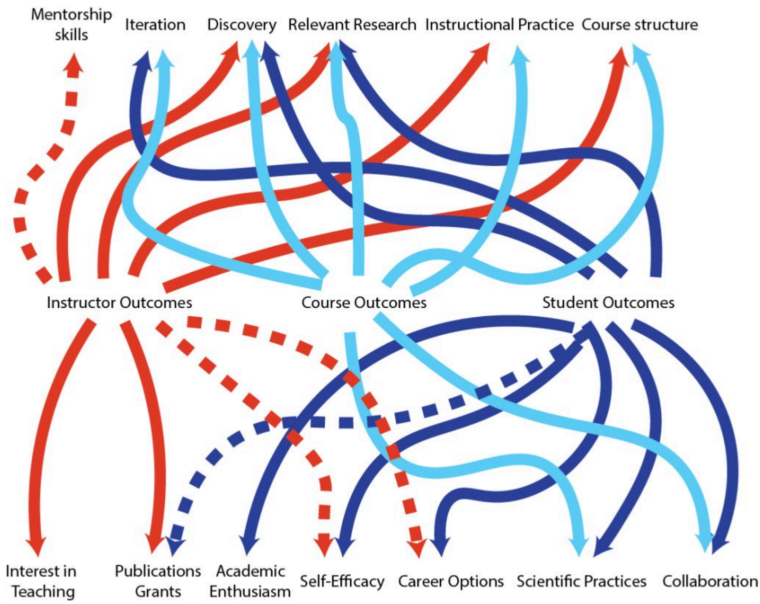

Figure 4. CURE assessment "meta-framework" (redrawn and modified from Brownell & Kloser, 2015). Dashed lines were added to reflect the importance and value of outputs (publications and grants) to students, and the roles of graduate students, peer-assistants, and postdoctoral researchers as instructors.

This section enables you to determine:

1. The value of the individual assignments and activities implemented
2. The usefulness of the scaffold
3. The fit of the assessment and learning goals
4. The research outcomes of the CURE and their significance to stakeholders
5. The success of the CURE in promoting the success of all students

Education starts here:

- Are the assessments aligned with the learning goals of the course?
- Are the formative and summative assessments of the students' learning also assessed for the success of the course activities and

scaffold?

- Does the scaffold for the CURE need to be revised?
    - Are there bottlenecks to learning that remain to be addressed by the CURE scaffold?
    - Are some parts of the course "over-scaffolded"? Is the preparation of the students underestimated for specific activities?
- Are there concept inventories or professional society standards that can be used to assess students' proficiency on certain topics of the CURE?
- Did students encounter problems with specific activities?
    - Are there assignments that were unclear?
    - Were there homework assignments that multiple students asked for clarifications about?
- What are the perceived gains from the CURE that students express?
- Can specific assignments' rubrics be edited to include elements useful to assessing the efficacy of the activity?
- Does your institution have survey tools (including some incorporated into student evaluations) that can be leveraged to assess your pedagogy of the course?
- Can you engage peer instructors in reviewing your course?
- Can you present the CURE you developed at an education conference or in the education session of the annual meeting of your professional society to get feedback and thoughts from colleagues?
- Can you gather data on the success of the CURE in closing the equity gap and promoting the learning and success of all?

Scholarship starts here:

- Can the research findings of the CURE be presented to the research community for feedback?
    - Is the work ready to be submitted in the form of a proposal or manuscript?
    - Is it appropriate to present the work at a conference?
- Are there other stakeholders of the research who could provide critiques of the work and assess its significance?

Research and Education together:

- The efficacy of the scaffold and activities can be in part assessed through the performance and success of students. Each assessment of the students' work is also an assessment of the work of the instructor. In many ways, some of the issues associated with CURE assessment can be answered through student assessment, an issue discussed earlier in the document.
- A key element of the assessment of the activities and assignments of the CURE is to define clear goals for each of them. This participates in increasing transparency for students and enables the determination of their success and therefore yours.
- Assessments of students' work and survey tools can be used to identify knowledge/skill bottlenecks to address in iterations of the CURE.
- There are numerous forms of formative assessment that can be implemented throughout the CURE to help determine the efficacy of the CURE activities and interventions:
    - Minute papers or muddy point papers (Anderson & Burns, 2013; Stead, 2005) can help assess whether or not a particular activity fulfilled its learning goals. Example of prompts are available from multiple sources (e.g., Tufts University; University of Wisconsin)
    - Concept maps and Venn diagrams can help students synthesize information and be assessed by instructor(s) for learning and efficacy of scaffolding activities (Bauman, 2018; McConnell et al., 2003).
    - Group and individual presentations of research updates enables the instructor to assess the efficacy of the scaffold in supporting the research progress.
- Group reviews and self-reviews ([**Activity 19**]) can help assess group dynamics and the effect of team building efforts.
- Questions can be included in the reflection workbook ([**Activity 26**]) to enable the assessment of the students' understanding of concepts presented in the CURE activities, thus determining their efficacy. Student reflections can be evaluated with students to get additional insights in the student experience (McLean et al., 2022).
- Many institutions allow the design of a few custom questions to add to student evaluations of instruction. These custom questions can be used to assess the pedagogy of the course. Examples of questions can be found in the project ownership survey (Hanauer & Dolan, 2014),

the classroom and school community inventory (Rovai et al., 2004), the laboratory course assessment survey (Corwin et al., 2015), the classroom undergraduate research experience survey (Denofrio et al., 2007), the science process skills inventory (Arnold et al., 2013), or a combination of these tools (Lo & Le, 2021).

- Some surveys have been developed to specifically assess the efficacy of CUREs, or even specific activities of the course (e.g., Satusky et al., 2022)
- Online survey tools (e.g., Qualtrics and SurveyMonkey) or paper survey tools (including some standard student evaluation forms) administered as part of midterm evaluations and end-of-term evaluations can enable instructors to poll students on affect towards specific activities, perceptions of learning gains, and self-efficacy.
- Concept inventories (**Table 6**) as well as professional standards (e.g., American Psychological Association) can be used to devise summative assessments.
- Many indicators of learning outcome satisfaction can be assessed by integrating appropriate criteria into grading rubrics (Chamely-Wiik et al., 2014).
- Extensive notetaking of class observations, student behaviors, reflections on pedagogy, problems encountered in the classroom, failures, and successes can be used to revise individual activities as well as their organization.
- Interviews and focus-groups by the instructor or by a neutral third party can enable students to share their thoughts and feelings about the CURE and its outcomes (e.g., (Brownell & Kloser, 2015; Turner et al., 2021; Wooten et al., 2018). This approach can also be used to assess the experience of graduate student instructors and peer assistants to ensure positive and improved experience for all members of the CURE team (see Heim & Holt, 2019). Essays can also be used to gather the thoughts of CURE participants (Wooten et al., 2018).
- Partnering with colleagues and education researchers can be helpful in determining the impact of the CURE on all students and the success of the CURE in mitigating systemic biases and enabling the learning of a diverse student body.

Box 11: Important points

- Take abundant notes during the implementation of the CURE to guide redesigns, expansions, and modifications to the course
- Ask yourself numerous questions when grading and/or assessing student work, for example:
- Did this assignment fulfill its goal of assessing the associated ELOs?
- Did this activity support the associated learning goal(s)?
- Does your institution enable custom questions on student evaluations?
- Can you use surveys or include questions within assignments to gather data from your students on the activities and assignments of the CURE?
- Reviews by peers of manuscripts, conference presentations, and grant proposals are a measure of the success and progress of the research of the CURE

F) ASSESSING CURES

Several tools have been designed explicitly for the assessment of CUREs or can be utilized to assess the outcomes of CUREs. Shortlidge and Brownell (2016) present over 30 different assessment tools that can be used to investigate the efficacy of CUREs. Detailed publications are associated with each of those, including for tools specifically designed for CUREs (Corwin et al., 2015; Lopatto et al., 2008; Lopatto, 2004). More recent tools have also been published (Angra & Gardner, 2018; Clemmons et al., 2020; Killpack & Fulmer, 2018; Wang et al., 2018) and there are several databases of assessment tools (e.g., Q4B). New tools are also being developed as the popularity of CUREs increases (e.g., E-CURE). Many of these tools have been validated in multiple CUREs (e.g., Jordan et al., 2014; Shaffer et al., 2014), offering the opportunities for comparisons with the course being assessed. Additional tools exist for specific research experience. For example, there exist guidelines for the assessment of field-based courses (Pyle, 2009; Shortlidge et al., 2021).

One of the obstacles to the rigorous analysis of a CURE through qualitative and quantitative analyses of student surveys is the need for a comparison group (Shortlidge & Brownell, 2016). However, it is possible for instructors to explore the efficacy of their CURE without the need for a formal rigorous experimental setup. Such analyses should focus on the expected learning outcomes (ELOs) of the CURE. Existing analytical tools can be matched to the ELOs of the CURE to enable data collection. Such work should consider the following issues: (1) the sample of students that the survey tool was validated on and (2) the time necessary to administer, score, and analyze the results of the survey tools (Shortlidge & Brownell, 2016). **Table 17** presents a selection of assessment tools that are readily accessible in the literature or online, validated, and can be implemented with little to moderate efforts by instructors.

Selected assessment tools for the classroom organized by topic (modified

from Shortlidge and Brownell, 2016)

List of assessment tools to explore attitudes about science, cognitive skills, critical thinking, experimental design, communication, and motivation, among others

ATTITUDES ABOUT SCIENCE	
Colorado Learning Attitudes about Science Survey	Semsar et al., 2011
Classroom Undergraduate Research Experience	https://www.grinnell.edu/academics/resources/ctla/assessment/cure-survey
Research on the Integrated Science Curriculum	https://www.grinnell.edu/academics/centers-programs/ctla/assessment/risc
COGNITIVE SKILLS	
Blooming Biology Tool	Crowe et al., 2008
California Critical Thinking Skills Test	http://www.insightassessment.com/Products/Products-Summary/Critical-Thinking-Skills-Tests/California-Critical-Thinking-Skills-Test-CCTST
Study Process Questionnaire	Biggs et al., 2001
COLLABORATION, DISCOVERY AND RELEVANCE, ITERATION	
Laboratory Course Assessment Survey	Corwin et al., 2015
Perceived Cohesion scale	Bollen and Hoyle, 1990
CRITICAL THINKING	
Blooming Biology Tool	Crowe et al., 2008
California Critical Thinking Skills Test	http://www.insightassessment.com/Products/Products-Summary/Critical-Thinking-Skills-Tests/California-Critical-Thinking-Skills-Test-CCTST

DEEP AND SURFACE LEARNING	
Study Process Questionnaire	Biggs et al., 2001
ENVIRONMENTAL AWARENESS AND ATTITUDES	
Environmental Attitudes Inventory	Milfont & Duckitt, 2010
New Ecological Paradigm Scale	Dunlap et al., 2000
EXPERIMENTAL DESIGN	
Biological Experimental Design Concept Inventory	Deane et al., 2014
Expanded Experimental Design Ability Test	Brownell et al., 2014
Experimental Design – First Year Undergraduate	https://q4b.biology.ubc.ca/concept-inventories/experimental-design-first-year-undergraduate-level/
Experimental Design – Third/Fourth Year Undergraduate Level	https://q4b.biology.ubc.ca/concept-inventories/experimental-design-thirdfourth-year-undergraduate-level/
Experimental Design Ability Test	Sirum & Humburg, 2011
Rubric for Experimental Design	Dasgupta et al., 2014
Tool to assess interrelated experimental design	Killpack & Fulmer, 2018

COMMUNICATING RESULTS	
Graph Rubric	Angra & Gardner, 2018
The Rubric for Science Writing	Timmerman et al., 2011
MOTIVATION AND RESILIENCE	
Grit Scale	Duckworth & Quinn, 2009
National Survey of Student Engagement	Kuh, 2009
Science Motivation Questionnaire II	Glynn et al., 2011
OWNERSHIP AND BELONGING	
Project Ownership Survey	Hanauer & Dolan, 2014
Career Decision Making Survey – Self Authorship	Creamer et al., 2010
Perceived Cohesion scale	Bollen and Hoyle, 1990
Transparency in Learning and Teaching in Higher Education Survey	https://tilthighered.com/abouttilt
PERSONAL GAINS	
Classroom Undergraduate Research Experience	https://www.grinnell.edu/academics/resources/ctla/assessment/cure-survey
Colorado Learning Attitudes about Science Survey	Semsar et al., 2011

Research on the Integrated Science Curriculum	https://www.grinnell.edu/academics/centers-programs/ctla/assessment/risc
Science Motivation Questionnaire II	Glynn et al., 2011
Survey of Undergraduate Research Experiences	Lopatto, 2004
Undergraduate Student Self-Assessment Instrument	Weston & Laursen, 2015
Transparency in Learning and Teaching in Higher Education Survey	https://tilthighered.com/abouttilt
NATURE AND PROCESS OF SCIENCE	
Biological Experimental Design Concept Inventory	Deane et al., 2014
BioSkills Guide	Clemmons et al., 2020
Classroom Test of Scientific Reasoning	Lawson et al., 2000
Laboratory Course Assessment Survey	Corwin et al., 2015
Views About Sciences Survey	Halloun & Hestenes, 1998
Expanded Experimental Design Ability Test	Brownell et al., 2014

Experimental Design – First Year Undergraduate	https://q4b.biology.ubc.ca/concept-inventories/experimental-design-first-year-undergraduate-level/
Experimental Design – Third/ Fourth Year Undergraduate Level	https://q4b.biology.ubc.ca/concept-inventories/experimental-design-thirdfourth-year-undergraduate-level/
Experimental Design Ability Test	Sirum & Humburg, 2011
Molecular Biology Data Analysis Test	Rybarczyk et al., 2014
Rubric for Experimental Design	Dasgupta et al., 2014
Test of Scientific Literacy Skills	Gormally et al., 2012
The Rubric for Science Writing	Timmerman et al., 2011
DATA ANALYSIS AND QUANTITATIVE REASONING	
Statistical Reasoning in Biology Concept Inventory	Deane et al., 2016
BioSkills Guide	Clemmons et al., 2020
Psychological Research Inventory of Concepts	Veilleux & Chapman, 2017
Molecular Biology Data Analysis Test	Rybarczyk et al., 2014

Table 17. Selected assessment tools for the classroom organized by topic (modified from Shortlidge and Brownell, 2016).

G) OVERCOMING THE CHALLENGES OF CURES

Numerous studies have focused on barriers to the design and implementation of CUREs affecting instructors. Open answer surveys and Likert-scale questions have been particularly helpful in identifying the main obstacles standing in the way of the development of CUREs (**Table 18**). Many of these challenges are problems for the implementation of undergraduate research in general, including mentored undergraduate research experiences (Doyle, 2002).

Financial obstacles	Limited funding to undertake expensive analyses
	Limited ability to buy equipment and consumables for experiments
Technical obstacles	Lack of access to equipment and resources to collect data in the field or in the lab
	Troubles scaling for large class sizes
	Lack of support from staff
	Limited or no availability of teaching assistants
	Lack of access to quality computing resources including software and support
Research obstacles	Questions and protocols that are amenable to classroom setting
	Technical skills, knowledge, and experience to gide the experiments
	Lack of guaranteed outcomes and possible failure of experiments
Pedagogical obstacles	Lack of personal time and energy to design a CURE or manage its implementation
	Lack of time in the course to fit the CURE because of required content coverage
	Limited lab or recitation hours to fit the CURE
Student obstacles	Students do not like uncertainty
	Students do not like group work
	Student competence or readiness is not sufficient to successfully participate in the CURE
Instructor obstacles	Emotional investment of mentoring
	Topic of the CURE is not instructor's specialty
	Conflicts within the instructor's institution

Table 18. Summary of the main obstacles to the design and implementation of CURES perceived or encountered by instructors (compiled and modified from DeChenne-Peters & Scheuermann, 2022; Genné-Bacon et al., 2020; Govindan et al., 2020; Lopatto et al., 2014; Roberts et al., 2019; Shortlidge et al., 2016; Spell et al., 2014).

Other obstacles have also been mentioned in the literature. Some represent obstacles specific to CUREs, others are obstacles to undergraduate research or creative teaching in general. These obstacles include the time to publication of research projects (Turner et al., 2021), issues of identity as a teacher in environments that emphasize research productivity (Brownell & Tanner, 2012), time and emotional investment for graduate teaching assistants (Goodwin et al., 2021), fear that the CURE time will take away from content delivery and lead to detrimental effect on understanding of course concepts (Lopatto et al., 2014), the loss of favorite labs and activities not compatible wit the CURE (DeChenne-Peters & Scheuermann, 2022), and the lack of expertise of support staff (Wolkow et al., 2014).

A survey of instructors at the Ohio State University mirrors the data from the literature presented above. The open answers of (a) instructors who have developed and implemented CUREs (N=16), (b) instructors who have developed but not yet implemented a CURE (N=2), and (c) instructors who have not yet developed a CURE (N=10) were categorized in each of the 18 items presented in **Table 18,** or assigned to new categories to identify the challenges experienced by Ohio State instructors specifically. Instructors were able to identify more than one obstacle to their design and implementation efforts resulting in 47 coded difficulties. None, even within the group of instructors that has not implemented a CURE, expressed a lack of interest in the development of one. Because of the small number of responses associated with CUREs that have been developed, but not yet implemented, two categories are considered: CURE developed, and CURE not yet developed (**Table 19**).

Obstacles		Implemented a CURE % (N=18)	CURE not yet developed % (N=10)
Financial	Limited ability to buy equipment and consumables for experiments	6	
Technical	Lack of access to equipment and resources to collect data in the field or in the lab	6	
	Troubles scaling for large class sizes		10
	Lack of access to quality computing resources including software and support	11	
Research	Questions and protocols that are amenable to classroom setting	17	10
	Lack of guaranteed outcomes and possible failure of experiments	6	
	Ability to provide students with the basis for data collection	6	
Pedagogical	Lack of personal time and energy to design a CURE or manage its implementation	44	50
	Lack of time in the course to fit the CURE because of required content coverage	11	
	Limited lab or recitation hours to fit the CURE		10
	Difficulties evaluating students in authentic ways	6	
Student	Students do not like uncertainty	11	
	Students do not like group work	6	10
	Student competence or readiness is not sufficient to successfully participate in CURE	39	10
	Resistance to time investment required of CURE	22	
Instructor	Conflicts within the instructor's institution	6	
	Instructor preparedness and training in pedagogical methods		20

Table 19. Percentages of instructors surveyed who identified each of the obstacles from table 18 as relevant to their own CURE development efforts. Only coded obstacles were retained.

The data from instructors at The Ohio State University are consistent with prior studies. Yet, they also provide interesting additional information. For example, the comparison between instructors who have developed (and for all but two implemented) a CURE and those who are yet to engage in this practice shows that student obstacles, particularly student preparedness and time investment, are important impediments to the implementation of CUREs; they also may be underestimated by instructors developing a CURE. These issues are usually not presented as major challenges to the development and implementation of CUREs in the literature (but see Spell et al., 2014). Yet, student attitudes are critical to learning gains (Lopatto et al., 2022), suggesting the importance of shaping the approach of students to the course at the start of the CURE. In fact, the only greater obstacle to the development and implementation of CUREs than student preparedness and investment is the lack of instructor time to design and manage the implementation of the experience. The fact that this latter obstacle is identified as the number one hurdle to CURES by both categories of instructors shows that it is both a barrier to the initial development and conceptualization of a CURE as well as the full design and enactment of the course experience. Experienced CURE instructor interviews show that managing the class time for CURE students, and to a lesser extant, the time demand on instructors, are indeed big challenges (DeChenne-Peters & Scheuermann, 2022). One important obstacle identified by Ohio State instructors who have not yet developed a CURE is the need for additional guidance and resources, including model experiences, to support them in developing CUREs.

Additional conversations with colleagues at Ohio State emphasized very practical hurdles to CUREs, centering on hardware, software, and network support of computing needs. The prevalence of tablets and smartphones, often to the detriment of hardware better adapted to the use of professional, technical, and scholarly software programs, among students is a central issue for many instructors. The lack of availability or cost of resources extends to software needs, including for popular programs with a university license that are not free (e.g., NVivo), and the hosting of project websites onto which student deliverables can be uploaded. Even freeware programs may not be easily used because of restrictions on the ability of instructors to install software on university-owned devices and the resulting complexities of coordinating with support staff. Coordination with staff and bureaucratic hurdles extend to cost-sharing between teaching and research budgets; they become overwhelming when incorporating field work into the CURE.

Some perceived obstacles and challenges to the creation of CUREs may in fact be just that, perceived. Research shows that the implementation of CUREs does not in fact lead to a loss of content knowledge, but quite the opposite (Lopatto et al., 2014). Buy-in from colleagues and departments is also often (although not always) not as absent as feared (Govindan et al., 2020; DeChenne-Peters & Scheuermann, 2022).

The potential problems of undergraduate preparedness and time commitment should not be underestimated when developing a CURE. A highly structured scaffold (**Figure 2**) and the TILT framework (Winkelmes et al., 2016) are important tools to mitigate student difficulties, increase engagement, and guide students through the acquisition of new skills. The use of interventions targeting procrastination, time management, and organizational skills may also be helpful (Häfner et al., 2014; Stevens et al., 2019).

Several possible solutions to some of the other challenges identified above are suggested throughout this document. Some of those are repeated below in **Table 20** along with additional ideas and recommendations from the literature.

Possible solutions to some of the challenges posed by the development and implementation of CUREs

Solutions and resources to financial, technical, research, pedagogical, student, and instructor obstacles

Category	Possible solution	Reference
Financial obstacles	Professional societies (and your institution) may offer funding for research and travel to conferences by undergraduate students	Matyas et al., 2017
	Established databases provide sources of data that can be used in CUREs	Table 13
	Use collaborations to reduce costs, promote publishability of findings, and distribute costs and rewards of research	Govindan et al., 2020
Technical obstacles	Use a central course to support undergraduate research efforts across several laboratories	Dillon, 2020
	Freeware programs can be used by students to engage in data analysis	Table 14
	Some field work can be undertaken through asynchronous self-led field trips.	Washko, 2021
	Support teaching assistants to help them overcome the obstacles of implementing the CURE	Heim & Holt, 2019
	Involve students in the logistics of implementing the CURE and teach them the full scope of research project management	Govindan et al., 2020
	Work with collaborators, mentored research students, graduate students, and postdocs to distribute the emotional labor and time commitment	—
Research obstacles	Publish the CURE itself in education literature, even if research findings themselves cannot be published	—
	National programs provide research questions and contexts that are relevant to the community and adapted to the classroom setting of the CURE	Lopatto et al., 2014
	Use collaborations to reduce costs, promote publishability of findings, and distribute costs and rewards of research	Govindan et al., 2020

Category	Possible solution	Reference
	Professional societies offer peer-reviewed curricula and pedagogical resources	Matyas et al., 2017
	Use CUREs to explore new areas of research and risky research projects to limit pressure for success	—
Pedagogical obstacles	Align core concepts and competencies of the CURE and the class ELOs	Petersen et al., 2020
	Teach students how to learn in your disciplines by making learning how to learn part of your curriculum	Petersen et al., 2020
	Have students focus on the problem-solving process, rather than just the correct answer	Petersen et al., 2020
	Professional societies provide online learning and networking communities for both instructor and students	Matyas et al., 2017
	Adjust the content to free the time necessary to enable students' mastery of technical skills	Wolkow et al., 2014
	Professional societies offer peer-reviewed curriculum and pedagogical resources	Matyas et al., 2017
	Involve students in the planning and development of the project through the writing of proposals	Govindan et al., 2020
	Involve students in the logistics of implementing the CURE and teach them the full scope of research project management	Govindan et al., 2020
Student obstacles	Increased student ownership and involvement in experimental design helps mitigate frustrations	Govindan et al., 2020
	Use affirming language to frame discussions and activities	Govindan et al., 2020
	Transparent expectations and grades disjunct from experimental success or publishability of findings can help overcome student fears of unknown	—

Category	Possible solution	Reference
	Emphasize to students the significance of the research to the broader community of scholars	Cooper et al., 2019; Hanauer et al., 2012
	Involve students in the logistics of implementing the CURE	Govindan et al., 2020
	Involve students in the planning and development of the project through the writing of proposals	Govindan et al., 2020
	Use group contracts and best practices to design successful group experiences	—
Instructor obstacles	Invite faculty members and institutional stakeholders to students' CURE colloquium	Govindan et al., 2020
	Promote the success and outcomes of the CURE to the university community	—
	Select professional societies and published examples of cures can provide guidance for the development of CUREs	Govindan et al., 2020
	National programs provide workshops and curricular materials	Lopatto et al., 2014
	National programs may have staff to help troubleshoot	Lopatto et al., 2014
	Help preparation of instructors and support staff with training videos, more thorough instructor lab manuals, reference sheets, and training workshops	Wolkow et al., 2014
	Work with collaborators, mentored research students, graduate students, and postdocs to distribute the emotional labor and time commitment	—

Table 20. Possible solutions to some of the challenges posed by the development and implementation of CUREs.

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APPENDIX 1: EXAMPLE FRAMEWORK FOR CURE ACTIVITIES

Notes to instructor:

- The structure presented here is a simplified scheme summarizing a possible framework. The actual document presented to students should include all activities with specific deadlines.
- **Figure 2** presents a summary of the structure in a graphical format. Generally speaking, the framework applies, in order, to the following elements of the CURE:

1. Framework
2. Bibliography
3. Data Collection
4. Data Analysis
5. Material and Methods
6. Figures and Tables
7. Results
8. Discussion
9. Introduction

Purpose

Our goal this semester is to produce a manuscript (per group) akin to one that academics and professional [scholars] submit for publication to academic journals. Yes, I am talking about you putting together an article that could be published for the entire world to read. You will be no longer simply consuming research through your readings and classwork but creating new content for scholars of today and tomorrow to build upon.

This project is an opportunity for you to undertake [scientifically] significant work and possibly publish ground-breaking research. You will be directing your own learning (and mine) as part of a community of learners analogous to those of the professional world. Your work this semester in will be similar to the work of professional researchers (like me).

You will be asked to read articles from the primary literature, think through problems, collect data, develop analyses, interpret results, write, revise your writing, revise your writing, revise your writing … You will be a member of a team and will have to communicate effectively with other students on the team and myself to achieve your goals.

This research project is a training ground for many performance-based open-ended inquiry activities you will encounter in the professional world. Although you are unlikely to spend the rest of your career working on [topic of the CURE], I expect you will spend the rest of your career working with others, producing various reports and deliverables, and thinking through data of one sort or another.

After this project, you will be able to:

[Enter here the ELOs for the CURE]

Most importantly, my hope is that this experience will help you build your identity as a researcher.

Tasks

The table on the following pages presents a summary of the structure of the entire project along with deadlines. Some assignments and meetings will take place during class time; others will be assigned as homework. You are also welcome to complete your assignments for this project during my office hours with my help. All teams will be communicating with one another (and me) throughout the semester using a discussion board (DB in the table) on [LMS].

By the end of the semester, you will have produced:

- A group research manuscript on an important question aimed at a professional audience beyond the classroom.
- A series of individual and group assignments that will have helped you frame and scaffold your manuscript.
- An individual workbook with answers to reflection questions you will have used to improve your manuscript.

In addition to the manuscript, assignments, and workbook, the discussion board will be regularly assessed for a grade (based on engagement and specific guidelines provided in the rubric [**Appendix 3**]).

It is very important that you stick to the deadlines expected of you. Deadlines are critical to academic work. Academics face deadlines for the submission of papers and grant proposals all the time. Accountability towards collaborators, and students (who may face thesis deadlines for example) is critical to the success of any academic. Similarly, meeting deadlines is integral to professional success in all fields. This project is an opportunity for you to develop project management skills that are very much in demand in the professional world.

Research, and many other intellectual tasks, require adjustments, revisions, and redoes. For every assignment and deadline this semester, I encourage you to ask: "What happens when things do not work like an analysis, or you need more data?" Do not work last minute because there is no room for adjustments and no way to still meet the deadline. Build-in fail safes. Remember that I am here to help you and am always open to discussing your personal situation. Qualifying events will always be excused and accommodated.

Structure

Structure of the units of the course

Homework and in-class activities that will be used to navigate each unit of the course

Order	In-class/Homework	Element of the framework
1	In-class	Tutorial
2	Homework	Reflection Workbook I
3	In-class /Homework	Scaffolding activity
4	Homework	Group meeting agenda
5	In-class	Group meeting
6	Homework	Reflection Workbook II
7	Homework	Deliverable
8	Homework	Peer-review of deliverable

- The discussion board is graded every other unit.
- The reflection workbook activities are sometimes used to prepare the tutorial (i.e. reflect on prior knowledge and misconceptions), sometimes to reflect on it, sometimes used to reflect on the group meeting, etc.

APPENDIX 2: EXAMPLE CRITERIA FOR THE EVALUATION AND GRADING OF A CURE

Notes to instructor:

- There is an extensive primary literature on contract grading (e.g., Elbow & Danielewicz, 2015; Hiller & Hietapelto, 2001; Lindemann & Harbke, 2011)
- Additional examples of contract grading frameworks can be found online including https://www.hastac.org/blogs/cathy-davidson/2011/01/03/contract-grading-peer-review-heres-how-it-works?

Philosophy: One of the goals of this project is to help you develop as an independent professional and [scientist]. To that end, a number of activities are meant to encourage you to structure your own experience and learning. This includes the use of a discussion board, the workbook activities, the development of your own learning goals, and the development of your meeting agendas. Other components of this structure are the all-important peer-reviews, which will give you an opportunity to give feedback to your classmates and reflect upon your own work.

Structure: My approach to grading this project will emphasize personal responsibility and metacognition. This will involve several components:

- An individual-grade component and a group-grade component
- Clear rubrics for specific assignments
- Peer-evaluations and self-evaluations independent of my assessment
- Grading for genuine quality work on a check/check plus/check minus basis

- A contract grading approach

Commitment: In general, I define genuine quality work as fulfilling the following requirements:

- Did you follow the process laid out in the prompt/explanations in good faith?
- Did you complete the activity in its entirety?
- Did you reflect on this work? Are you engaged in the activity? Did you think through it and demonstrate that thinking to your reader(s)?
- Did you complete the work on time?
- Was the work completed taking into account the following elements of professional good practices: inclusivity, working well with others, integrity, demonstrated critical thinking, proper analytical reasoning, and clear communication of your results?

Rationale of contract grading: In my experience teaching, I have repeatedly confronted the fact that students often care deeply about their grades, sometimes to the detriment of the learning experience itself. This is not to blame you. I understand that there can be a lot of pressure to get high grades to be competitive for scholarships, on applications, and for yourself. I also know that the standardized testing approach of our K-12 education system has emphasized this way of thinking. However, I am MUCH MORE interested in your learning than your grade. I care a lot about your knowledge and skills acquisition. I would like to free you from the pressure of thinking about every assignment in terms of a grade and instead help you focus on what you are gaining from that assignment. Grading does not reflect the way (for the most part) you will be evaluated in your professional careers in which peer-evaluations, client feedback, the completions of deliverables, and your standing in the profession/institution play a big role. Contract grading is more analogous to a professional evaluation than a grade. It also encourages you to take responsibility for your learning.

Evaluation method: You will obtain a grade for the project component of this class based on the contract spelled out below, which lists the requirements to obtain a grade and penalties for not fulfilling the terms of your contract. Every assignment linked to the project in the CURE (except the final paper; see below) will be assigned one of four qualifiers: unsatisfactory, check minus, check, or check plus:

- **Check plus:** given to work that goes above and beyond the requirements spelled out in the prompt and other documents associated with the project. This is an evaluation that reflects extraordinary work. What qualifies as extraordinary work will be highlighted in rubrics.
- **Check:** given to work that meets the requirements of genuine quality work. This is an expression of the accomplishment of good work that you should be proud of.
- **Check minus:** given to work that attempted to meet the requirements of the assignment but did not quite succeed. This reflects work that should be extensively revised and needs some reflection but does show engagement with the material and willingness to complete the tasks.
- **Unsatisfactory:** given to assignments that do not meet the requirements for genuine quality work including assignments not turned in, turned in too late, plagiarized assignments (note that any student code of conduct issue will also be referred to the appropriate university-wide process), and superficial work that does not meet the requirements of the prompt.

Late penalty: Deadlines are meaningful in academic and professional work, just like they are in the real world. Not meeting a deadline can impact others. Indeed, in this project it will, because you are working with others. If your lateness on an assignment delays the work of your group, you will earn an unsatisfactory for this assignment. If your lateness does not delay your group, you will earn a check minus on the assignment. Note that the late policy of the class as a whole also applies. This means that qualifying events will be excused and that I am always open to discussing your personal situation. Communication is key. Talk to me ahead of the deadline if you will not meet it (and note that "ahead of the deadline" doesn't mean the night before except in emergency situations—come talk to me sooner rather than later).

Contracts: Contract grading is not an opportunity to not complete the work. To fulfill ANY grade contract (i.e. earn a passing grade on the project), a student must fulfill all of the following tasks:

- **Announce in writing to the professor (by email) the contract you are pursuing by [DATE] at [TIME].**
- Come to class prepared to discuss the project, its progress, your

writing, and scaffolding assignments.

- Participate actively and inclusively in group meetings, the discussion board, and the group reviews.
- Meet with me (during office hours or another scheduled time) at least once around [week 6-8 of the semester] to check you are on-track to meet your contract requirements and discuss any concerns you have about it. **You are responsible for scheduling this meeting with me by email at least a week in advance.**
- Contribute significantly to the final manuscript produced by the group turned in at the end of the semester.

<u>"A, B, and C contracts"</u>

The table below shows how many checks you need to earn for each type of activity to satisfy the requirements of each contract. At the bottom of the table, the number of check pluses expected from you for each contract (on any of the activities) is also showed. Note that the explicit mention that you should not obtain any "unsatisfactory" is also spelled out.

Expectations for group contracts

Number of tasks across categories of assignments that should receive a check to fulfill an A, B, or C contract

Tasks	Total	A contract	B contract	C contract
Group input, RCR training, Learning goals	—	ALL	ALL	ALL
Tutorials	8	7	6	5
Scaffolding activities	7	6	5	4
Group meetings	9	8	7	6
Meeting agendas	7	6	5	4
Deliverables	8	6	5	4
Peer-reviews	8	7	6	5
Reflection workbook	3	3	2	2
Chalkboard Presentation	1	1	1	1
Manuscript	1	1	1	1
Discussion board	3	3	2	2
Group reviews	3	3	3	3
Check+ earned	—	11	7	4
Unsatisfactory grades received	—	0	0	0

- Lettered goal above you do not fulfill will earn you penalties against your contract.
- Every check plus you get beyond the required number above compensates for a check minus.

“D” and “E” grades:

You cannot and should not be aiming for a D or E in a class (obviously). However, I reserve the right to award such a grade (D or E) should you fail to meet your contractual obligations specified above in a systematic way. If you demonstrate minimal effort or achievement in fulfilling your contract, you will earn a D. If you do not turn in enough satisfactory work to satisfy the spirit (see section on genuine satisfactory work above) of the project in addition to the letter of the contract, you will earn an E.

Percentage grade: The reality of the university system is that your contract will be converted to a numerical grade (as a percentage) at the end of the semester:

Correspondence between contract grade and percentage grade for the course

Letter grades for each contract correspond to the standard grading scheme of the university

Contract grade	Percentage
A	93
B	83
C	73
D	63
E	53

Contract tracking and adjustment: I encourage you to keep track of your performance throughout the semester (I will as well) to be able to tell where you stand at all times. You will make an appointment to talk to me about your progress on your contract about halfway through the semester (see above). This will also be an opportunity to request a change in contract (up or down).

Note on contract choice: You will NOT be judged for the choice of contract you make. In the words of Cathy Davidson: "If you complete the work you contracted for, you get the grade. Done. I respect the student who only needs a C, who has other obligations that preclude doing all of the requirements to earn an A in the course, and who contracts for the C and carries out the contract perfectly. This is another one of those major life skills: taking responsibility for your own workflow." There is no penalty whatsoever for choosing a particular contract. You can always earn a higher grade then the contract grade based on your achievements.

APPENDIX 3: RUBRIC FOR DISCUSSION BOARD

The rubric below was derived from the rubric published at: https://www2.uwstout.edu/content/profdev/rubrics/discussionrubric.html

Rubric for discussion board

Expectations for the discussion boards across a number of categories including frequency timeliness of posts, and quality of posts

Criteria	Unsatisfactory	Check minus	Check	Check plus
Frequency and timeliness of posts	Did not submit at least three initial posts. Did not submit at least five responses to peers' posts. Posts are not well distributed since last grading of the board (e.g., all or most on the last day before grading of the board).	Submitted three initial posts. Submitted at least four responses to peers' posts. Posts are not well distributed since last grading of the board.	Submitted four initial posts. Submitted at least six responses to peers' posts. Posts are not well distributed since last grading of the board.	Submitted five initial posts. Submitted at least eight responses to peers' posts. Posts are well distributed since last grading of the board (not posted all on one day or only at the beginning or only on the last day of the module).
Critical Analysis – Quality of content posted	Discussion postings show little or no evidence that readings were completed or understood. Postings are largely personal opinions or feelings, or "I agree" or "Great idea," without supporting statements or references to concepts from the scaffolding assignments and primary literature.	Discussion postings repeat and summarize basic, correct information, but do not link the scaffolding assignments and primary literature. Posts do not consider alternative perspectives or connections between ideas. Sources are not cited.	Discussion postings display an understanding of the scaffolding assignments and the primary literature. They demonstrate an engagement with underlying concepts including correct use of terminology and proper citation of sources.	Discussion postings display an excellent understanding of the scaffolding assignments, primary literature, and underlying concepts. The correct terminology is used throughout. Postings integrate references to the scientific literature to support important points. Well-edited quotes are cited appropriately. No more than 10% of the posting is a direct quotation.

Criteria	Unsatisfactory	Check minus	Check	Check plus
Participation in the Learning Community	Discussion postings do not contribute to ongoing conversations or respond to peers' posts. There is no evidence of replies to questions.	Discussion postings sometimes contribute to ongoing conversations as evidenced by affirming statements or references to relevant research, asking related questions, or making an oppositional statement supported by research.	Discussion postings regularly contribute to ongoing conversations as evidenced by affirming statements or references to relevant research, asking related questions, or making an oppositional statement supported by research.	Discussion actively stimulate and sustain further discussion by building on peers' responses as evidenced by a focused argument around a specific issue, asking a new related question, detailed affirming statements or references to relevant research, or oppositional statements supported by research.
Etiquette in Dialogue with Peers	Written interactions on the discussion board show disrespect for others.	Some of the written interactions on the discussion board show respect and interest for the ideas and writing of teammates.	Written interactions on the discussion board show respect and interest for the ideas and writing of teammates.	Written interactions on the discussion board show respect and interest for the ideas and writing of teammates. Team member encourages a positive interaction with others by their constructive and positive comments.

Criteria	Unsatisfactory	Check minus	Check	Check plus
Quality of Writing and Proofreading	Does not submit posts that are in complete sentences. Written responses contain numerous grammatical, spelling or punctuation errors. The style of writing does not facilitate effective communication.	Submitted posts that are in complete sentences. Written responses include some grammatical, spelling or punctuation errors that distract the reader.	Submitted posts that are in complete sentences. Written responses are largely free of grammatical, spelling or punctuation errors. The style of writing generally facilitates communication.	Submitted posts that are in complete sentences. Written responses are free of grammatical, spelling or punctuation errors. The style of writing facilitates communication.

ACTIVITIES

Introduction to Activities

The activity templates provided below are merely examples and prompts to help spur the development of assignments suited to the CURE you are implementing. Each of them should be customized to your audience, course structure, grading scheme, time frame, etc. Throughout the activity prompts below, [text in square brackets] denotes text that will need to be edited with the appropriate information for your course. Additional edits may be required depending on the structure of your course. For each activity, a link to a Word version of the file that can easily be edited is provided next to the activity title.

Activity 1: Learning Goals – Activity 1

Notes to instructor:

- The recommendation would be to use the specific CURE goals developed in section E2 for the list presented to students in question 1 of the activity.
- Depending on the size of the class and the instructor resources, it might be valuable to pair this activity with a beginning of the CURE conference with each student to discuss question 5.

—

Purpose of this assignment: Develop a list of personal goals and concerns for the entire project.

How does it fit within the entire project? You should be coming back to this document several times throughout the project as you reflect upon your experience with this research project. We will formally evaluate our personal learning goal progresses at the end of the semester.

Tasks required:

- Identify learning goals of interest within a list
- Write personal learning goals
- Express your concerns with the project

Deliverable: A completed version of this handout uploaded on [LMS] by deadline.

Estimated time: Less than 30 minutes

Group work or individual work? Individual work

Step-by-step:

1. Identify which of the goals presented on the first page of the [Document introducing the CURE to students] repeated below are most important to you. Select three or four.

- [Analyze multivariate morphological data
- Summarize (including graphically) your results
- Engage with the primary literature
- Synthesize information
- Tackle the study of novel data
- Manage a semester-long project
- Think like a scientist and
- Help move forward a scientific line of inquiry]

2. Explain for each of the goals selected WHY they are important to you.

-
-
-
-

3. Articulate in a short bullet-point list what your personalized learning goals for the projects are. This does not mean repeating any of the learning goals above but rather writing out something that I did not.

You should write three goals that are specific to you.

-
-
-

4. Write out what your three biggest concerns for the project are. Be specific. The more specific you are, the easier the next question will be.

-
-
-

5. How will you try to mitigate these concerns? For each concern above, explain what steps you will take. These might involve particular scheduling, specific approaches to interacting with students or myself, resources you will seek, help you will ask me for, etc. Think about what has helped you before. Feel free to talk to classmates, friends, or myself to fill out this table.

Concern	Mitigation

Activity 2: Narrowing a Research Question – Activity 2

Notes to instructor:

- This activity was modified from an activity developed by Jane Hammons.
- Provide students with a sample research question—this should be a complex question (perhaps multi-part) that would require a lengthy publication or even a set of publications to adequately answer.
- This activity was designed to take place in class.

—

Purpose of this assignment: The goal of this activity is to lead you to understand the constraints inherent to research and the importance of defining a specific question as part of the research process. You will learn to determine an appropriate scope of investigation and deal with complex research by breaking it into simple questions, limiting the scope of investigation.

How does it fit within the entire project? This activity will help you learn to focus your research question by taking a broad, complex question and breaking it down into a more manageable question.

Tasks required: Complete the activity below.

Deliverable: Completed version of this handout uploaded to [LMS] by [deadline] (one per person).

Estimated time: [to determine based on the initial question provided to the students]

Group work or individual work? Group work.

Step-by-step:

1. On your own, consider the research question presented to you. Break it down into less complex questions that would be appropriate. You have 10 minutes to brainstorm as many sub-questions as you can think of related to the main question. It may help you to think about the following ways to narrow a broad research question [these should be edited based on the initial question]:

- specific population or group
- more limited date range
- geographical area

- specific events

2. Consider the limitations of time, access to data and equipment, and other constraints on research undertaken as part of this class. Associate appropriate levels of concerns with each of your sub-questions.

3. Share your more focused research questions with your group members. Together, narrow down your list of combined questions to three or four you find particularly interesting. Make sure to associate with each their list of concerns. Write the list of questions on the whiteboard [or shared document].

4. Turn your attention to the list of questions of another group. Discuss which of the questions would be manageable, given the requirements of the course. Rank the questions from most (1) to least (4) interesting.

Activity 3: Researching Research in the Discipline – Activity 3
Notes to instructor:

- This activity was modified from an activity originally developed by Jane Hammons.
- Provide students with different articles that give students an illustration of the types of research that scholars in the field might undertake. Depending on the number of articles you select, students

could discuss all of the articles, or each individual student or group could be assigned one article to review.

—

Purpose of this assignment: The goal of this activity is to help you identify what "research" in the field means and how it is conducted.

How does it fit within the entire project? This activity will help you approach the research process recognizing the need to consider research as open-ended exploration and engagement with information and the importance of using various research methods, based on need, circumstance, and type of inquiry.

Tasks required: Complete the activity below.

Deliverable: Completed version of this handout uploaded to [LMS] by [deadline] (one per person).

Estimated time: [to determine based on the depth of the reflection, the number of source provided to the students, etc.]

Group work or individual work? Individual work [can be also used for group work].

Step-by-step:

1. Write a short reflection describing your understanding of research. Consider the following questions:

    - What does it mean to do research?
    - What is the purpose of research [in field of the CURE]? Why do people research?
        - To gain knowledge?
        - To share knowledge?
        - To answer questions?
        - To solve problems?
    - What are the actions that someone takes when they are researching?

2. Look at the articles you were provided and answer the following questions for each publication:

    - What is the purpose of the research? What was the author hoping to do or find?

   - What actions did the authors take? What constituted their research process?
   - What specific research methods did the authors use? Why did they select that method?

3. What are the differences and similarities across publications?
4. Write a synthetic summary addressing the following questions:

   - Why do scholars research?
   - What are the different steps of the research process in [the field of the CURE]?

5. Review your answer to question 1. What is your understanding of research now? How does your previous view match with your answer to question 4? Did your view of the purpose and process of research change?

Activity 4: Mind-mapping – Activity 4

Notes to instructor:

- This activity can be undertaken on paper or in a graphics software like Microsoft Paint. One can also use VUE (https://vue.tufts.edu/) or Google Jamboard (https://jamboard.google.com/) to create concept maps that can easily be edited. Directions for the download, installation, and use of the software program should be added to the step-by-step guide below.
- This activity was developed for a CURE in which students were given the opportunity to select from a series of defined projects consisting of one main question.
- Each project was provided two recent papers from the primary literature that represented model papers that investigated similar questions in different study systems.
- Students had already completed an in-class activity on reading and analyzing the primary literature [**Activity 2**].

—

Purpose of this assignment: The purpose of this assignment is to help you think about the questions and issues associated with your project, the existing literature, and necessary data for the analyses you are planning.

How does it fit within the entire project? This exercise will help you jumpstart your reflection on the analytical framework of your project, the basis of your work.

Tasks required: Read the two papers associated with your project following the approach we went over in class and complete this activity

Deliverable: PDF of your completed mind map

Estimated time: Less than two hours

Group work or individual work? Individual work

Step-by-step:

1. Start your mind map by entering the title/question of your project from the syllabus/class presentation.
2. Identify the three keywords/expressions of your project title. Create independent bubbles stemming from the title for each of them. Do not count the study system as one of the keywords; fo
cus on concepts.
3. Away from the existing bubbles, create a new bubble and name it after one of the two example papers associated with your topic.
4. Do the same thing for the second paper.
5. For each of the two papers, create two new bubbles. One should be titled "Question", the other "Hypothesis".
6. Can you identify the question and hypothesis for each of the two papers associated to your project? Add them to your mind map.
7. Using the two papers and the data from the initial project presentation to the whole class, can you develop your own question(s) and hypothesis(-es) for your project?
8. Create bubbles for the three keywords/expressions you identified for your project but for the two example papers (as appropriate).
9. What other keywords and concepts come to your mind from reading the papers that are associated to each of the three keywords/expressions? Complete the bubbles for the two example papers. Use as many bubbles as necessary and selectively reread the papers as necessary.
10. Use the bubbles from the two example papers to expand the bubbles for your own project. Ask yourself questions like:

- "What data do I need to represent the variables associated to my project?"
- "How is this variable commonly measured in published analyses?"
- "What analyses have already been undertaken in the literature? What do we already know about the question and the study system?"
- Do you have any other question?

Activity 5: The Scholarly Conversation—True or False? – Activity 5
Notes to instructor:

- This activity was modified from an activity originally developed by Jane Hammons.
- Divide students into pairs or small groups.
- You should customize the list of statements for your discipline/ CURE.
- This activity is intended as an in-class activity including a class-wide synthesis and discussion after students have completed question 2.

—

Purpose of this assignment: The goal of this activity is to introduce you to the concept of the scholarly conversation and help you develop a greater understanding of who is involved and what their roles are. This activity will help you describe the concept of the "scholarly conversation", recognize that you are often entering into an ongoing conversation and not a finished one, recognize that scholarly conversations take place in various venues, and start to see yourself as potential contributors to scholarly conversations rather than merely a consumer.

How does it fit within the entire project? As a researcher yourself, you will be consuming scholarship (through your readings), will have to learn to be critical to it, and will be contributing to it with the product of your research. You should learn how to navigate scholarship, learn the codes of the conversation, and make your place in it.

Tasks required: Complete the activity below.

Deliverable: Completed version of this handout uploaded to [LMS] by [deadline] (one per group).

Estimated time: [to determine based on the number of statements given to the students]

Group work or individual work? Group work.

Step-by-step:

Consider the list of statements below:

- Scholars engage in ongoing debates or discussions through their work
- Each source you use in a research paper represents a "voice" in a scholarly conversation
- For most scholarly topics, there is one clear, right answer
- As a student, you are not allowed to insert your own voice into the scholarly conversations in your field
- Providing citations is a requirement of engaging in the scholarly conversations in your field
- Reading recent journal articles can help you to track the scholarly conversations in your field

1. ON YOUR OWN first, consider each of the statements above. Which one(s) do you agree with? Articulate in a single sentence your reasoning/justification.

2. Review and discuss the statements as a group. Consider the following follow-up questions as you prepare a series of short statements summarizing the group consensus on each of the statements above. You should be ready to present your work to the whole class.

    - How do you see your role in the scholarly conversations on your topic?
    - How else might you learn about the conversations that are taking place in the field?
    - What role do citations play as part of the conversations? How does this compare from your own view of why citations are necessary?

3. ON YOUR OWN, write a definition of the concept of the "scholarly conversation."

4. Compare your conversation with your teammate(s). What would the group consider to be your definition of a "scholarly conversation."

Activity 6: Scholarship as Conversation—Minute thesis – Activity 6

Notes to instructor:

- This activity was modified from an activity developed by Jane Hammons, itself originally derived from the Minute Thesis activity described by James Lang in *Small Teaching: Everyday Lessons from the Science of Learning* (2016), pp. 106-108.
- You should customize the list of concepts and actions for your discipline/CURE.
- You may wish to select only one or two of the three videos provided below.
- This activity is intended as an in-class assignment associated with a class-wide conversation after question three.

—

Purpose of this assignment: The goal of this activity is to be able to describe the concept of Scholarship as Conversation and explain how key activities that are part of the research process connect to the concept of Scholarship as Conversation.

How does it fit within the entire project? This activity will help you make connections between Scholarship as Conversation and actions that you complete as part of the research you are undertaking in this class, such as reviewing the literature and providing citations

Tasks required: Complete the activity below.

Deliverable: Completed version of this handout uploaded to [LMS] by [deadline] (one per person).

Estimated time: [to determine based on the number of videos and the number of concepts and actions given to the students]

Group work or individual work? Individual work [can be also used for group work].

Step-by-step:

1. Watch the following video [pick one of the videos or more]:
    1. Scholarship as Conversation
    2. How Library Stuff Works: Scholarship as Conversation
    3. Research is a Conversation
2. Consider the following list of concepts:
    1. Citations
    2. Developing a Research Question
    3. Literature Review
    4. Peer Review

Select two of the items on the list [depending on your goals, you could have students select the concepts themselves, or divide students into groups or pairs and assign concepts. You can also adjust the number of concepts students work with.].

3. For each concept you selected, write for one minute [or two or three] explaining how the concept connects to the broader concept of Scholarship as Conversation. How, for example, does providing citations part of engaging in the scholarly conversation? You should be prepared to present your work to the classroom.

Activity 7: Reading and Analyzing the primary literature – Activity 7

Notes to instructor:

- The key to this activity is to choose a well-written model paper from the published literature on a topic related to the one discussed in the CURE.
- The template below should be completed with the relevant sections from the chosen publication.
- Depending on the structure of the publication read, some adjustments to the prompt will be necessary, but the activity should make sure to match the critical elements of a publication identified in the introduction to the activity with the elements showed to students.
- The handout should be designed such that students do not look ahead while completing the activity (use explicit guidelines such as "Do not look below the line" or "Do not turn the page yet").

—

Purpose of this assignment: Learning the structure of [scientific] papers and an effective approach to reading the primary literature

How does it fit within the entire project? This activity will help you prepare for your literature review and help set the stage for the structure of the entire project by highlighting the different sections of an article from the primary literature.

Tasks required: Complete the handout below.

Deliverable: Completed version of this handout.

Estimated time: About one hour

Group work or individual work? Individual work and group discussion during class.

Introduction: When reading an article from the primary literature, you should (almost) never read it in its entirety. Unless you are reviewing a paper, plan to replicate the study, or do a follow-up experiment, you only need to focus on the following sections of a [scientific] article to get the main points of it:

(1) the title gives you the main topic or point of the paper, sometimes even the punchline.

(2) the abstract is essentially a summary of the paper and should introduce the questions or hypotheses investigated, the main results and conclusions of the study.

(3) the figures and tables are critical because they present the data, results and sometimes interpretations

(4) the introduction and conclusion (or end of the discussion) may sometimes be useful

If you cannot get the key points of the study from these sections of the paper, it is not your fault. The paper was not well written. Let's practice on the paper below published recently in [XXXXXXXXX], a journal where some of the projects of this class could be published.

[Full reference for the article formatted according to the guidelines the students will have to follow in their main written deliverable, if applicable, or a standard/classic publication outlet in the field]

Exercise: Answer the questions below based on the information presented to you up to that question in the handout. Do not jump ahead, you will spoil the fun!

[Insert here the title, author information, abstract of the publication, and introduction omitting the approach adopted by the authors]

1. Based on the title and abstract above as well as the introduction , what was the **question** the authors sought to answer in this study? Use your own words. Do not quote the paper.
2. What was/were the **hypothesis(es)** the authors were testing? It may not be stated explicitly.
3. What is the [scientific] significance (i.e. importance/meaning) of this study that is articulated by the authors? Highlight the relevant sections in the text.
4. I have purposefully truncated the last paragraph of the introduction in which the authors describe their methodology. **Do not peak at the following pages of this handout.** Can you devise an analysis of your own to investigate the same questions as the authors? You do not have to know the technical terms, use your own words to describe your approach.

[Insert here the last paragraph of the introduction in which the authors describe their approach]

5. Use a schematic to draw expected results if the hypothesis tested by the authors is verified. Also include an alternative schematic in case the hypothesis is not supported. Use a different diagram to represent each of the hypotheses tested in the study.

[Insert here any figure or table associated with the material and methods section of the paper]

6. What data were collected by the authors based only on figures and tables? What other critical piece of information about the material and methods is not presented in the form of a table or figure in this article?

[Insert here any figure or table associated with the results section of the paper]

7. Based on the figures and tables, what tests did the authors of this paper actually perform?
8. Can you summarize the **results** (not interpretations) of the authors?
9. What conclusion can **YOU** draw from the results? (This is the time for interpretations).

[Insert here excerpts from the discussion section focusing on the conclusions drawn by the authors. Includes any associated summary figure(s)]

10. What are the conclusions of the paper according to the authors?
11. Do you think their conclusions are supported? What is a strength of this study? A weakness?
12. What would be the next step in this field of study in your mind? What follow-up study would you carry? Any lingering question?

Activity 8: Annotated Bibliography – Activity 8

Note to instructor:

- Also include guidelines from the library services of your institution on how to incorporate direct access to articles in Google Scholar as well as how to find articles not directly accessible via Google Scholar.

—

Purpose of this assignment: The goal of this assignment is to identify relevant papers from the published literature to help you develop your project.

How does it fit within the entire project? The publications you will find and analyze will help you identify the dialogue around your research topics, develop analyses, compare your results to previous findings, and place them in a broader context.

Tasks required: Read five articles following the methods demonstrated in class and complete the activity below.

Deliverable: A completed copy of this handout uploaded on [LMS] by [due date] AND a PDF copy of each paper you are summarizing uploaded to the [online shared folder] for your project.

Estimated time: About two hours and a half

Group work or individual work? Individual work requiring group coordination.

Step-by-step:

1. Use your answers to the mind mapping activity to identify below keywords associated to your project:

2. Go to https://scholar.google.com/. Use the keywords you identified to search for relevant papers.

3. Click on the link to the papers that have cited the most relevant publications to find additional papers ("Cited by ..."):

4. Consider also clicking on the "related articles" link for other suggestions:

5. Enter the title of each of the papers provided to you at the start of the semester. Search for papers that have cited these publications and related research.

6. Look at the authors of the paper you find. Are there authors that have published multiple papers on a topic of interest to you? Look at their other publications. Some authors have a Google Scholar profile (their name is underlined), for those who do not, consider searching by authors in Google Scholar or search for their website.

7. Search the literature cited/references of the papers you find to get older papers. Use the search function of Adobe Acrobat Reader and keywords to find other references cited in the papers you have found. You can apply these techniques to the papers I provided you at the start of the semester.

8. Use this tool: https://www.connectedpapers.com/. Enter the title of a paper to explore related papers and find papers central to the conversations.

9. You should coordinate with your teammates to avoid overlaps in publications among you. Your literature review should only be based on research publications (peer-reviewed articles, university press books/book chapters). If you are unsure whether or not a publication is appropriate, feel free to check with me. For a minimum of **five** publications, you should provide:

- Full reference (title, authors, journal, etc.) formatted as in [the Journal of Morphology] (see https://tinyurl.com/ycm7u9r8)
- Summary of the paper (<100 words)
- Why it is important to your research (i.e. what you will gain from it) in <100 words

Very important notes from the Library system:

[If you do not see OhioLink hyperlinks in your results, you must do the following:

Go to Google Scholar (http://scholar.google.com)

Click on the hamburger button.

Click on "Settings" near the gear.

Click on "Library Links" on the left side

Type OhioLINK in the text box and hit enter

OhioLINK-Find it with OhioLINK will now appear below that text box

Be sure the check box next to it IS checked

Click on "Save" at the top or bottom

Search with the OhioLINK connection!

If you are off-campus, you must ALSO do the following:

Open a new tab in your browser

Go to this address: https://auth.ohiolink.edu/DS/

Select Ohio State University

Select OARDC campus (this is the other Wooster campus)

Log in with your name.#

You will see a page for OhioLINK databases; leave this tab open while searching Google Scholar with the OhioLINK connection!]

[Use these Ohio State Libraries' services if you do not find free full text through Google Scholar:

- Research Databases List: search or browse by database name or browse by subject. Many database have full text or use Find It! to locate available full text provided by the Ohio State Libraries or OhioLINK.
- Online catalog: search by journal title or book title.
- Online Journals List: search or browse by journal title.
- Request a copy via the Ohio State Libraries' Interlibrary Services.]

Activity 9: Tracing the Scholarly Conversation – Activity 9

Notes to instructor:

- This activity was developed by Jane Hammons.
- Provide students with a source that is a few years old (it should be old enough that other researchers will have had time to cite it in their own published works). Or, have them locate a source relevant to their topic that is a few years old.

—

Purpose of this assignment: The goal of this activity is to help you learn how to trace the scholarly conversation on a topic, using references and "cited by" tools to find previous and more recent works related to a specific source.

How does it fit within the entire project? The review of the existing literature on a topic is critical to assessing the knowns and unknowns of the topic, the context for the scholarly conversation on this topic, the important actors of this conversation, and identify the contribution that particular articles, books, and other scholarly pieces make to knowledge on the topic.

Tasks required: Complete the activity below.

Deliverable: Completed version of this handout uploaded to [LMS] by [deadline] (one per person).

Estimated time: [to determine based on the depth of the reflection, the number of source from the citation list to study, etc.]

Group work or individual work? Individual work [can be also used for group work].

Step-by-step:

Tracing the Conversation Backward

1. Look at the source provided to you. Review and summarize briefly the source.
2. Answer the following questions:
    - Do you think this researcher(s) was the first to explore this topic?
    - How would you use this source to find previous research on this topic?
3. Review the citations/Literature cited for the article. Answer the following questions:
    - What is the oldest source that you can find listed?
    - Are there any journals that you see that are cited more than once?
    - Are there any authors that are cited more than once?
    - Which sources do you see that look as if they would be the most relevant to the specific research question?
4. Select [one] source from the citation list. Locate that source and compare it to the original source—what is the relationship between the two sources?
5. Repeat steps 3 and 4 for this second publication.

Tracing the Conversation Forward

6. Return to the original article. Answer the following questions:

    - Do you think this was the final word on the topic?
    - How could you use this source to find more recent sources on the topic or research question?

7. Locate the original source on "Google Scholar". Review the citations for the article by clicking on "Cited by …". Identify at least one source that cites the original source.
8. Compare the original and the more recent source. How would you describe the connections between the two sources?
9. Continue to trace the conversation forward, by finding a source that cite the newer publication.

Reflection

10. Write a short reflection on what the activity taught you. Answer the following questions:

    - What did you learn in this activity about the importance of citations (or how scholars use citations)?
    - What did you learn about the scholarly conversation on the topic?
    - How do you plan to apply what you learned to your own research practices?

Activity 10: Visualizing the Scholarly Conversation – Activity 10

Notes to instructor:

- This activity was developed by Jane Hammons.
- Provide students with a focused research question relevant to the CURE. You can also work with a student-generated question.
- Provide students with several articles or scholarly works on the topic. Depending on how much time you want students to take on the activity, you may want to provide them with summaries of the source. Be sure to include the citation information for each source, as well as the reference list.

- This activity can be undertaken on paper or in a graphics software like Microsoft Paint. One can also use VUE (https://vue.tufts.edu/) or Google Jamboard (https://jamboard.google.com/) to create concept maps that can easily be edited. Directions for the download, installation, and use of the software program should be added to the step-by-step guide below.

—

Purpose of this assignment: The goal of this activity is to help you come to better understand the concept of the scholarly conversation by creating a visual representation of (a small part) of the scholarly conversation on a specific topic or research question.

How does it fit within the entire project? This activity will help you approach the research process including your literature review as well as the discussion of your findings by encouraging you to suspend judgement on a particular piece of scholarship until the larger context for the scholarly conversation is better understood, recognize that a given work may not represent the only or even the majority perspective on a topic, understand the context for the scholarly conversation on your topic of research, the important actors of this conversation, and what each element of the conversation has contributed.

Tasks required: Complete the activity below.

Deliverable: Completed version of this handout uploaded to [LMS] by [deadline] (one per person).

Estimated time: [to determine based on the depth of the reflection, the number of source provided to the students, etc.]

Group work or individual work? Individual work [can be also used for group work].

Step-by-step:

1. Create a visual representation that demonstrates the connections between the sources and the contribution that each has made to the conversation on the topic. You may wish to follow the model of a concept map (examples).
2. Consider the following questions:
    - Does it appear that the sources can be grouped or divided in any way? For example, are there any sources that provide a similar

perspective on the topic, or come to similar conclusions?
    - Are there any sources that provide a perspective or conclusion that is radically different from the others?
    - Are there other similarities between the sources in terms of research methods?
    - Are there any of the sources that appear to have influenced the other sources? For example, are there sources that are cited by the majority of the other sources?
    - Are there sources that appear disconnected from the conversation? Are not cited by any of the other authors?

3. Write a summary of the conversation based on the sources provided.

Activity 11: Identifying Commonly Cited Sources – Activity 11

Notes to instructor:

- This activity was modified from a set of activities originally developed by Jane Hammons.
- Have each student locate a set of academic journal articles relevant to the course or field a part of the exercise or provide students with a list of articles relevant to the CURE and assign different students or groups of students to work with specific subsets of articles from the list.

—

Purpose of this assignment: The goal of this activity is to help you understand the types of sources that are most commonly cited in research in the field and lead you to identify disciplinary authorities and recognize that authority is constructed and contextual.

How does it fit within the entire project? This activity will help you recognize the books, journals, databases, and scholars that are generally considered more authoritative than others and identify the types of sources that are most commonly cited by scholars in the field.

Tasks required: Complete the activity below.

Deliverable: Completed version of this handout uploaded to [LMS] by [deadline] (one per person) and participation on the discussion board of the [LMS] by [deadline].

Estimated time: [to determine based on the number of source provided to the students]

Group work or individual work? Individual work [can be also used for group work].

Step-by-step:

1. For each of your selected [or assigned] articles, you should review the citations **AND** the literature cited. Answer the following questions:
    - Rank the following source categories in order from most often cited to least often cited: academic journal articles, books, government reports, news and magazine articles, [insert other source types relevant to the CURE].
    - What other types of sources are cited?
    - Identify any scholar(s) whose work is cited multiple times by multiple authors across all sources.
    - Identify any journals that are cited multiple times. Are there journals that are cited more often than others? Which ones? Identify the top five.
    - Is there a specific source (e.g., an academic journal article) that is cited by a majority of other sources available to you?
2. Share your results on the [discussion board] by [deadline].
3. Between [date] and [date], review the combined results. Answer the following questions:
    - What types of sources seem to be most commonly cited by scholars in the field?
    - Are there any types of sources that rarely seem to be cited in the field?
    - Whose voices may be missing from these sources?
    - What did you learn in this activity that may be relevant to you as a future scholar in this field?

Activity 12A: Peer-Review (Model A) – Activity 12A

Notes to instructor:

- Try to provide every student/group of students with two or three peer-reviews.
- The framework presented here can be truncated to enable peer-reviews at earlier stages of the CURE.
- Iterative reviews can be associated with additional peer-review elements such as: "Did the revisions incorporate your feedback? If not, what are they yet to implement?"
- Consider sharing with students examples of constructive and respectful peer-reviews (of your own work or other students' work following ethical guidelines) that can act as models for the work they are expected to produce.

—

Purpose of this assignment: The goals of this assignment are (1) to provide your peer(s) with constructive feedback on their writing that will help them improve their papers and (2) to encourage you to reflect on your own writing.

How does it fit within the entire project? The process of scholarly publication involves peer-reviews. As such, the peer-review you are performing here is akin to the work asked of professional academics. The peer-review process is critical to assessing the quality of the research work, the modifications necessary to it, and the advancement of the scholarly dialogue. The peer-reviews you receive will directly enable you to improve your paper and those you provide will help you reflect on your own writing, thus indirectly leading to improvements in your paper.

Tasks required:

- Critically read the [paper] of your [classmate].
- Answer the questions below with complete sentences. Do not simply write yes or no. Explain every "no" answer and support your argument. Provide information on how each element of the paper could yet be improved when answering "yes"
- Remember to be constructive and acknowledge positive points.

Deliverable: Completed copy of this handout uploaded on [LMS] by [due date].

Estimated time: About [xxxx]

Group work or individual work? Individual work.

Step-by-step:

1. Please summarize the paper (less than 200 words): *In other words, write an abstract for it*
2. Highlight here three things that were done well in this paper
3. Highlight here three things that need to be revised for the final version of this paper
4. Answer the questions below in the table provided.

General issues
Is the writing appropriate for an academic paper?
Is the paper appropriately formatted?
Are the paper and its different sections of appropriate length?
Are the paper and its different sections clearly organized following the structure of [scientific] publications?
Is the paper free of writing, spelling, and grammatical errors that impact its understanding?
Material and Methods
Are the methods appropriate, given the research question?

Are the data used appropriate (including sample size, variables measured, sampling across categories, etc.)?
Are predictions derived from the hypothesis (-es) laid out?
Are all analyses undertaken described with sufficient detail to enable another researcher to repeat the work?
Does the paper repeat standard procedures that all scholars know how to do?
Results
Are the results thoroughly presented?

Does the text reference the figures and tables?
Is the interpretation clearly excluded from the results section?
Discussion
Does the paper skillfully interpret the results? Is the data interpretation appropriate, accurate, and unbiased?
Does the paper provide a thoughtful and thorough discussion of possible future studies or alternative approaches?
Does the paper provide an insightful explanation of the reasons underlying the pattern in the data?

Is there a compelling discussion of the implications of findings?
Does the paper explicitly interpret the results in relation to the hypothesis (-es)?
Does the paper discuss inconsistencies, uncertainties, or limitations of the results?
Are the findings compared to those published in prior research or put into contest (as appropriate)?
References
Are the citations presented consistently and professionally throughout the text and in the list of works cited?

Figures and Tables
Are the tables and figures clear, effective, appropriate, and informative?
Are the figures and tables accompanied by brief but adequate captions?
Do the figures and tables each have adequate labels (including legends and axes' labels)?
Are the figures and tables numbered and cited within the text?
Are the tables properly formatted with no vertical lines and no unnecessary formatting?
Is the text on the figures large enough to be read?

Is the format of the graphics appropriate for the data represented?
Are the figures informative and relevant to the paper?
Do all captions start with the appropriate figure number?
Is the caption informative?
Are all elements of the figure appropriately explained?
Are all abbreviations used in the image provided in the caption?

Does each caption follow the required format?

5. Write below a bullet point list including six elements of your paper you will revise in light of your reading of your classmate(s) paper. For each of them, provide details about the change you will make and the rationale for that change.

Activity 12B: Peer-Review (Model B) – Activity 12B

Notes to instructor:

- This activity was modified from an activity originally developed by Ryan Norris.
- This activity is based upon the peer-review template of a discipline -specific journal (here the *Journal of Mammalogy*). The activity should be adapted to fit an appropriate model journal for the discipline of the CURE.
- Examples provided throughout the document should also be edited to reflect the disciplinary focus of the CURE.

—

Purpose of this assignment: The goals of this assignment are (1) to provide your peer(s) with constructive feedback on their writing that will help them improve their papers and (2) to encourage you to reflect upon the process of scholarly publishing.

How does it fit within the entire project? The process of scholarly publication involves peer-reviews. As such, the peer-review you are performing here is akin to the work asked of professional academics. The peer-review process is critical to assessing the quality of the research work, the modifications necessary to it, and the advancement of the scholarly dialogue. The peer-reviews you receive will directly enable you to improve your paper and those you provide will help you reflect on your own writing, thus indirectly leading to improvements in your paper.

Tasks required: Complete a review of a peer's paper following the guidelines provided in this prompt.

Deliverable: Completed copy of this handout uploaded on [LMS] by [due date].

Estimated time: About [xxxx]

Group work or individual work? Individual work.

Step-by-step:

Regardless of your final profession, you will be influenced by the peer-review process. It is foundational to modern science and allows for science's gold standard, the peer-reviewed publication. The process is similar whether it involves a publication in mammalogy, medicine, or astrophysics. You have read many peer-reviewed papers, but I'm hoping to de-mystify how they came to be what they are, and, hopefully, why we hold them in high regard. You and your classmates have written papers that involve novel data that allow for you to address questions in a way that is unique relative to what's come before. Some of you have drawn exciting conclusions or refuted established ideas.

There are numerous online sources suggesting how to write a good review; I might suggest this one: http://www.indiana.edu/~halllab/grad_resources/Benos_2003_HowToReviewAPaper.pdf I will provide a short set of explanations below, but bear in mind two primary goals. You are reviewing this paper: 1) to help the editor assess the quality of the paper and its conclusions 2) with the goal of helping the authors make it as good as can be. As with more senior scientists, you should not go into a review with the intent to help your friends or to thwart your competitors. The process is often anonymous to aid in that purpose.

Your review has two components: "Confidential comments to the editor" and "Comments for the author". Please clearly divide your review into these two sections.

Confidential comments to the editor

These comments will not be shared with the author(s).

1. Begin with your final recommendation. Your four options are "Accept", "Accept pending minor revision", "Reject but encourage resubmission following major revision", and "Reject". If you would like, you may use a shorthand of Accept, Minor revision, Major revision, or Reject. The [model journal] has an online form for the upload. It involves a button indicating your decision and two simple plain text boxes. You will just be including this recommendation in your email to me. Some journals have an "Accept pending major revision" decision, but these are rarely used and we are copying [model journal], which does not use this.

I generally think of minor revision as restricted to situations where there are a few problems, but no new analyses are needed and the conclusions are soundly supported by the data. As soon as you start to require a new analysis, you open up the possibility that the conclusions will no longer be supported and it becomes major revision. Reject involves situations where it is not appropriate for the journal, the core conclusion of the paper cannot be justified, or the paper is in such bad shape that you don't anticipate it can be made acceptable without overwhelming changes.

The reason your recommendation is not shared with the author is because the final decision rests with the editor after receiving all reviews. You may have overlooked a fatal flaw in the manuscript or you may have been much harder on the authors than other reviewers. The editor may decide after reading your review that you may be too close to the author or topic, that your recommendation is completely at odds with your review, or that you may not have adequate knowledge about an important component.

2. Beyond the recommendation, you may have nothing else you need to say to only the editor. That is fine. You may, however, want to share information exclusively with the editor. For example, if you are really unhappy about some aspect of the paper, this is the place to tell the editor you're your concerns are and why you think these preclude the publication of the paper. You might also be wary to note something in the comments to author that may expose your identity. Mostly, however, this section is used to clearly explain your recommendation. For example, you might wish you were given an option for "moderate revision". Let the editor know that. The bulk (or all) of your review, however, should be available to the author.

Comments for the author

3. Both the author(s) and editor will be reading this section. There are many ways to construct a review. It's one of those writing tasks with no formally correct methodology. I do, however, tend to think that effective reviews contain 4 main components: summary, positive statements, major concerns (if present), and minor concerns. I will make recommendations along those lines.

Summary. Start by summarizing the paper and your thoughts about the paper. This isn't exactly an abstract; your focus should relate to the major conclusions in plain language and how well they are supported. By summarizing the paper, you establish your understanding of what you read and can often explain that to the editor in less technical language than the authors are able to use.

Positive statements. It is important to acknowledge the positive in your colleague's (or classmate's) work. Acknowledging the good in a work has several other benefits. If your editor is not knowledgeable about the topic, they may need you to tell them that what is presented here is important or valuable. You not only need to justify why you failed to suggest a paper be accepted, but also why you failed to suggest a paper be rejected.

Major concerns. What are the main points that represent the focus of your review? If you did not recommend accept or minor revision, why? (Hint: it's not because they mixed up "their" and "there" on page 14). Do you think they need to conduct a different analysis? Repeat the one they conducted using different parameters? Did they misinterpret their statistical test? Are they trying to draw bigger conclusions than their data justify? Did they overlook an important paper?

I tend to number these major concerns and devote at least a paragraph to each. This gives the authors a clear set of bullet points in their response. Note that the authors do not have to accept everything you say (and even the editor may tone it down in his/her decision letter), but if they disagree with you, they will need to justify it. You may disagree with the conclusions the authors present, but your main job is to decide whether their conclusions are justifiable. Throughout the review, refer to the paragraph or sentences in question using the line numbers. For example: "I disagree with the statement (line 76) that *Myodes* is clearly monophyletic. Kohli et al. (2014) clearly demonstrated that several *Alticola* species are part of the *Myodes* clade."

I tend to end my major revisions section by stating something along the lines "Minor concerns follow."

Minor concerns. This is where I place changes that, absent the major concerns noted above, might only warrant a "minor revision" decision. These may require a paragraph for explanation, a sentence, or just a few words. This may involve good science (e.g. "Line 56: Report your standard deviation in addition to your mean." Or "Lines 19-24: Explain the settings of your BEAST analysis"), clarity ("Fig 3: Your gray icon on white background is not visible. Try black."), or spelling/grammar ("Line 78: "their" should be "there").

I will often use a shorthand that looks like this but you are not required to use this.

Minor suggestions follow:

Line 5: their -> there

L7 Italicize Myodes.

L10-11 This sentence is unclear

L17-19. Have you looked at Kohli et al. (2014)?

L27 "2010), the next" -> "2010); the next"

Note that your review is usually converted to plain text. If you want to refer to italics, for example, you should say so and not rely on something you wrote being italicized.

4. Finally, you probably cited literature in your review. If the papers you cite are already in the manuscript's Literature Cited section, you don't need to add the full citation in the review. If not, however, add a Literature Cited section at the end of your review. Formatting rules are looser here, but generally follow the journal's approach.

Activity 13: In-Class Group Meetings – Activity 13

Notes to instructor:

- The example provided here is for the material and methods. Similar meeting structures can be developed for other elements of the CURE.

- This activity is designed for groups of four students. Adjust accordingly.
- The dates in the last table are the dates between the day of the group meeting and the due date of the deliverable. The number of rows should be adjusted accordingly.

—

Purpose of this assignment: The goal of the meeting today is to help you prepare the [material and methods] section of your paper.

How does it fit within the entire project? [Explain here the purpose of the relevant section of the deliverable. Here is an example for the material and methods: The material and methods present to your readers all of the information necessary to explain how you obtained your results and how these analyses might be replicated. It mentions the nature and origin of the data studied (the material), how they were analyzed (the methods). This is a critical element of every research publication.]

Tasks required: Complete the activity below.

Deliverable: Completed version of this handout uploaded to [LMS] by [deadline] (one per group).

Estimated time: [to determine based on the number of group members, number of questions, etc.]

Group work or individual work? Group work.

Step-by-step:

1. Within your group, you will all, in turn assume the following roles:

- **Recorder:** Takes notes of the conversation taking place.
- **Presenter:** Presents their findings.
- **Encourager:** Pushes back on specific statements or too quick a consensus . Encourages the consideration of a number of options or viewpoints, focuses on potentially rich areas of disagreement.
- **Facilitator:** Ensures the group stays on task and on time. Additionally, the facilitator will enforce speaking opportunities (see below).

Fill out table below with your names. Notice that you will change roles throughout the conversation:

	Recorder	**Presenter**	**Encourager**	**Facilitator**
Summary 1	Person 1:	Person 4:	Person 3:	Person 2:
Summary 2	Person 2:	Person 1:	Person 4:	Person 3:
Summary 3	Person 3:	Person 2:	Person 1:	Person 4:
Summary 4	Person 4:	Person 3:	Person 2:	Person 1:

2. The structure of the conversation is the following. Please read the list in its entirety **before** to start the conversations:

    - The facilitator will remind everyone of their roles for the conversation that is about to take place.
    - The facilitator will yield the floor to the presenter who will go over their answers to the following questions from the agenda activity associated with this meeting.
        - Are there elements of your material and methods outline that need to be edited or added based on comparisons with the two template papers?
        - What other papers have you found to have helpful material and methods section?
        - Are there elements of your material and methods outline that need to be edited or added based on your readings beyond the two template papers? Mention specific elements.
    - The facilitator will (kindly) ask the person to stop their presentation after five minutes.
    - The facilitator will ask the encourager to ask questions and raise concerns or counterpoints for three minutes.
    - The facilitator will also raise concerns and ask questions for a maximum of two minute.
    - The presenter will reply to those for a maximum of two

minutes.
- The facilitator will check the clock and announce the time elapsed. The encourager should push for additional conversations drawing on points raised so far to get the time to approximately twelve minutes of conversation.
- The recorder will take notes throughout the entire conversation and then provide a summary to the entire group in a maximum of two minutes.
- The group will submit corrections to the record as they wish for a maximum of one minute enforced by the facilitator.
- All members of the group should make use of the board as necessary to show information or organize their thoughts.
- Go to the next person and repeat until everyone has presented their answers and had a chance to (respectfully) debate the other group members.

3. Using the notes from the recording role you assumed earlier, complete the following questions as a group:

    - What is the final outline of your material and methods section?
    - For each of those, provide a one to three sentence summary of the information that will be included. Use the table below. Leave the second column of the table blank.

Outline	Refs.

- For each element of your material and methods above, add in the second column relevant and necessary references. Those would be the papers that you will cite in your writing.
- Use different colors (use the highlight tool of Word) to assign each section of your material and methods to a member of the group.

Section color	Team member
Yellow	
Cyan	
Purple	
Green	

In doing so, keep in mind the following:

- The length of the section/subsection assigned to each person
- The familiarity of each team member with the relevant references/ sections/concepts
- The technical complexity of each section/subsection
- The number of references to read/skim/check/cite
- Your own commitments to other classes, job, life …

4. Use the end of this page to develop a timeline for the writing process. The draft is due on [due date]. Keep in mind that you will need to check the entire work for a sense of unity. It should be a single piece, not a collection of pieces put together. The different sections of the material and methods should work TOGETHER both in terms of writing and in terms of concepts/explanations/narrative.

Date	**Commitment**
[date 1]	
[date 2]	
[date 3]	
[date 4]	
[date 5]	

Activity 14: Meeting Agendas – Activity 14

Notes to instructor:

- Select the appropriate information above depending on the specific group meeting.
- Select the appropriate set of questions below depending on the specific group meeting.

—

Purpose of this assignment: Develop an agenda for your [specific meeting] meeting during class

How does it fit within the entire project?

[Framework]: The framework of your project will guide the entire experience. The framework is the basis of the analytical thinking. It is critical that you come to class with a sense of where you are taking your project.

[Material and Methods]: This agenda will enable you to have a productive in-class meeting to develop your material and methods section and articulate your data collection and analysis process in details to your readers.

[Figures and Tables]: This agenda will enable you to have a productive in-class meeting to develop your figures and tables, which are central to the presentation of your findings to readers.'

[Results]: This agenda will enable you to have a productive in-class meeting to develop your results section, which will complete your work on the figures and tables.

[Discussion]: This agenda will enable you to have a productive in-class meeting to develop your discussion section, which is one of the most critical element of your manuscript because it summarizes your findings, places them in context (of prior results, the field, etc.), and explains the significance of your work.

[Introduction]: This agenda will enable you to have a productive in-class meeting to develop your introduction section, which is the sister section of the discussion because it presents the questions and hypotheses you are investigating, places your work in context (of prior results, the field of research, etc.), and explains the significance of your work.

Tasks required:

- Coordinate with your team members to fill out the worksheet below
- Upload complete agenda on the discussion board

Deliverable: Upload of agenda on discussion board of [LMS] by [deadline].

Estimated time: Less than [thirty] minutes

Group work or individual work? Individual and Group work

Step-by-step:

[Framework]:

1. Much of the meeting will be devoted to the sharing of the information you prepared as part of your workbook activity reflecting upon your readings and mind mapping activity. You

should make sure to do the following prior to the meeting

- Complete and bring your workbook questions for [Framework I].
- Complete and bring your [mind mapping activity].
- Read the [project framework meeting sheet].

2. Complete the questions below individually:

    - What are your biggest concerns about the project so far?
    - What resources do you need from me?
    - What terms from your readings do you not understand?
    - Do you have questions for me about specific components of your readings?
    - Are there aspects of the project that still confuse you (structure and/or subject)?

3. AS A GROUP, go over your answers to the questions above.

    - Can you answer some of your teammate's questions?
    - Combine redundant questions as necessary.
    - Make a list of all remaining questions. This is the agenda for the meeting to upload (we will go over these questions in class).

[Materials and Methods]:

1. Much of the meeting will be devoted to the discussion of the outline of your material and methods and the development of this section of your paper. You should make sure to do the following prior to the meeting

    - Complete and bring your workbook questions for [Material and Methods II].
    - Complete and bring the [outline activity from the last class meeting].
    - Read the [material and methods meeting sheet].

2. Complete the questions below individually:

    - Write out below an outline for your material and methods section that includes all headers and subheaders.
    - Go back to the two template papers you were provided at the start of the semester. Write out below an outline for each paper's material and methods section including headers and subheaders (note that they might not be explicit).

Paper 1:	**Paper 2:**

    - Are there elements of your outline that need to be edited or that you need to add based on a comparison with the two published template papers?
    - What other papers have you found to have helpful material and methods section? These might include papers that describe analyses you will be using, papers that address similar questions to the one you are working on in a different study system … For each of them, provide a full reference as you would cite them in your paper.

3. Do you have questions for me about specific components of your material and methods?
4. AS A GROUP, put together a complete list of all of the references you included in your answer to question 2d. Upload it on the discussion board. It is your agenda assignment for the meeting. Make sure that a PDF copy of every paper that will be useful to you is available in [a shared folder] for all team members to see and download.

[Figures and Tables]:

1. Much of the meeting will be devoted to the discussion of the choice

of figures to include in your paper, their format, and their captions. You should make sure to do the following prior to the meeting

- Complete and bring your workbook questions for [Figures and Tables II].
- Complete and bring the [Graph Predictions activity].
- Read the [Figures and Tables meeting sheet].

2. Complete the questions below individually:

    - List below all figures and tables you expect to include in your paper.
    - Go back to the two template papers you were provided at the start of the semester. Write out below for each paper a list of all figures and tables included in the main section of the paper. Make sure to provide a shortened title or description for each. Differentiate between figures and tables explicitly.

Paper 1:	**Paper 2:**

        - Compare your answers to questions 3a and 3b. Are there figures you should add or delete from the main section of your paper? What about tables?
        - Consult the supplementary information for one of the papers you have read. Write out below in the format of the [Journal of Morphology] the reference for this paper.
        - What figures or tables are you planning on including in the supplementary information/appendices of YOUR paper that will not be in the paper but online

(Accessible via a link)? *Explain why these are necessary but will not be in the main paper.*

3. Do you have questions for me about specific components of your figures and tables?
4. AS A GROUP, make a list of your answers to question 3 combining them as appropriate. Put together a complete list of all of the references you included in your answer to question 2d. Upload this information as a single file on the discussion board. It will be your agenda assignment for the meeting. Make sure that a PDF copy of every paper that will be useful to you is available in [a shared folder] for all team members to see and download.

[Results]:

1. Much of the meeting will be devoted to the discussion of the outline of your results sections. You should make sure to do the following prior to the meeting
    - Complete and bring your workbook questions for [Results I].
    - Complete and bring the [Writing a results paragraph activity].
    - Read the [Results meeting sheet].
2. Complete the questions below individually:
    - Repeat below the outline for your results section that includes all headers and subheaders (from your workbook).
    - What are the highlights of your findings? Summarize in no more than two sentences each the four main findings of your study.
    - Match these four elements to the outline you wrote in question 3a. Do they all fit? Do you need to revise your outline?
    - How does each figure and each table associated with your results section fit onto the outline from 2c? Do you need to revise your outline?
    - Write below a revised outline including two sentences per section/subsection summarizing the gist of the findings and associate all necessary figures and tables.

3. Do you have questions for me about specific components of your results section?
4. AS A GROUP, make a list of your answers to question 3 combining them as appropriate. Upload this information as a single file on the discussion board. It will be your agenda assignment for the meeting. Make sure that a PDF copy of every paper that will be useful to you is available in [a shared folder] for all team members to see and download.

[Discussion]:

1. Much of the meeting will be devoted to the discussion of the significance of your research and its inclusion in your discussion section. You should make sure to do the following prior to the meeting
    - Complete and bring your workbook questions for [Discussion I].
    - Complete and bring [the Writing a discussion paragraph activity].
    - Complete and bring [the Response to counterarguments activity].
    - Read the [Discussion meeting sheet].
2. Complete the questions below individually:
    - Repeat in the first column of the table on the next page all of the main findings of your research you have identified. Add rows as necessary.
    - For each of those findings, identify in **one** sentence why that result is important to the study of [insert here relevant topics and keywords of the CURE].
3. Go back to the literature and answer the following questions:
    - Does your work provide an answer to a long-standing question

in the field?
  - Are you the first to provide evidence for a pattern that has been assumed for a long time?
  - Do you provide broad support for a pattern proposed before by studying a small sample (few specimens, few species ...)?
  - Are you providing the first evidence of a particular pattern or the first line of evidence for a question never studied in this study system?
  - What element of your work is novel? Think about method, sample, and variables in particular.

Finding	**Significance**

4. Do you have questions for me about specific components of your discussion section?
5. AS A GROUP, make a list of your answers to questions 2b and 3 as well as a list of your questions for me, combining them as appropriate. Upload this information as a single file onto Carmen. It will be your agenda assignment for the meeting

[Introduction]:

1. Much of the meeting will be devoted to outlining the introduction and developing a plan for the final version of the manuscript of your project.
2. You should make sure to do the following prior to the meeting

  - Complete and bring [your workbook questions for the

    Introduction].
    - Complete and bring [the Writing an Introduction activity].
    - Complete and bring [the Response to counterarguments activity].
    - Read the [Introduction meeting sheet].

3. On your own, use the answers to your workbook activity to organize the information from the activity on Writing an introduction. In other words, create a detailed outline of your introduction that includes all necessary elements (i.e. Background information, Problematic / Question(s), Hypothesis (-es), Motivation and significance of study, Setup of study).
4. Include all necessary references for each element of your outline.
5. Do you have questions for me about specific components of your discussion section?
6. AS A GROUP, make a list of your answers to questions 5, combining them as appropriate. Upload this information as a single file onto the discussion board. It will be your agenda assignment for the meeting.

Activity 15: Project Framework – Activity 15

Notes to instructor:

- In an effort to guide students, they are provided below with examples from a published paper. The publication chosen as a reference should be:
    - Recently published
    - Relevant to the topic of the CURE
    - If appropriate be authored or co-authored by an instructor of the course to enable (1) a personal connection with the research of students and (2) students to see their instructor as experts they can turn to. Consider featuring peer-assistants, graduate student instructors, or postdoctoral researchers involved in the course if relevant and possible.
- Similarly, the selection of articles presented as examples for the selection of titles should be selected carefully, although the direct

relevance to the CURE is not as necessary.

—

Purpose of this assignment: The goal of this assignment is to help you develop the structure for your research project.

How does it fit within the entire project? The key to a successful research project lies in part in a well-structured study with a clear question, hypotheses, and data collection plan. These guide the project throughout its entirety, determine the scope and focus of the work, and serve as reminders of the intent of the research all the way to its completion.

Tasks required: Complete the activity below.

Deliverable: Upload of agenda on discussion board of [LMS] by [deadline].

Estimated time: about 1 hour

Group work or individual work? Combined individual and group work – use the discussion board

Step-by-step:

1. Identify a title for your paper. This does not have to be the final title of your manuscript. Rather, you should think of it as a guiding thread. There are many different ways to phrase a title. Below are a few examples from my own research:

- A narrow topic and the more general issue it relates to are mentioned together: [A new species of *Ceratogaulus* from Nebraska and the evolution of nasal horns in Mylagaulidae (Mammalia, Rodentia, Aplodontioidea) – Calede and Samuels 2020]
- The title is a simple statement of the topic of research: [Locomotory adaptations in entoptychine gophers (Rodentia: Geomyidae) and the mosaic evolution of fossoriality – Calede et al. 2019]
- The title gives away the main finding: [Geometric morphometric analyses of worn cheek teeth help identify extant and extinct gophers (Rodentia: Geomyidae) – Calede and Glusman 2017]
- A colon enables the specific scope or focus of the paper to be mentioned: [Skeletal morphology of *Palaeocastor peninsulatus* (Rodentia, Castoridae) from the Fort Logan Formation of Montana (Early Arikareean): ontogenetic and paleoecological interpretations –

Calede 2014]

Your title should be different from the project topic I gave you.

2. Go back to your mind mapping activity as well as the notes from your framework meeting. What are the questions you are investigating in your project? Remember that a question ends with a question mark.

[For example, in the Calede and Samuels (2020) paper mentioned above and available on the shared box folder, the question we addressed was: "What was the pattern and process of the evolution of horns in mylagaulids?"]

3. Explicitly articulate the hypothesis or hypotheses you will be testing. A hypothesis is an affirmative or negative statement that can be tested. A hypothesis proposes a specific pattern, relationship, or explanation for a phenomenon. A hypothesis is not a theory. In research, a theory is a general explanation backed up by lots of data (e.g., the theory of evolution). A hypothesis may be a small-scale observation that is yet to be tested. Do you have a null hypothesis and an alternative hypothesis?

[For example, in the Calede and Samuels (2020) paper, the hypothesis was: "Mylagaulid horns were linked to defense and could have been subject to natural selection driven by their effectiveness in increasing survival"]

4. What data support your hypothesis / lead you to state your hypothesis as such? Reference the papers from the literature you have read as necessary. In other words, what is the context from the published literature for your hypothesis? Are you trying to test a long-standing assumption? Are you trying to test a pattern supported in one taxon in another? …?

[For example, in the Calede and Samuels (2020) paper, we based our hypothesis on body mass and locomotion data on rodents and horn data from lizards (and other more minor lines of evidence).]

5. What variables will you be analyzing? How will you treat your data (use of averages, use of subset of data, data normalization, etc.), what summary statistics you will be calculating (mean, median, centroid, standard deviation …), and any other variable you will include in your analyses (mention all control variables, explanatory variables, response variables).

[For example, in the Calede and Samuels (2020) paper, we used data on horn height in relation to body mass, data on body mass evolution, and data on the pattern of evolution of horns in mylagaulids. We log-transformed linear measurements and use phylogenetic comparative methods to account for the role of evolutionary history. The data are all based on adult unbroken fossils (no sex data) at the species level (means).]

6. What are the predictions you make for your variables if your hypothesis is supported? What about if it is not?

[For example, in the Calede and Samuels (2020) paper, we predicted (among other things) that we should see jumps in body size when horns evolved if the two are in fact associated. We also predicted that the horns should scale with positive allometry if they are indeed associated with defense.]

Activity 16: Deliverable Tutorials – Activity 16

Notes to instructor:

- The purpose of the assignment is to help [students] understand what constitutes a good [section of deliverable (e.g., introduction)] section, how it is organized, and how to approach writing it.
- The task required always consists of completing the handout. The activity is usually done in class with frequent conversations with group members and the entire class, possibly in a thin-pair-share format.
- The example papers chosen should fit the topic of the CURE.
- The work involves the instructor sharing their writing from past or

current projects. This assumes that the CURE is relevant to the research program of the instructor and therefore applies most directly to researcher-driven CUREs.

- By sharing their own writing, the instructor opens themselves to critique from students and actively engages them in the collaborative and constructive process of peer-review.
- Students should be introduced to best practices on the sharing and distribution (or lack thereof rather) of unpublished research prior to the activities.
- Select the appropriate set of questions for the section from the options provided below.

—

Step-by-step:

[For all section except the introduction]: Our work today will be divided into three steps:

1. Read and analyze the [section of deliverable (e.g., material and methods)] from a published study.
2. Draft the [section of deliverable (e.g., material and methods)] section for a project that [the instructor] is working on.
3. Compare the draft produced in class to the one written by [the instructor].

[For the introduction]: Our work today will be divided into three steps:

1. Read and analyze the introduction section of a published study.
2. Identify key elements of the introduction of your paper.

READING AND ANALYZING:

We will be first reading the material and methods section from the following article: [Full reference for the article formatted according to the guidelines the students will have to follow in their main written deliverable, if applicable, or a standard/classic publication outlet in the field]

1. First, read the abstract below so you are familiar with the research project as a whole: [Insert here the full abstract of the article].

2. The following pages show the [section of deliverable (e.g., introduction)] section of the [author(s) of the paper the students are reading] paper. Use it to answer the questions starting on page [number] of this handout.

<u>Questions [for material and methods]:</u>

1. Identify the different sections of the material and methods of this paper (hint: look at headers and subheaders).
2. Use a highlighter to identify key components of each of the sections you identified (no more than one or two sentences should be highlighted).
3. For each section you identified, use a bullet point list to summarize the key elements you highlighted. For example, if you highlighted the following: "… from one to six specimens from each of 34 species from the …", this would be the sample size and distribution.
4. Compare your list with your classmates. Edit accordingly.
5. Make a note on your list of the information that is presented in the form of figures, tables, and appendices.
6. Be prepared to present your lists to the whole class.

<u>Questions for [results]:</u>

1. Identify the information presented as text, figures, or tables.
2. How is the results section of this paper divided? (Hint: look at headers and subheaders).
3. Use a highlighter to identify key components of each of the sections you identified (no more than one or two sentences should be highlighted).
4. For each section you identified, use a bullet point list to summarize the key elements you highlighted. For example, if you highlighted ["… from one to six specimens from each of 34 species from the …", this would be the sample size and distribution].
5. Compare your list with your classmates. Edit accordingly.

<u>Questions for [discussion]:</u>

1. How is the discussion of the paper organized? (Hint: look at headers and subheaders).

2. Choose a sub-section of the discussion: how is the information organized? Make sure to address the following elements: summary of the findings of the paper, putting them in the context of the literature, supporting those findings with other data, considering the limitations of the findings, and articulating their significance to the [scientific] community.
3. Answer the question above for a different section.
4. How is each of the elements of a discussion you discussed above communicated to readers? Once again, answer this question for two different subsections/topics of the discussion. Make sure to explicitly go over the structure of the text.
5. Compare your list with your classmates. Edit accordingly.

<u>Questions for [introduction]:</u>

1. Identify the following elements in the introduction you are reading. Note that they are not always presented in the same order as they are below.

    - Background information: This provides the reader with the context and knowledge necessary to understand the study system and the importance of this work by grounding in a big picture (for the study) issue.
    - Problematic / Question(s): This states explicitly what big question or issue the work sets out to explore.
    - Hypothesis (-es): The introduction states (best done explicitly) the hypothesis (-es) tested in the study.
    - Motivation and significance of study: It is important to explain the significance of the work for the [scientific] community at large including our understanding of the study system, big picture questions in [field of research], possible applications, relevant future applications to other systems, etc.
    - Setup of study: The introduction should preview the structure of the rest of the paper and set the stage for the reader by giving an overview of the work accomplished.

2. Compare your work to that of your teammates. Make necessary edits.
3. Answer the following questions:

- How is the introduction of the paper organized? Are the elements described above in a particular order or are they woven together? Give details.
- Are certain elements of the introduction provided to reader in the form of tables or figures? If so, which ones? If not, could some of the information have been provided in such formats? What info specifically?
- Compare your answers to the questions above with your teammates. Edit accordingly.

DRAFTING:

For the [material and methods]: Below is some basic information on a research project that [the instructor] is working on. Use it to draft a mock material and methods section. Do NOT look at the rest of this handout. Note that I am having you focus on just a couple sections of the material and methods section. I am not asking you to understand the details of the research or provide any references (other than those given to you). I simply want you to create a **narrative** of the content (not a full-on material and methods section). I have somewhat organized the information so it would not be overwhelming.

For the [results]: A good results section will be written around high quality figures. The text should explain the entirety of the figure, highlighting the critical points, and provide associated statistical information. Below are two figures from a research project on [topic] that [the instructor] is working on. Use it to draft a mock results section. Do NOT look at the rest of this handout. Note that I am having you focus on just two figures and therefore only part of the entire results section for this paper.

For the [discussion]: A good discussion section will summarize the findings of the paper, put them in the context of the literature, support those findings with additional data, consider the limitations of the findings, and articulate their significance to the scientific community. Below are the text and figures/tables associated with the results section of a paper published by [the instructor]. Use it to draft a mock discussion section. Do NOT look at the rest of this handout.

[For all section except the introduction]: **COMPARING:**

Below is a draft of (a portion of) the text that [the instructor] wrote for this paper. Read the text below and reread your own writing. Answer the following questions:

- What information was your [material and methods, results, or discussion] section lacking (besides details I had not provided you with the info for)?
- Are there any elements missing in the text of [the instructor]?
- What are the critical elements of a [material and methods, results, or discussion] section you can identify in the text below and the paper we looked at together earlier?
- What would you need to do to transform the text you wrote earlier into something like the text below?

[For the introduction]: **REFLECTING:**

1. Let's start the process of writing the introduction for your paper. ON YOUR OWN, take NO MORE THAN 5 MINUTES and jot down a few bullet points for each of the elements of the introduction in the table below. This time limit will force you to focus on the essential elements.

Background information	
Problematic / Question(s)	
Hypothesis (-es)	
Motivation and significance of study	
Setup of study	

2. Compare your table with your teammates. Fill out the table below with the consensus of your group. It will likely be more thorough than the one above because of the time limit I imposed.

Background information	
Problematic / Question(s)	
Hypothesis (-es)	
Motivation and significance of study	
Setup of study	

3. ON YOUR OWN, focus on the Background information. Expand upon each of the bullet points, transforming each of them into two sentences that summarize the key point you want to make. For each set of sentences, provide at least one supporting reference to the literature.
4. ON YOUR OWN, focus on the Motivation and significance of the study. Expand upon each of the bullet points, transforming each of them into two sentences that summarize the key point you want to make. For each set of sentences, provide at least one supporting reference to the literature.
5. AS A GROUP, write below the most up-to-date version of your Problematic / Question(s).
6. AS A GROUP, write below the most up-to-date version of your Hypothesis (-es).
7. AS A GROUP, go over your answers to questions 3 and 4. Combine your answers into two sets of sentences (between 5 and 8 sentences each) and references (a minimum of 3).

Activity 17: Sequential Manuscript Drafts – Activity 17

Notes to instructor:

- The purpose, fit, tasks, deadline, and time commitment of the assignment are provided to students as part of the handouts for the associated agendas, meetings, and tutorials.
- This assignment is iterative with students submitting several versions of the document throughout the CURE, incorporating feedback

from peers and instructor(s) every time:
  - Material and Methods
  - Material and Methods and Figures and Tables
  - Material and Methods, Figures and Tables, and Results
  - Material and Methods, Figures and Tables, Results, and Discussion
  - Material and Methods, Figures and Tables, Results, Discussion, and Introduction
- The expectations are articulated in the rubric for the manuscript, which is presented as part of [**Activity 6**].
- The formatting should be adjusted to mimic the formatting of a suitable publication outlet.

—

Directions: You should upload the [first draft of your material and methods]. **Upload a single document per group.** Make sure to follow these requirements:

- You should upload a doc or docx file.
- Your text should be formatted with a spacing of 1.5 lines with 0 additional spacing between lines.
- Your text should be in Calibri, font size 12 pts.
- Your document should have margins that are uniformly of 1 inch.
- All references to figures and tables you foresee including should be included in square brackets. Example: ... cranial measurements (Fig. 1 [figure showing the cranial measurements measured]).
- All text should be aligned left.
- All primary headers should be all caps (e.g., INTRODUCTION) with no line skipped afterwards.
- All secondary headers should be in bold with title capitalization. (e.g., **Hypotheses and Predictions**)
- All tertiary headers should be underlined with sentence capitalization (e.g., Sampling)
- Do not indent paragraphs.
- All sections should end with two skipped lines.

Make sure to include all necessary references in a REFERENCES section at the end of the document. Those references should be formatted according to the requirements of the [relevant scholarly format]. See example below for an article and guidelines linked in the Bibliography assignment: [Provide example here]

Activity 18: Group Contracts – Activity 18

Notes to instructor:

- This group contract is used at the very start of the CURE to set personalized rules for each research group (if the CURE is implemented in a group format).
- This group contract template was developed in part from resources at https://uwaterloo.ca/centre-for-teaching-excellence/teaching-resources/teaching-tips/developing-assignments/group-work/making-group-contracts where several examples of group contracts and templates are provided in addition to other helpful documents.

—

Purpose of this assignment: This assignment help you develop rules for the work of your group throughout the semester.

How does it fit within the entire project? A well-designed and agreed-upon set of rules will facilitate your collaboration, prevent conflicts, and mitigate disagreements.

Tasks required:

- Decide on a team name.
- Complete the handout below by adding commitments to the table using the resources at the end of the document.
- Sign the document once agreed upon.

Deliverable: A completed version of this handout uploaded on [LMS] by the end of class.

Estimated time: Around 30 minutes

Group work or individual work? Group work

Team Name: ____

Date: ________________________________

PARTICIPATION:
COMMUNICATION:
OUT OF CLASS MEETINGS:
CONDUCT:
CONFLICT AND RESOLUTION:

DEADLINES:
DIVISION OF LABOR:

We share the goals, guidelines, and expectations set out above and agree to all of the policies, procedures, and consequences described.

Team Member's Name	Team Member's Signature

You can pick rules from the options below, modify them, or develop your own:

PARTICIPATION:

- Participating fully (in spirit and actuality)
- Giving group members appropriate credit where due.
- Not giving credit where it isn't due

COMMUNICATION:

- Every group member will check the discussion board for the group once a day.
- No "cross talking" is allowed. This means not interrupting when someone else is talking.
- We agree to share our phone numbers with one another to be able to communicate by texts and calls.
- We agree to share our Ohio State emails with one another to be able to communicate by emails.
- Every group member will check their Ohio State email address for project communication once a day.
- We will be setting up a Microsoft team board/Buckeye Box folder/ Google Drive folder/... to share documents. Note that you should invite me to any folder you use to share documents.

OUT OF CLASS MEETINGS:

- All group members will be punctual. Meetings will start five minutes after the agreed start time, and everyone should be there and ready by then.
- We should turn up to all meetings unless it has been agreed beforehand or unless there are unavoidable events such as illness.
- Group members who are avoidably late must: [write out a consequence for being late.]
- All group members will remain in the meeting until (a) all tasks for that meeting are completed, or (b) there is unanimous adjournment.
- All group members will come to the meetings prepared by reading the assigned material and coming with ideas pertaining to the tasks and decisions to be made.
- Roles will be assigned prior to a meeting or, if this is not possible, at the beginning of a meeting. Roles will rotate each meeting.
- Roles will be assigned following the structure of the in-class meetings.

CONDUCT:

- There will be an assimilation period at the end of each meeting to evaluate group mechanics and ensure that all tasks have been completed adequately.
- Each member will take turns listening as well as talking, and active listening will be a strategy for all group discussions.
- Sexist and racist remarks are not acceptable.
- Aggressive and dominating behavior is not acceptable.
- Members agree to treat one another with respect. Respect includes no name-calling. If you don't like an idea, address the idea, not the person (for example, "I don't think that idea will work because…" not "That's stupid").
- The group will actively seek a consensus based on the opinions of every member.
- Participating professionally (i.e., civil discourse; abiding by the rules of academic honesty)
- Meeting responsibilities (i.e., completing assigned tasks on time and to the best of your ability).
- If a member submits plagiarized material and/or cheats, the group

agrees to bring this to Jonathan's attention immediately.
- Taking the consequences of not abiding by the group's rules.

CONFLICT AND RESOLUTION:

- In the event that a group member treats someone inappropriately, she/he/they will [write a consequence].
- Each group member has the right to point out whether any of these rules are being broken.
- The group members will isolate areas of disagreement, and the group will come to a consensus. If no consensus is reached, the moderator of the meeting will decide the amount of time for discussion or arbitration before calling a vote. If the vote is a stalemate, the issue will be brought to Jonathan.

DEADLINES:

- Tasks that group members agree to undertake should be completed to the agreed deadline.
- If it looks as though there will be a problem meeting a deadline, the person concerned should seek help from other members of the team in time to avoid a delay.

DIVISION OF LABOR:

- The division of tasks between group members will be agreed upon by a vote.
- All tasks will be identified in writing on the discussion board.

Activity 19: Group Reviews – Activity 19

Notes to instructor:

- This group review framework can be used in association with different milestones of the CURE process. It can be truncated to

enable group reviews at earlier stages of the CURE. This enables the instructor to catch and mitigate problems early on and regularly.
- Consider combining this activity with an informal review of the CURE by the student (and yourself) to engage your own work in the critique process.
- The tasks in the table can be customized to reflect the scope of the work covered by the CURE activities.

—

Purpose of this assignment: This assignment enables you to reflect on your contribution to the project and behavior. It is also meant to enhance your group work and ensure that you work well together as a research team.

How does it fit within the entire project? This short group review gives me an opportunity to review the situation in your group, mitigate any problem, mediate conflicts, and help you achieve the best possible dynamic. Remember that a professional is often called upon to work with a diverse set of colleagues, including some difficult personalities. This is the nature of the workplace and research. Always remember to be respectful and treat others with dignity.

Tasks required: Complete the handout below.

Deliverable: A completed version of this handout uploaded on [LMS] by [due date].

Estimated time: Around 20 minutes

Group work or individual work? Individual work

Step-by-step:

1. Estimate the relative contribution as a percentage (e.g., half the work is 50%) of the work accomplished by yourself as well as your teammate so far. Start by putting the initials of each team member (including yourself) in the first row.

Task	
Developing questions, hypotheses, predictions	
Reading the literature	
Developing the methods (data collection protocol and analyses)	
Implementing the analyses	
Writing the material and methods section of the paper	
Developing the table and figure captions	
Writing the results section	
Interpreting the data	
Writing the discussion section	
Writing the introduction section	
Writing the abstract	
Writing the reference section	
Other:	

2. Please tell me how often you have met since the last group review outside of the class meetings to work on this project? What was the total number of hours?
3. How often would you say you communicate about the project outside of class (through emails, texts, calls, discussion board …)?
4. How many hours did YOU spend on this project since the last group review?
5. Please comment briefly on yourself with regards to the following criteria:

    - Did you come to class sessions or group meetings prepared?
    - How did you prepare?
    - What could you have done differently to be better prepared?
    - Did you complete all of the work you had committed to do?
    - Were you respectful of all of your teammates?
    - What have you done since the last group review to improve your interaction with other members of your team? Did you

meet your own goals expressed in the last review (if applicable)
    - Did you give everyone the opportunity to speak, present arguments, and participate equally in the term project?

6. Please comment briefly on each of your term project partners with regards to the following criteria:

    - Did your classmates come to class sessions or group meetings prepared?
    - Did they do the work they had committed to do on their own?
    - Was your teammate respectful?
    - Did they give you the opportunity to speak, present arguments, and participate equally in the term project?

7. Do you have any violation of the group contract to report?
8. Has your group discussed amending the group contract? If so, provide details.
9. Do you have any other comment or concern you would like to share with me?

Activity 20: How to Analyze Data – Activity 20

Notes to instructor:

- This activity was developed for a CURE in which students were provided two recent papers from the primary literature that represented model papers that investigated similar questions in different study systems.
- Students had already completed two scaffolding activities prior to this one [**Activities 4 and 8**].

—

Purpose of this assignment: Identifying the analyses you will need to test your hypothesis (-es).

How does it fit within the entire project? These analyses will be the test of your hypothesis. Settling on the right analyses will be critical to being able to draw conclusions from your dataset and to contributing meaningfully to research.

Tasks required: Critically read three papers from the primary literature and complete the handout below.

Deliverable: Completed version of this handout uploaded to [LMS] by [deadline].

Estimated time: less than an hour and a half

Group work or individual work? Individual work

Step-by-step: Recall that you have already done some of this work as part of your framework.

Fill out a table for each publication you were given at the start of the semester..

1. Identify the hypothesis (-es) you will be testing in your study:
2. For each hypothesis above, identify the variables you will be using in your analyses:
3. In general terms, what will you need to do with these variables? In other worlds, identify the comparison you will be making. Examples: "We will be comparing variable x between males and females for all species in our sample", "We will be comparing the variable x between all species in our sample", ...
4. What variables do you need to control for?
5. What analyses did the published articles provided to you at the start of the semester employ? Look at the material and methods as well as the figures. Replace [name] with the name of the analysis in the tables Paper 1 and Paper 2 below and complete the first row with the full reference for each of the two "model" papers associated with your project.
6. Identify a paper from the primary literature that has undertaken an analysis you are interested in running on your own data and complete the table for Paper 3 below. Think back to your bibliography activity for help.
7. How do your data differ from those published in the papers above?
8. How do your questions/hypotheses differ from those tested in the papers above?
9. Fill out the table just below for YOUR study. Note that the number of analyses is not fixed. You may have one, two, three, four ... The research should dictate this. Add rows to the table as necessary.

Analysis 1: [name]	Dependent variable(s):	
	Independent variable(s):	
	Control variable(s):	
	Goal of the analysis	
	Conclusion drawn from analysis:	

Analysis 2: [name]	Dependent variable(s):	
	Independent variable(s):	
	Control variable(s):	
	Goal of the analysis	
	Conclusion drawn from analysis:	

10. How does your proposed analytical protocol differ from those previously used in the primary literature? Why?
11. What are some possible obstacles or challenges to the analyses you propose to run?

<table>
<tr><td colspan="3">Paper 1:</td></tr>
<tr><td>Hypothesis:</td><td colspan="2"></td></tr>
<tr><td rowspan="5">Analysis 1: [name]</td><td>Dependent variable(s):</td><td></td></tr>
<tr><td>Independent variable(s):</td><td></td></tr>
<tr><td>Control variable(s):</td><td></td></tr>
<tr><td>Goal of the analysis</td><td></td></tr>
<tr><td>Conclusion drawn from analysis:</td><td></td></tr>
<tr><td rowspan="5">Analysis 2: [name]</td><td>Dependent variable(s):</td><td></td></tr>
<tr><td>Independent variable(s):</td><td></td></tr>
<tr><td>Control variable(s):</td><td></td></tr>
<tr><td>Goal of the analysis</td><td></td></tr>
<tr><td>Conclusion drawn from analysis:</td><td></td></tr>
</table>

<table>
<tr><td colspan="3">Paper 2:</td></tr>
<tr><td>Hypothesis:</td><td colspan="2"></td></tr>
<tr><td rowspan="5">Analysis 1: [name]</td><td>Dependent variable(s):</td><td></td></tr>
<tr><td>Independent variable(s):</td><td></td></tr>
<tr><td>Control variable(s):</td><td></td></tr>
<tr><td>Goal of the analysis</td><td></td></tr>
<tr><td>Conclusion drawn from analysis:</td><td></td></tr>
<tr><td rowspan="5">Analysis 2: [name]</td><td>Dependent variable(s):</td><td></td></tr>
<tr><td>Independent variable(s):</td><td></td></tr>
<tr><td>Control variable(s):</td><td></td></tr>
<tr><td>Goal of the analysis</td><td></td></tr>
<tr><td>Conclusion drawn from analysis:</td><td></td></tr>
</table>

<table>
<tr><td colspan="3">Paper 3:</td></tr>
<tr><td>Hypothesis:</td><td colspan="2"></td></tr>
<tr><td rowspan="5">Analysis 1: [name]</td><td>Dependent variable(s):</td><td></td></tr>
<tr><td>Independent variable(s):</td><td></td></tr>
<tr><td>Control variable(s):</td><td></td></tr>
<tr><td>Goal of the analysis</td><td></td></tr>
<tr><td>Conclusion drawn from analysis:</td><td></td></tr>
<tr><td rowspan="5">Analysis 2: [name]</td><td>Dependent variable(s):</td><td></td></tr>
<tr><td>Independent variable(s):</td><td></td></tr>
<tr><td>Control variable(s):</td><td></td></tr>
<tr><td>Goal of the analysis</td><td></td></tr>
<tr><td>Conclusion drawn from analysis:</td><td></td></tr>
</table>

Activity 21: Condensing the Primary Literature – Activity 21

Note to instructor:

- This activity can be used to prepare students to write the discussion section of a manuscript.

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Purpose of this assignment: The goal of this assignment is to help you summarize the current knowledge and arguments in the published literature.

How does it fit within the entire project? This activity will help you write your discussion section. It is important to put your work in the context of the existing literature in that part of the paper.

Tasks required: Complete the handout below.

Deliverable: Completed version of this handout uploaded to [LMS] by [deadline].

Estimated time: Less than two hours

Group work or individual work? Individual work with some group coordination.

Step-by-step: Note that the lengths of the different writing assignments of this exercise are important to that exercise. Please adhere to them.

1. Write below the most up-to-date hypotheses you are testing in your project. MAKE SURE to coordinate with your group members (I should see the same set of hypotheses from all group members):
2. List here a minimum of **five** papers that have explored one or more of these hypotheses in your study system. Think of "study system" broadly including [provide details here appropriate for the field of research and questions explored]. Think back to your bibliography and your framework assignments for help. Format the references according to the [journal format the students will follow for their deliverable].
3. For each of those five (or more) papers, identify in **four** sentences (no less, be thorough) the main conclusions of the paper with regards to the topic/hypothesis of interest to you.

    - Paper 1:
    - Paper 2:
    - Paper 3:
    - Paper 4:
    - Paper 5:

4. Bring together the information from those different papers. Write a paragraph that is **twenty** sentences long and summarizes the conclusions of all five papers. You should NOT merely copy-paste the sentences from the previous question but instead make sure that you are comparing and contrasting the different conclusions. Think about the following questions: Are different authors/datasets in agreement? On the contrary, are there differing findings? Are there particular patterns? Some exceptions/outliers? What is the strength of the relationships that have been recovered in prior analyses? Make sure that you cite the papers appropriately throughout your paragraph.
5. Condense this twenty-sentence paragraph to a paragraph that is only **ten** sentences long. Focus on the most important points. Get to the gist of the patterns. Make sure that you cite the papers appropriately throughout your paragraph.
6. Go back to your hypotheses. For each of them, provide a **two**-sentence summary of the position of the literature on the issue.
7. For each of your hypotheses, provide a **two**-sentence summary of YOUR relevant findings. MAKE SURE to coordinate with your group members (I should see the same set of conclusions from all group members).

Activity 22: Arguments and Counterarguments – Activity 22

Note to instructor:

- The appropriate number of tables should be added to the template below

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Purpose of this assignment: The goal of this assignment is to help you build your discussion section with an eye towards contrasting your findings to those from the literature.

How does it fit within the entire project? This activity will help you write your discussion section. It is important to put your work in the context of the existing literature in that part of the paper.

Tasks required: Complete the handout below.

Deliverable: Completed version of this handout uploaded to [LMS] by [deadline].

Estimated time: About one hour

Group work or individual work? Group work.

Step-by-step: Note that for the first four of the following questions, I have provided an example in the first table based on [provide the reference for a relevant example paper], a paper available on [LMS].

1. List in the top left cell of each table on the next pages the main findings of your work. Place one finding per cell.
2. For each of those findings, identify the associated argument. This could be an explanation for the pattern, an implication of this pattern, an association between this pattern and another one of your findings or a prior finding.
3. Add to the table a co-argument. This is a supporting line of evidence for your argument. It could be a similar argument made in a different study system, a response to an obvious weakness of the argument, another finding of yours (or from the literature) that is consistent with your interpretation, etc.
4. Finally, add to the table at least one (could be more) counterargument. This is a skeptical response to your interpretation, a caveat, a "hole" in your reasoning, another line of evidence that does not support the explanation proposed, etc.
5. For each of those cells, make sure to identify the relevant sources to cite (a figure or table of yours, a statistical test result [e.g., regression, p value, AIC score, Akaike weight], a paper from the literature, etc.)

Finding	**Argument**
[provided by instructor]	[provided by instructor]
Co-argument	**Counterargument**
[provided by instructor]	[provided by instructor]

Finding	**Ar**
Co-argument	**Count**

Activity 23: Responding to Counterarguments – Activity 23

Note to instructor:

- The appropriate number of tables should be added to the template below

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Purpose of this assignment: The goal of this assignment is to help you build your discussion section with an eye towards building the argument of your discussion.

How does it fit within the entire project? This activity will help you write your discussion section. It is important to put your work in the context of the existing literature in that part of the paper.

Tasks required: Complete the handout below.

Deliverable: Completed version of this handout uploaded to [LMS] by [deadline].

Estimated time: About one hour

Group work or individual work? Individual work.

Step-by-step:

1. Go back to the "Arguments and Counterarguments" assignment you have already completed. Copy-paste into the tables on the next pages the information from the tables of that activity. In other words, replace the gray areas.
2. Write a response to the Counterargument in the bottom row for each table. Note that this is not necessarily a rejection of the counterargument. You may use this to revise your original interpretation. The statement you write in the last row of the table should be a statement supporting your argument AND explaining away the purported weakness/caveat/issue/… OR a statement supporting your argument AND incorporating/considering/explaining the weakness/caveat/issue/… OR a revised explanation that takes into account the counterargument.

3. Is there a counterargument to the response? Do you need to provide a new explanation for the new counterargument? Make sure to consider this for EVERY single one of your finding/argument/counterargument sets.

Finding	**Argument**
Co-argument	**Counterargument**
Response to counterargument	

Activity 24: Closing – Activity 24

Note to instructor:

- The appropriate number of tables should be added to the template below

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Purpose of this assignment: The goal of this assignment is to help you identify the next steps in the research avenue you have been exploring with this project.

How does it fit within the entire project? This activity will help you write your discussion section. It is important to explicitly articulate the next steps in the research, whether or not you will be investigating them yourself.

Tasks required: Complete the handout below.

Deliverable: Completed version of this handout uploaded to [LMS] by [deadline].

Estimated time: Less than two hours

Group work or individual work? Individual work with some group coordination.

Step-by-step: Note that all of the answers to the questions below should be entered in the table provided.

1. Identify below the hypotheses you tested in your project (one per table) as well as the questions you set out to answer (go back to [your framework and associated assignments as necessary]). MAKE SURE to coordinate with your group members (I should see the same set of hypotheses and questions from all group members).
2. For each of them, answer the following questions:
    - What questions are still unanswered at the end of your research project?
    - Are there specific datasets/variables/etc. that should be studied to shed further light on the questions you explored?
    - Are there analyses you now wish you would have run?
    - Are there outliers that should be further analyzed?
    - Are there analyses or studies that your work enables?
    - Could your results be combined with some additional information to provide a new perspective?
    - Consider the application of your work to other study systems. What is the feasibility of such work and what can be gained from it? Do you have predictions?

Hypothesis/ Question	
a. Unanswered questions	
b. Specific things to study	
c. Analyses to run	
d. Outliers	
e. Future analyses	
f. New perspective	
g. Other study systems	

Activity 25: Understanding and Designing Figures – Activity 25

Notes to instructor:

- The number of figures in the first part of the activity can easily be modified.
- One can also ask students to bring figures from their readings to share with others in the class for the first part of the activity.
- It is useful to present information for the datasets that is similar to the work the students are undertaking in the CURE themselves. Information/Associated figures can be drawn from the research of the instructor or published papers for the second and third parts of the activity.

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Purpose of this assignment: The goal of this assignment is to help you develop an eye for the figures that will help represent your data and analyses the best.

How does it fit within the entire project? Figures are a critical component of a research paper. As you go through this activity you should consistently ask yourselves: Can my reader grasp the gist of my work by simply looking at my figures and tables?

Tasks required: Complete the activity below.

Deliverable: Completed version of this handout uploaded to [LMS] by [deadline].

Estimated time: about one hour and a half.

Group work or individual work? Individual work and group discussion during class.

Our work today will be divided into three steps:

- 1) Looking at and analyzing a selection of figures from published papers.
- 2) Designing a couple figures for some projects that [the instructor] is working on.
- 3) Compare your design to the figures developed by [the instructor].

ANALYZING PUBLISHED FIGURES:

We will be looking at figures from a selection of papers analyzing [topics of the CURE].

1. Look at the eight figures I have selected presented below. For each of them, categorize the figure or elements of the figure according to the following crude categories: [insert here a list of categories of graphical representations relevant to the CURE. Examples include bivariate regression plot, boxplot, dendrogram, structural formula, phylogenetic tree, photographs, network diagram, violin plot, Venn diagram, etc.]
2. For each graph, using YOUR OWN WORDS, describe the data represented. In other words, what does the graph show? [insert here the eight figures along with citations]

DESIGNING FIGURES:

Below is some basic information on a couple research projects that [the instructor] is working on. Use it to design a figure presenting the data. Do NOT look at the following pages of this handout. For each set of data, you should provide the following:

- The type of graph you would use
- The variables that would be graphed (what would be the labels on the axes, legends)
- A rough sketch of what the figure would look like
- A draft caption explaining the figure

[insert here the necessary information]

COMPARING FIGURES:

Below is a set of draft figures for manuscripts that [the instructor] and his students as well as collaborators are working on. Look at the figures and captions provided below. Look again at your own figure and caption designs above. Answer the following questions:

- How do your figure designs differ from the figures produced by [the instructor] and his colleagues?
- What are the characteristics of a good figure caption?

[insert here the figures and their captions]

Activity 26: Reflection workbook – Activity 26

Notes to instructor:

- Several of the questions used in this handout were derived from the framework provided by the Association of American College and Universities VALUE rubrics (https://www.aacu.org/value-rubrics).
- Others are taken or modified from the Framework for Information Literacy for Higher Education developed by the Association of College & Research Libraries: https://www.ala.org/acrl/standards/ilframework
- The exact structure of the workbook should be adapted to the structure of the whole CURE. Because it is meant to be discipline/topic-relevant, it should also be modified to better match the specific CURE implemented.

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Purpose of this assignment: The goal of this workbook is to help you reflect upon your writing and research process, help you self-correct, and most importantly help you develop metacognition: an understanding of your own thought processes. The work you put into this workbook will directly improve your research manuscript.

How does it fit within the entire project? This workbook is critical to helping you throughout the semester. It is critical that you complete it when prompted (see below) so that you can use the reflection to improve each section of your project and, eventually, your research manuscript.

Tasks required: Answer the questions below.

Estimated time: An average of 30 to 45 minutes per section.

Deliverable: Complete the different sections of this reflection workbook below according to the timeline provided. The workbook will be graded on the following dates: [dues dates]

Group work or individual work? Individual work

<u>Framework I</u>

Complete between [xxx] and [xxx]

Purpose: The goal of these questions is to help you develop the framework of your project and reflect on your mind mapping exercise.

Questions 1a and 1b: What do you already know about the topic? What do you need to explore further? Be specific.

Question 2: What is the scope of your research? Be specific.

Question 3: What is the existing knowledge or assumptions about your topic? List several specific elements.

<u>Framework II</u>

Complete between [xxx] and [xxx]

Purpose: The goal of these questions is to help you revise the framework you developed during your framework class meeting and articulate the significance of your work.

Question 1: What is the dialogue or debate surrounding your topic? Think about any disagreement and any outstanding question in particular.

Question 2: Have you sought a variety of perspectives? Have you consulted the [xxx], [xxx], and [xxx] literature?

Question 3: For whom is this project being developed? Provide details on the audience of your final manuscript. What stakeholders are likely to be interested in this work? How will your work be communicated to its audience? Think about format of the paper and its sections.

Question 4: What will your research enable (future analyses and investigations)? Be specific about possible follow up studies.

Material and Methods I

Complete between [xxx] and [xxx]

Purpose: The goal of these questions is to help you select your dataset, develop the approach you will take to analyzing those data, and reflect on your documented problem solutions exercise.

Question 1: Who else has done such analyses? Provide specific citations so you can consult them later.

Question 2: What analyses have published articles employed? Look at the material and methods as well as the figures. (Look at your Bibliography assignment for help)

Question 3: What other analyses would be helpful as follow-up analyses?

Data Collection I

Complete between [xxx] and [xxx]

Purpose: The goal of these questions is to help you plan your data collection.

Question 1: What data (that you need) already exist? Have any data already be published in the peer-reviewed literature? Make sure to check supplementary information files. What about as part of online databases? Insert below the references for all data sources and the details of the sample size / nature of the sample they include.

Question 2: Based on your reading of the literature, your questions/ hypotheses, and your answer to question 1, what is the nature and size of the sample you need to collect yourself? Be as specific as possible in describing your data collection goals. Include the nature of the variables and their source.

Question 3: Describe the method by which you will be collecting these data. Essentially, write a DETAILED protocol for your data collection. Include all necessary supplies and equipment.

Data Collection II

Complete between [xxx] and [xxx]

Purpose: The goal of these questions is to help you plan your data collection.

Question 1: Collect data from a small subsample of your expected dataset. Make a note of the amount of time involved in the process. Based on this information, calculate the total amount of time that will be involved in the data collection process. Schedule this effort now to meet the deadline(s) of your project.

Question 2: Did you encounter any problem with data collection? Does the protocol you wrote for question 3 (Data Collection I) need to be revised based on your pilot data collection?

Data Analysis

Complete between [xxx] and [xxx]

Purpose: The goal of these questions is to help you reflect upon your data collection and initiate your data analysis.

Question 1: What is your final sample size? Are there data that could not be collected after all? Are all analyses that you had planned feasible given the actual data collected?

Question 2: What software programs or technological support will you need to analyze data? Which analyses will require technical assistance?

Question 3: Do your data need to be formatted in a particular way or a particular file format to be visualized/analyzed? Is any data manipulation necessary prior to analyses?

Question 4: List all analyses in the order that they are going to be undertaken associating the necessary data every time.

Material and Methods II

Complete between [xxx] and [xxx]

Purpose: The goal of these questions is to help you outline your material and methods section.

Question 1: What are the different subsections of a material and method section in similar studies? Make a bullet-point list for a few (two or three) different publications.

Question 2: Think about the following "classic" elements of a material and methods section. For each of them, provide a one sentence explanation of what you would include in your Material and Methods section to cover it.

Sampling (size/nature)

Data acquisition/sources

Data manipulation (standardization/normalization)

Analyses (software/nature/parameters)

<u>Figures and Tables I</u>

Complete between [xxx] and [xxx]

Purpose: The goal of these questions is to help you design the figures that will be part of your paper.

Question 1: What is the nature of the data you will be presenting to your readers? How many figures/tables will you need to represent these data? Make a numbered list of the figures/tables in your paper and the data they will represent.

Question 2: Based on the exercise we did in class and your readings, what broad category of figures would effectively represent these data?

<u>Figures and Tables II</u>

Complete between [xxx] and [xxx]

Purpose: The goal of these questions is to help you refine your figures for the paper.

Question 1: Pick a published article that published a similar analysis to the one you are proposing for your own paper. Observe carefully the corresponding figure and compare it to your proposed figure (in Graph Predictions activity). How do the two differ? Provide the complete reference for the paper selected as part of your answer and upload a PDF of it on the shared folder. You should do this for each figure included in your project. This may mean that you will have to select more than one published paper. Use the boxes below as appropriate.

Question 2a: As you read the results section of the published papers you selected for *Question 1*, what information is provided by the authors in the form of tables? Is all of this information provided in one of your tables? Make sure to check references to supplementary information/tables.

Question 2b: As you read the results section of the published papers you selected for *Question 1*, what information do you find yourself wondering about or do you wish was provided but is not? Is all of this information provided in one of your tables?

<u>Results I</u>

Complete between [xxx] and [xxx]

Purpose: The goal of these questions is to help you outline your results section.

Question 1: Choose two to three relevant papers from the primary literature. Make sure to provide the references for these papers and upload

PDFs of them on the shared folder. How have they organized their results section? Did they go analysis by analysis? Question by question (lumping different analyses addressing the same question for example)? Any other structure?

Question 2: Based on your answers to the first question, outline your own results section. Make sure to include a justification for your decision.

Question 3: Look at the peer-reviews you have received and the comments from Jonathan. How have you modified your material and methods to address these comments? How would you modify the outline you sketched out above to preemptively address some of the structural and conceptual issues raised by reviewers on other sections of your paper?

Results II

Complete between [xxx] and [xxx]

Purpose: The goal of these questions is to help you reflect upon your results and how they shape your paper.

Question 1: How do your results differ from published data? What is novel about your results? Are they surprising or expected (i.e. matching predictions)? Make sure to cite each paper you reference and upload a PDF of that paper in the shard folder.

Question 2: Result sections must always reference relevant information including relevant statistical test results, tables of data, figures of the analyses, etc. List below every claim you make in your results section (in an abbreviated fashion) and next to it how you will demonstrate its validity to your reader.

Discussion I

Complete between [xxx] and [xxx]

Purpose: The goal of these questions is to help you bring to the forefront the most critical points of your research for the discussion section of your paper.

Question 1: What is the significance of your work in three bullet points? This is NOT a summary of your results but a suite of statements summarizing WHY those results are important (to research, the [scientific] community ...)

Question 2: What point of view might be missing? This may be a point made from the literature that you are not addressing or an obvious alternative hypothesis you do not mention.

<u>Discussion II</u>

Complete between [xxx] and [xxx]

Purpose: The goal of these questions is to help you package your paper as an attractive narrative that guides your readers through the research.

Question 1: How do your findings contribute to your initial hypothesis? Write below your hypothesis and a sentence for your discussion section that explicitly addresses it.

Question 2: What is the next step in this line of inquiry? Do NOT think about simply increasing the sample size. Propose at least two new analyses, questions, or specific expansions of the framework of the project.

<u>Introduction</u>

Complete between [xxx] and [xxx]

Purpose: The goal of these questions is to help you develop the introduction section of your paper.

Question 1: Pick three papers from the primary literature. For each paper, provide the reference and upload a PDF on the shared folder. Detail below the structure of the introduction of each article including the different elements we discussed in class.

Question 2: How does the structure of the different papers differ? Note that I would like you to focus on the organization of the introduction specifically. Are those differences linked to the pitch/approach/structure/nature of the whole paper? Which of the three published studies is your work most similar to? Does your paper represent a hybrid approach instead?