Designing Well-Scoped Undergraduate Research Projects

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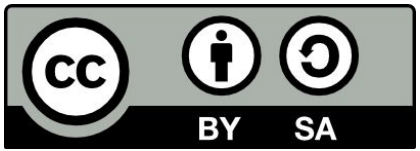
Attribution

This presentation and associated resources were developed for the Computing Research Association's UR2PhD program by Kelly Shaw, Williams College, Department of Computer Science.



Why Advise Undergraduate Researchers?

Benefits

- Additional contributors can help advance your research project
- Inspire and prepare the next generation of researchers
- Instill skills and experience in students for their careers
- Improve your mentoring skills
- Recruit future graduate students

Concerns

- UGrads work more slowly than you
- UGrads require frequent guidance and oversight
- UGrads disappear quickly, abandoning projects before completion
- Students might have mismatched background/skills for a project
- Bad research experiences turn UGrads away from research

Why Advise Undergraduate Researchers?

Planning Unlocks Benefits

Design projects to advance your research

Consider student skills in project design

Create well-scoped projects for given timeframe with frequent, concrete deliverables

Stitch multiple student research experiences together

Two Approaches for Beginner Project Design

Approach 1

Start a new exploratory project related to other research group efforts

Approach 2

Join an existing group project and work on an independent part

Suggestions for New Exploratory Projects

Projects with an initial hypothesis that can be **evaluated empirically** and whose results can lead to new questions to explore

Examples:

- Replicate an existing study and extend it using new data with different characteristics
- Study state of the art software tools on a new data set with different characteristics than the software was originally designed.
- Conduct a human subject study on a specific user interface or tool
- Modify and evaluate existing software to implement a new idea based on a hypothesis
- Analyze a new data set for specific characteristics
- Evaluate a system created for automating a task

Suggestions for Joining an Existing Project

Projects may involve **starting in the middle** of an existing project

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Examples:

- Data collection or generation for existing system or study
  - Perform interviews or administer survey
  - Collect data using existing software on new data inputs
  - Create scripts to generate data
- Analysis of already collected data
  - Write scripts to retrieve and analyze existing data
- Visualization of already collected data
  - Write scripts to retrieve and visualize data
- Implementation of a new instrument
  - Add new functionality to an existing system
  - Create a software implementation of a theoretical algorithm
  - Create a new human subject survey
  - Install new data sets or applications for use with existing system

Both Approaches Involve Subsets of Research Activities

- Search literature for papers
- Read technical papers
- Create instrument
  - Modify existing and/or create new
- Collect or generate data
- Analyze data
- Visualize data

Tips for Research Project Design


Design authentic research projects that matter to your research group


Design projects not on the critical path


Start at a theoretical level students can understand


Draw on skills students already possess or can learn quickly


Design projects with clearly defined, frequent milestones


Keep scope modest and flexible enough to be simplified or extended


Create low-risk projects with a good chance of producing results within given time frame

Tips for Designing the Research Project's Scope

Turn the research problem into explicit, actionable steps

- Identify deliverables or subgoals that are contributions that move the project forward
- Identify steps that require advanced knowledge and plan to do them in advance of project start
- Identify repetitive steps that could be independent subgoals / deliverables
- Identify skills or knowledge to be learned

Tips for Designing the Research Project's Timing

- Create a dependency graph of tasks
  - Including concrete deliverables and skill learning
- Realistically estimate time required for each task
  - Estimate time for each individual repetitive step
- Map tasks to a timeline using a Gantt chart
  - For repetitive steps, indicate that each is its own subgoal
- Adjust deliverables to fit work into time frame
  - Identify and truncate decomposable or repetitive tasks
  - Employ team of student researchers to parallelize repetitive tasks
  - Turn subgoal into a final goal

Example Project

A paper that you just presented implemented a new caching policy on a multiprocessor system. For 2 applications studied, the approach did not perform as well due to network congestion.

Goal: Understand 2 applications' characteristics that caused network congestion.

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Experimental framework:

- Large, complicated C code that simulates system and outputs results to files.
- Applications written in C.

Student info:

- Mostly experienced in Python programming.
- Some basic C programming skills.
- Taken introductory computer organization course.

Project Steps (Broad Strokes)

- Add functionality to simulator to collect data needed to examine network traffic and to output results to files
- Create code to analyze data in output files to identify network congestion
- Collect and analyze network traffic data for 2 applications, mapping network congestion back to the application source code

Key insights

- Student C programming skill not up to simulator modification
- Student will need to learn about networking and specific caching policy
- Student strength is Python programming skill

Project Steps : Pre-internship preparation

- Identification of papers / documentation for student to read
  - Research group orientation tutorials
  - Paper/video describing how to read a technical paper
  - Paper describing the caching policies and showing application results
  - Paper providing basic description of the 2 applications
  - Documentation describing the system and how to run applications on it
  - Background reading about network traffic in multiprocessor systems
- Implementation of data collection in system needed to explain network traffic resulting in congestion and output of data to files
- Creation of single microbenchmark application and generation of its output data
- Identification of Python libraries needed for analyzing output data

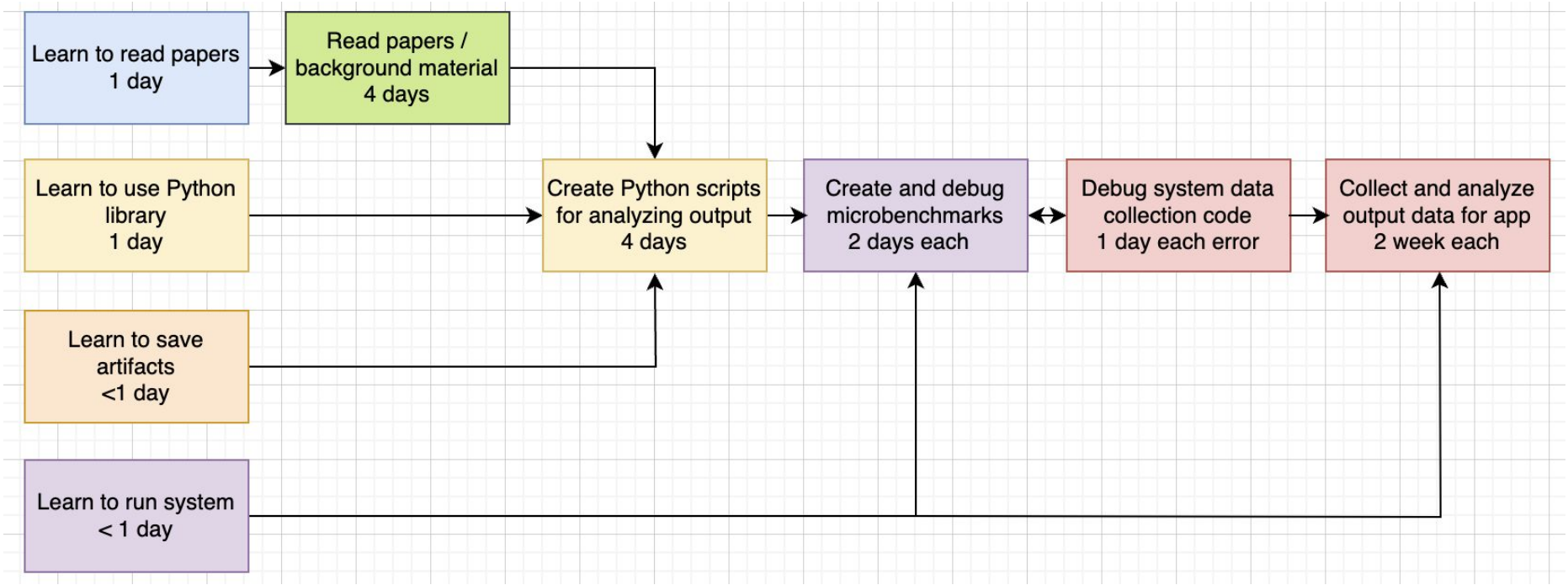
Project Steps for Undergraduate Researcher

- Read/discuss provided literature
- Create Python scripts for analysing network traffic in output files
- Write microbenchmark applications in C to test data collection and analysis code
- Provide feedback on correctness of data collection code (iterate)
- Run and analyze 2 applications' network traffic behavior

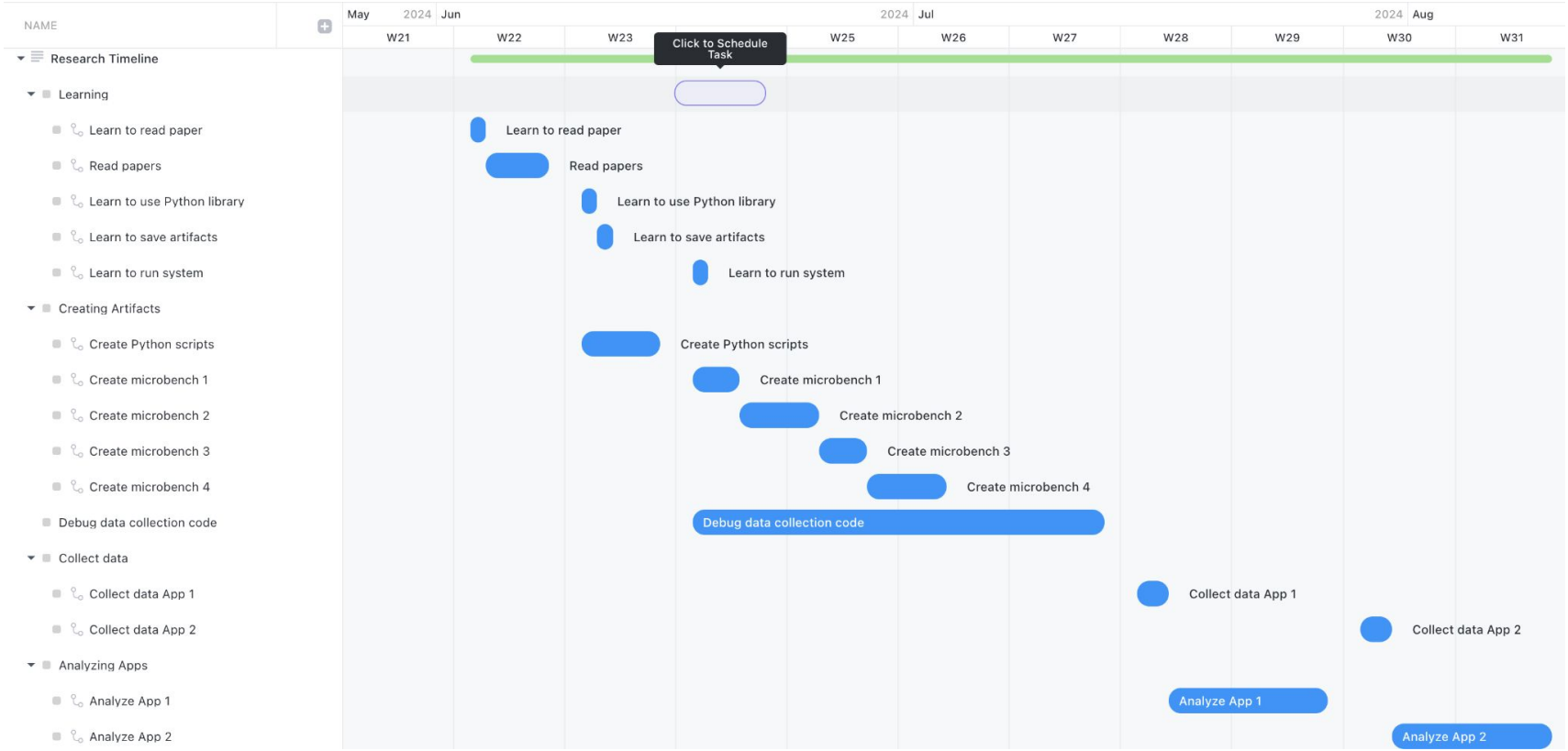
Project Steps for Undergraduate Researcher

- **Learn to read a technical paper**
- Read/discuss provided literature
- **Learn to use git**
- **Learn to save artifacts / data**
- **Learn to use Python libraries for data analysis**
- Create Python scripts for analysing network traffic in output files
- **Learn to run system to generate data**
- Write microbenchmark applications in C to test data collection and analysis code
- Provide feedback on correctness of data collection code (iterate)
- Run and analyze 2 applications' network traffic behavior

Create Dependency Graph With Timing



Create Timeline By Mapping to Gantt Chart



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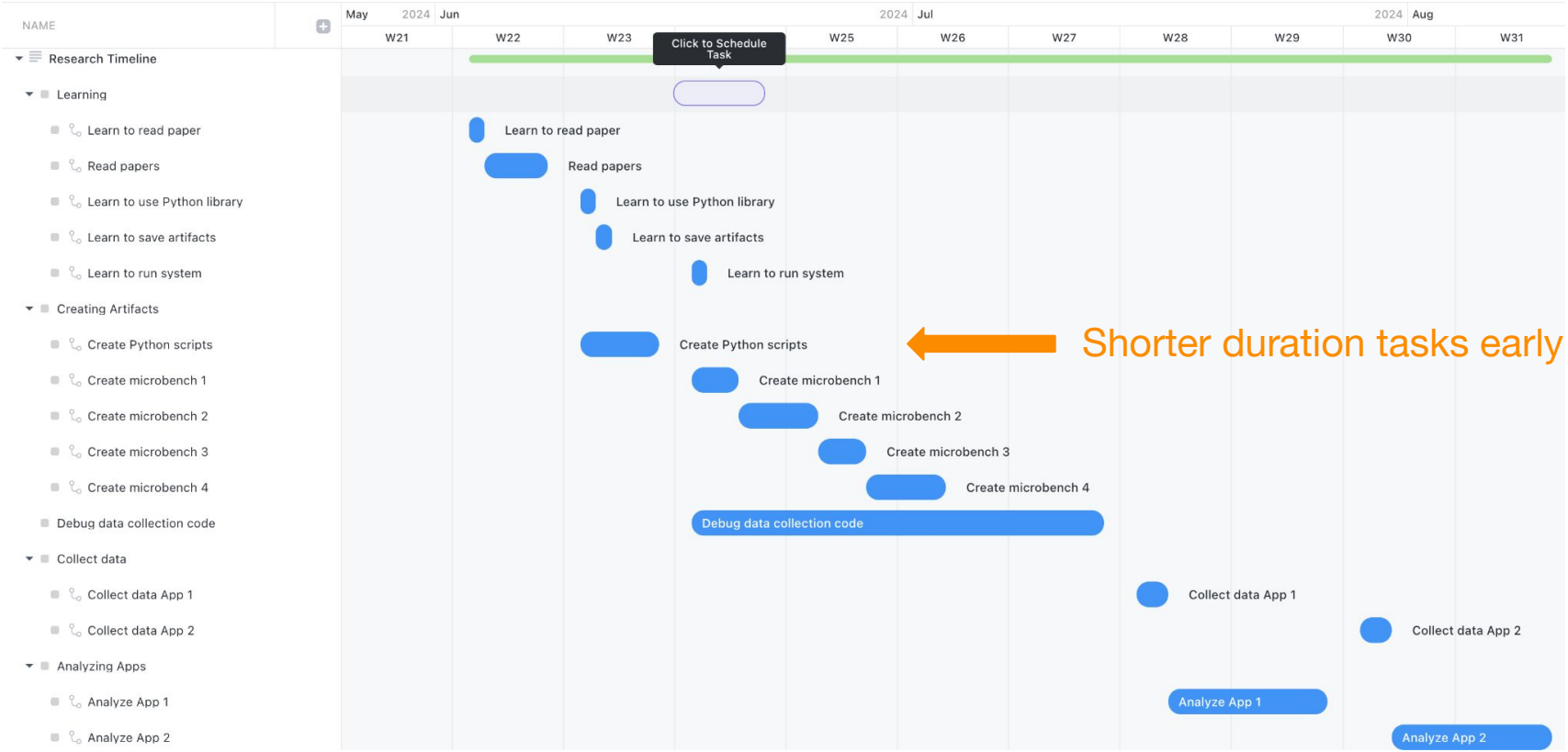

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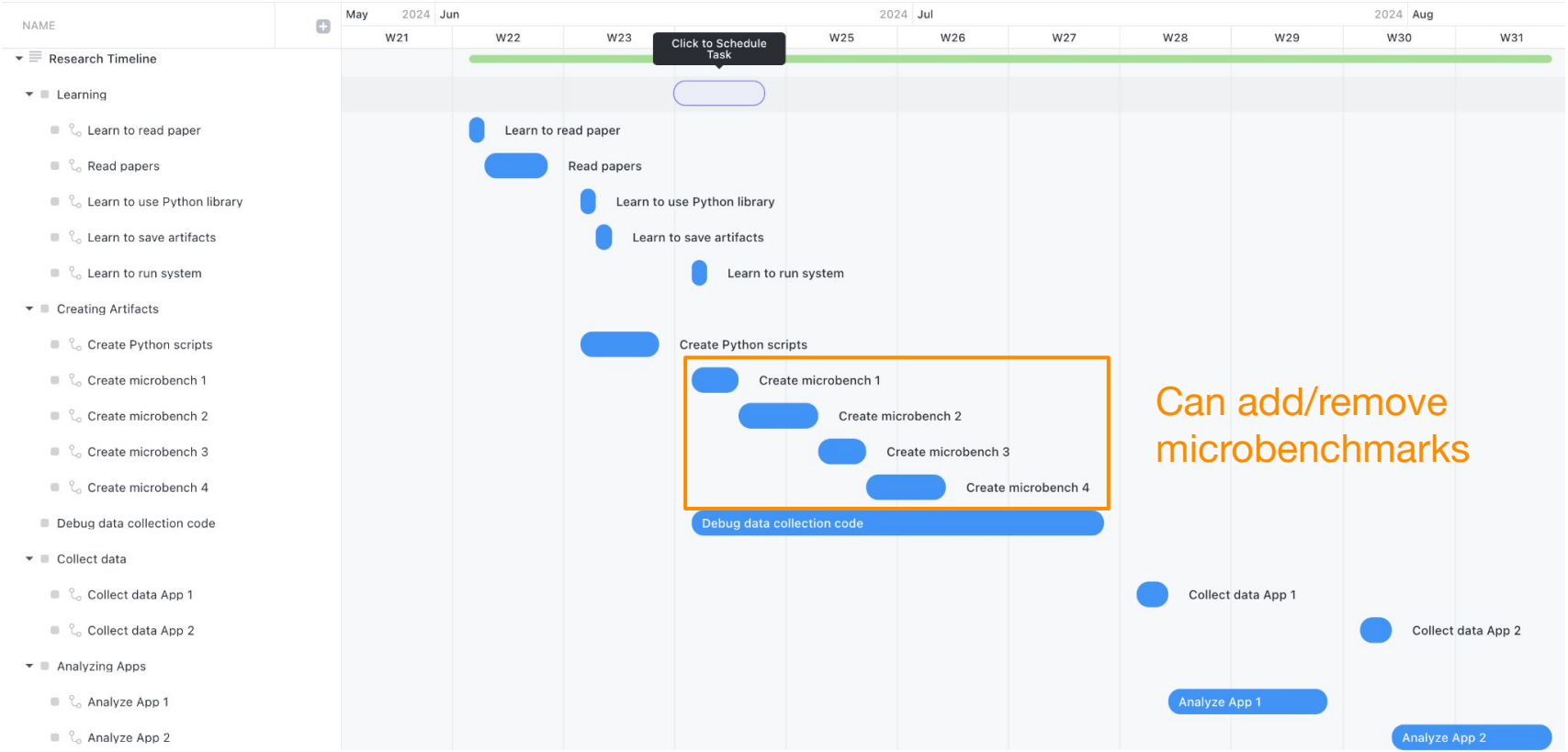

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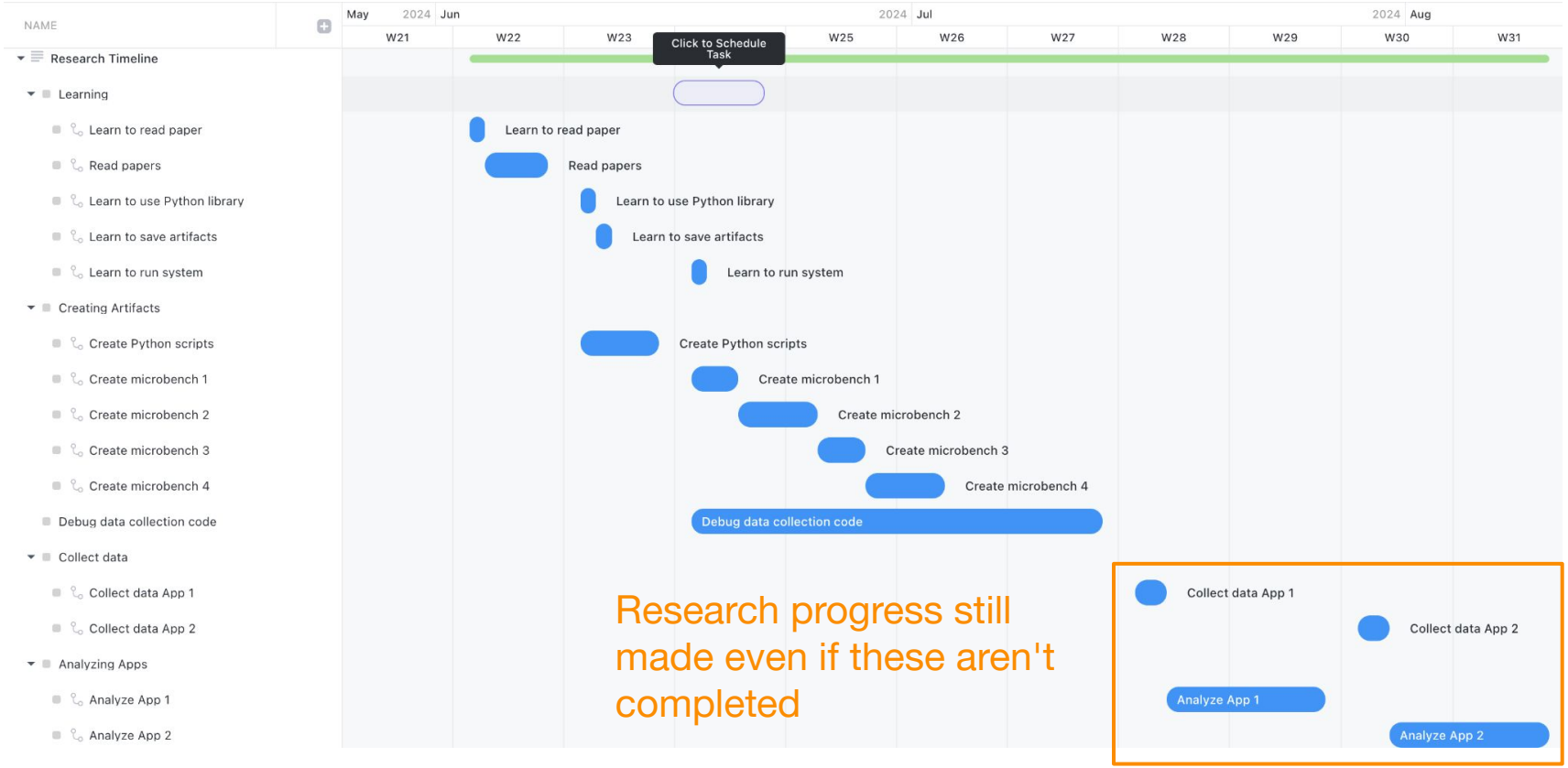


Additional Tips For Constructing a Feasible Timeline

- Identify tasks that contain rabbit holes and plan to proactively guide student through those tasks
- Actively engage with students and give feedback on each deliverable
- For large deliverables, create periodic check ins to give feedback
- Be willing to make a subgoal the final goal if time runs short
- Make sure all deliverables are documented and checked in for future student (at the time of delivery, not the end of the research experience)

Ensuring Project Completion: Stitching

Designing each project with many, small, concrete deliverables enables you to stitch multiple students' work together

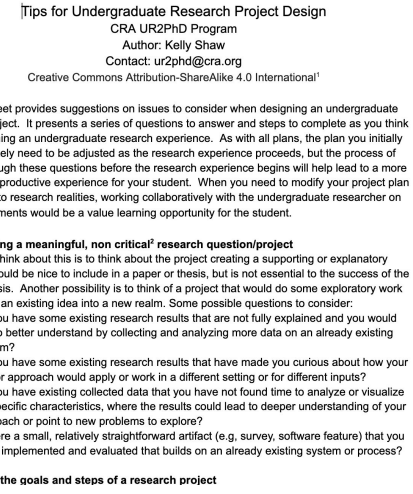
- Same or new student could start at a subgoal that became a final goal for previous undergraduate research experience

Requires in progress sharing, documentation, and review of deliverables, including

- instruments that were created
- collected data and description of method collection
- analyses performed and data used in analysis
- figures generated and data used
- …

Guided Worksheet to Help With Process

- Ideas for brainstorming projects
- Questions guiding
  - Decomposition into deliverables
  - Identification of needed skills / knowledge acquisition
  - Identification of resources researcher will need
- Tips for mapping items to a timeline
- Advice for stitching multiple projects together



Tips for Undergraduate Research Project Design

CRA UR2PhD Program

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This worksheet provides suggestions on issues to consider when designing an undergraduate research project. It presents a series of questions to answer and steps to complete as you think about designing an undergraduate research experience. As with all plans, the plan you initially create will likely need to be adjusted as the research experience proceeds, but the process of thinking through these questions before the research experience begins will help lead to a more positive and productive experience for your student. When you need to modify your project plan in response to research realities, working collaboratively with the undergraduate researcher on those adjustments would be a value learning opportunity for the student.

Brainstorming a meaningful, non critical[2] research question/project

One way to think about this is to think about the project creating a supporting or explanatory figure that would be nice to include in a paper or thesis, but is not essential to the success of the paper or thesis. Another possibility is to think of a project that would do some exploratory work that extends an existing idea into a new realm. Some possible questions to consider:

- Do you have some existing research results that are not fully explained and you would like to better understand by collecting and analyzing more data on an already existing system?
- Do you have some existing research results that have made you curious about how your tool or approach would apply or work in a different setting or for different inputs?
- Do you have existing collected data that you have not found time to analyze or visualize for specific characteristics, where the results could lead to deeper understanding of your approach or point to new problems to explore?
- Is there a small, relatively straightforward artifact (e.g, survey, software feature) that you need implemented and evaluated that builds on an already existing system or process?

Delineating the goals and steps of a research project

Guided Worksheet to Help With Process

- Ideas for brainstorming projects
- Questions guiding
  - Decomposition into deliverables
  - Identification of needed skills / knowledge acquisition
  - Identification of resources researcher will need
- Tips for mapping items to a timeline
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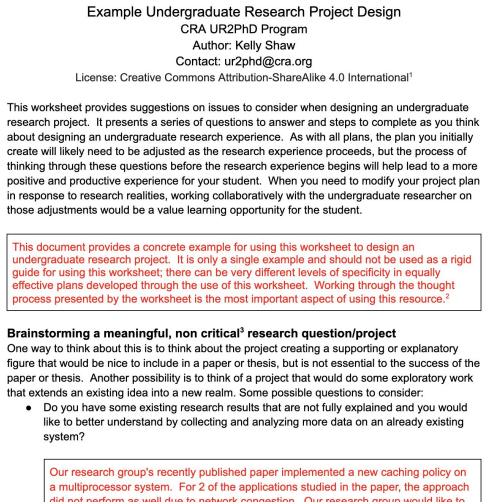
Also available: Completed worksheet using example from this presentation



Example Undergraduate Research Project Design

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This document provides a concrete example for using this worksheet to design an undergraduate research project. It is only a single example and should not be used as a rigid guide for using this worksheet; there can be very different levels of specificity in equally effective plans developed through the use of this worksheet. Working through the thought process presented by the worksheet is the most important aspect of using this resource.[2]

Brainstorming a meaningful, non critical[3] research question/project

One way to think about this is to think about the project creating a supporting or explanatory figure that would be nice to include in a paper or thesis, but is not essential to the success of the paper or thesis. Another possibility is to think of a project that would do some exploratory work that extends an existing idea into a new realm. Some possible questions to consider:

- Do you have some existing research results that are not fully explained and you would like to better understand by collecting and analyzing more data on an already existing system?

Our research group's recently published paper implemented a new caching policy on a multiprocessor system. For 2 of the applications studied in the paper, the approach did not perform as well due to network congestion. Our research group would like to

Quick Tips for Mentoring Undergraduates

- Give students frequent and early wins
- Help students learn when to ask for help
- Help students develop resilience to failure and understand that research is open-ended
- Work with students to adapt timeline and goals as research unfolds
- Consider working with groups of students
- Consider who else in your lab can provide support to students
- Set expectations, including for meetings and communication
- Get to know students as multifaceted people

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UR 2 PhD

Undergraduate Research to PhD Mentoring

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An 11-session course that provides mentors with the tools they need to cultivate strong, effective, and productive environments.

To be eligible for the course, students must:

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- Be actively engaged in mentoring a group of undergraduate researchers

Priority will be given to mentors of participants in the undergraduate research methods course.

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- Identify a research team of 2-4 undergraduates and a mentor
- Identify a research project

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