A CURE for Radar Meteorology: Piloting the Course-Based Undergraduate Research Experience Format at Purdue University

Robin L. Tanamachi[1]

[1] *Department of Earth, Atmospheric, and Planetary Sciences, Purdue University, West Lafayette, Indiana*

ABSTRACT: We present the first known example of a CURE in Radar Meteorology. In the CURE format, which is widely used in the field of biology, students collaborate as a research team on an authentic research project. This format stands in contrast to the "canned" exercises more typical of lab-based meteorology courses. In this pilot CURE at Purdue University, students batch-processed one year's worth of observations from the X-band Teaching and Research Radar (XTRRA) into quantitative precipitation estimates (QPEs), then validated them using observations from a local network of rain gauges. Results of this QPE project are reported elsewhere; this presentation focuses exclusively on the CURE framework and its potential use in lab-based atmospheric science courses.

Students' satisfaction with this course experience was assessed using pre- and post-course surveys. Students reported that they enjoyed working collaboratively as a team, rather than competitively, for credit. The author will share lessons learned in the deployment of the CURE format. Considerable preparation is required. It is recommended that this course be deployed in upper division settings where students have well-developed task management and technical skills. Where class participants may have mixed skill levels, peer mentoring can help elevate those who are less experienced in research.

1. Introduction to the CURE format

Experiential learning, defined by Kolb (2015) as "the process whereby knowledge is created through the transformation of experience," is indispensable in all spheres of science. In postsecondary atmospheric science, experiential learning commonly takes the form of an apprenticeship-style undergraduate research experience (URE), in which a single student and mentor (e.g., a professor or instructor) work together on a project. Such UREs can be highly impactful to the student (National Academies of Sciences, Engineering, and Medicine et al. 2017), as the aim is to enculturate the student in a scientific discipline (Hunter et al. 2007). However, for the mentor, such UREs are time-consuming, and mentors may only have time to provide a limited number of UREs each term. This supply limitation may create inequities in URE access, advantaging those students who know how to find UREs and already possess desired relevant skills (field experience, coding, technical writing) (Kuh 2008; Massey et al. 2022; Greenman et al. 2022). This condition exemplifies the "hidden curriculum" problem in undergraduate STEM (Cooper et al. 2021). Additionally, these apprenticeship-style UREs may produce limited professional benefit to the mentor. UREs seldom result in refereed publications, which are a heavily weighted promotion metric in many lines of work, particularly tenure-track professorship.

The Course-Based Undergraduate Research Experience (CURE; Auchincloss et al. 2014; Corwin et al. 2015) may be a feasible option in atmospheric science instruction. The CURE is a course format originally developed in biology education, in which an instructor and an entire classroom of learners function as a research team working on an authentic research activity. The research activity must be *cognitively* authentic (Herrington and Herrington 2007); in other words, the activity should accurately reflect the way the knowledge and skills will be used outside the classroom. Moreover, the CURE format requires that the problem that learners tackle is one of current interest to the scientific community, with the result not necessarily known in advance. In this way, the CURE is distinct from a "canned" laboratory exercise. For example, the instructor may guide a classroom of students in teams as they parallel-process subsets of a larger data set. Each team's findings are novel, and contribute to the overall success of the group project. The instructor evaluates learners' success in authentically applying their knowledge and skills to this new problem, thereby keeping learners in their zone of proximal development (Vygotsky 1980).

The CURE format has several possible advantages over the traditional, apprentice-style URE. First, by having the class function as a research team instead of individuals, the CURE format more closely emulates a work environment that the learner may encounter in future employment settings such as graduate school, operational settings (e.g. NWS), or the private sector. Second, because the CURE involves an entire classroom full of students at a time, the mentor is able to collectively work with a greater number of students. Third, equity is implicit in the course format. Where students may come into the CURE with mixed levels of knowledge and skills, the CURE makes for a friendly, collaborative (rather than competitive) environment in which students are actively encouraged to share

Corresponding author: Robin L. Tanamachi, rtanamachi@purdue.edu

expertise with one another. This structure "levels the playing field" for all students by the end of the course, and takes some of the mentoring burden off the instructor.

Fourth, CUREs are naturally conducive to peer mentoring, much as in a research laboratory setting. Lastly, CUREs are distinct from Research Experiences for Undergraduates (REUs) in that they occur at the students' home institution, with the instructor serving in the role of mentor-expert.

The CURE represents a significant paradigm shift in teaching, because the focus is on the *process* of research rather than on coming up with a "correct" answer. Accordingly, the learning outcomes may, at first, seem nebulous or uncomfortable to some students. It is imperative that the instructor provides clear milestones and guidelines for what constitutes a passing grade in a CURE. Clear rubrics are a straightforward way to accomplish this.

2. The Purdue radar meteorology CURE

We present the first known example of a CURE in radar meteorology, piloted at Purdue University in Spring 2022. At Purdue, Radar Meteorology (EAPS 52300) is an upper-division elective course. The 2022 cohort consisted of 20 students, ranging from second-year undergraduates to graduate students. Accordingly, a wide variety of knowledge and skill levels were in evident in pre-course knowledge and skill inventories.

Students were informed in advance that the course would be centered around a research project. Over the semester, students were introduced to the basic principles of radar meteorology using a mixture of textbook readings, laboratory exercises, and live demonstrations. Each of these components served double-duty to fulfill stated learning objectives as well as to create a training foundation for the CURE project.

In the CURE project, students reprocessed one years' worth of archived data from the X-band Teaching and Research Radar (XTRRA), near Purdue's campus, to produce quantitative precipitation estimates (QPEs) within a 50-km radius. Four different polarimetric rain rate relations were used to generate the QPEs. The QPEs were then compared to archived rain gauge measurements from the Wabash Heartland Innovation Network mesonet.

From the project description, the reader can surmise that a great deal of coordination and planning was required for this project to be successful. Students used a LINUX computing cluster specifically dedicated to courses (called Scholar) to run Python scripts in a custom Python environment. The instructor prepared Jupyter notebooks demonstrating what each block of Python code was doing and requiring the students to explain what was happening, so that students did not treat the scripts they were asked to run as a "black box." As processing proceeded, some of the more programming-savvy students suggested code changes that made scripts run more efficiently and with fewer interruptions, accelerating the pace of the project.

Students used Slack as a collaboration tool for the CURE project. The Slack workspace allowed students to post questions and request advice from one another and the instructor. The Slack workspace, along with other collaborative tools like a progress spreadsheet, functioned as a collective notebook for the project. The group worked as a research team, with the students helping answer one anothers' questions, debugging code, and deciphering the meaning of numerical output. Some students reported this was the first time they had participated in such a collaborative, rather than competitive, research activity. This enhanced relatedness among the students was meant to serve as a strong intrinsic motivator (Deci and Ryan 2000; Levesque-Bristol 2021). The instructor assigned occasional reflective journaling exercises, to gauge students' grasp of the project goals and their perception of its value.

Two students volunteered as peer mentors or "learning assistants" (as opposed to teaching assistants). These two students received additional credit for this role; in return, they had increased responsibility to respond to student questions and to work with them to overcome obstacles, appealing to the instructor when necessary.

From a scientific perspective, the results of the QPE comparison to the rain gauge data were suboptimal, and efforts to mitigate them are reported elsewhere in this conference. As a result, publication of these results has proven challenging. Nonetheless, students reported high satisifaction with many aspects of the CURE, as detailed in the next section.

3. Pre- and post-course surveys

To quantify the impact of the radar meteorology CURE, pre- and post-course surveys were administered to the students during the first and last week of the semester, respectively. The surveys gauged students' self-reported knowledge and skill levels, as well as aspirations to continue in science (Hanauer et al. 2016). The post-course survey contained additional questions pertaining to students' overall satisfaction with the CURE. Many of the CURE students took part in other courses concurrently, so the results shown below cannot solely be attributed to their participation in the CURE.

a. Paired responses

Seventeen valid paired responses were received from 20 students (i.e., an 85% response rate). We used normalized change metric, c (Marx and Cummings 2007), to quantify the impacts on students. c, shown in Eqn. 1, ranges from -1 (signifying complete loss of all preexisting knowledge or skill; i.e., the worst possible outcome) to 0 (no change) to +1 (maximum benefit realized by the individual student, relative to where they started the intervention). Normalized change is a more accurate metric for assessing benefits of an educational intervention than simply mean change, because c is calculated for each individual student. Values greater than or equal to +0.6 correspond to substantial gains. Formally stated:

$$c = \begin{cases} \frac{\text{post} - \text{pre}}{\text{max. score} - \text{pre}} & \text{post} > \text{pre} \\ \text{drop} & \text{post} = \text{pre} = \text{max. score or } 0 \\ 0 & \text{post} = \text{pre} \\ \frac{\text{post} - \text{pre}}{\text{pre}} & \text{post} < \text{pre} \end{cases} \tag{1}$$

Finding 1: The CURE helped level the playing field for all learners in skills related to radar meteorology. Students exhibited wide variability in self-reported technical skill levels in relevant domains like Python programming, data visualization, and scientific presentation at the beginning of the course (Fig. 1). With very few exceptions, students reported medium to high confidence in their skills by the end of the course. Overall, those who started out feeling like they had little to no skill in a particular domain, felt substantially more confident in those skills by the end of the semester. Normalized gain metrics for all eight of the skills queried ranged from 0.6–1.0, indicating significant gains for most students. In summary, the CURE format created a state of equity in radar meteorology-related skills.

Finding 2: The CURE did not detract from regular learning objectives in radar meteorology. When experimenting with a new course format, instructors should ensure that the intervention doesn't interfere with student achievement of the course's regular learning objectives. A student reasonably expects that by the end of a standard college level radar meteorology course, they should be able to explain how a weather radar operates, how to interpret Doppler velocity, and the physical meaning behind polarimetric radar variables, among other things. It can be seen that, for the CURE pilot described, these standard learning objectives were still achieved, with a majority of students reporting a ”high” level of topical knowledge post-course (Fig. 3). Normalized gains across all ten of the knowledge variables tested ranged from 0.6–1.0, again demonstrating that the course was highly effective in achieving learning objectives in radar meteorology.

Finding 3: The CURE helped students clarify their professional aspirations for science careers. To assess students' career aspirations in science, questions from the Persistence in the Sciences (PITS) survey (Hanauer et al. 2016) were administered. PITS is a survey designed to assess students' inclination toward science careers based on six psychological factors, such as identity and self-efficacy. Results of this survey were mixed, with a majority of (few) students indicating slightly increased (decreased) inclination to continue in a science career at the conclusion of the CURE. Two statements, "I derive great personal satisfaction from working on a team that is doing important research," and, "The daily work of a scientist is appealing to me," had large normalized gains (+0.7 and +0.8, respectively). Two additional statements, "I have a strong sense of belonging to the community of scientists," and, ”I have come to think of myself as a 'scientist'," exhibited small normalized gains (+0.3 and +0.1, respectively). The normalized gain for the statement, "I feel like I belong in the field of science" was -0.2, the negative value meaning the students *lost* a sense of belonging during the semester in which they partook in the CURE.

We cautiously interpret this result as *career trajectory clarification*. Some students may have found the mechanics of scientific research (analyzing data, writing papers) less enthralling than they expected, and this observation may have led them to question whether a career in scientific research was a desirable option. It is also possible that experiences outside the CURE influenced these responses. Because the data were anonymous, it was not possible to follow up with those students who indicated reduced desire to pursue science careers and determine why that was the case. With respect to persistence in science, these results indicate minimal attrition from science careers at this level, while simultaneously clearly signaling a need to foster students' sense of belonging in science. Future iterations of the CURE will incorporate one or more interventions to foster students' sense of belonging in science specifically, possibly those proposed by Walton et al. (2023) and others.

4. Conclusions and Advice

The first known example of a CURE in radar meteorology, and its effects on students, has been presented. While students overall exhibited large normalized gains in knowledge and skills, signals for students' persistence in the sciences were more mixed. Crucially, we identified a slight decline in the students' sense of *belonging* in science at the conclusion of the CURE. The cause of this decline is unknown, but signals a critical need for interventions that will increase students' resilience and sense of belonging in science.

Relative advantages and disadvantages of the CURE format are summarized in Table 1. For those instructors considering the adoption of the CURE format, we offer the following advice:

1. **The instructor should allocate ample time and resources before and after the course for preparation and publication, respectively.** The project may require, e.g., materials, suitable instructional space, computing resources, software development, and advertising, which may need to be secured many months or even a year in advance at many institutions. Furthermore, publication may take many months after the data analysis portion of the CURE ends, and require publication costs. Be sure to obtain "non-perishable"

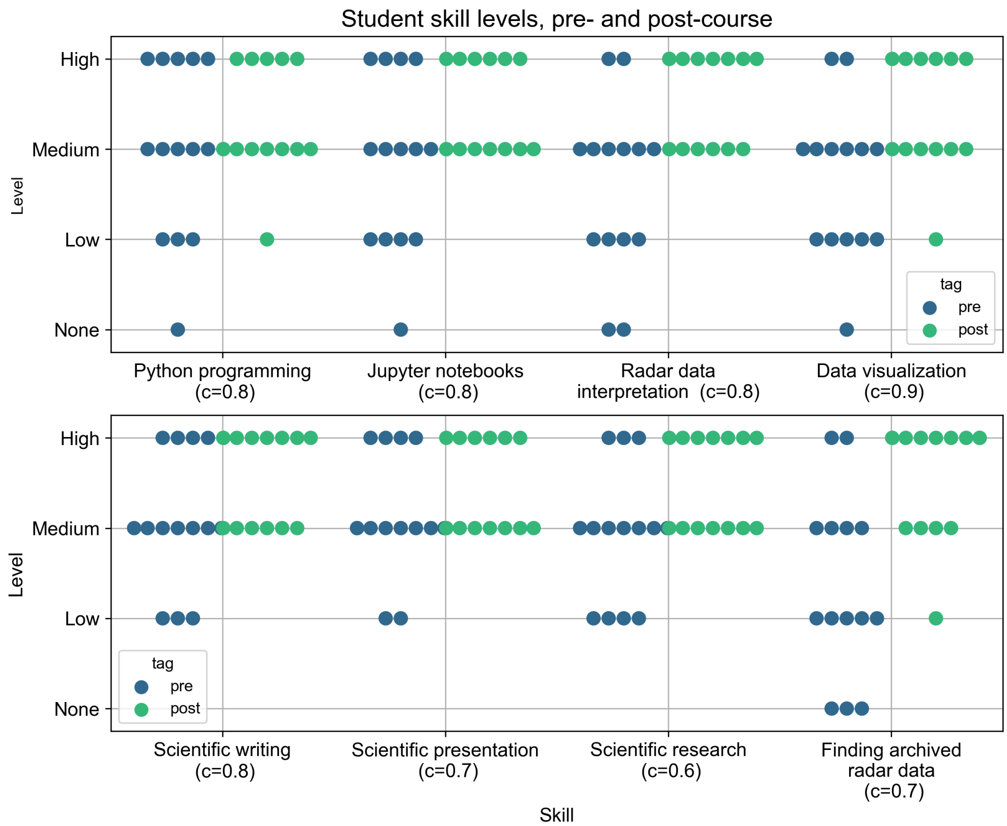

FIG. 1. CURE participants' self-reported skill levels in various tasks and tools related to radar meteorology, pre- (blue dots) and post-course (green dots).

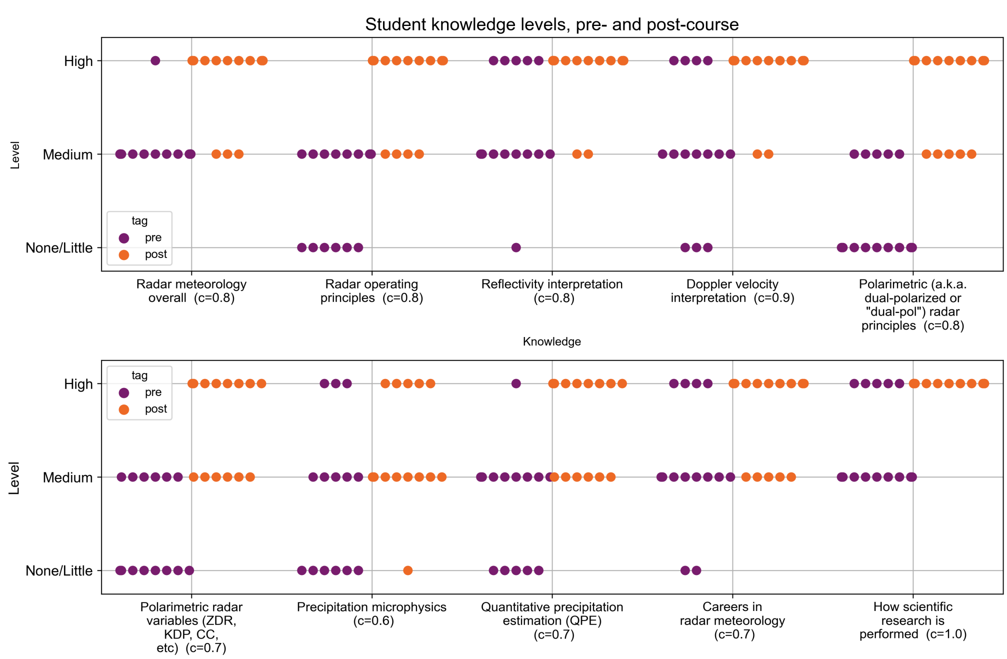

FIG. 2. CURE participants' self-reported knowledge levels in regarding topics in radar meteorology, pre- (purple dots) and post-course (orange dots).

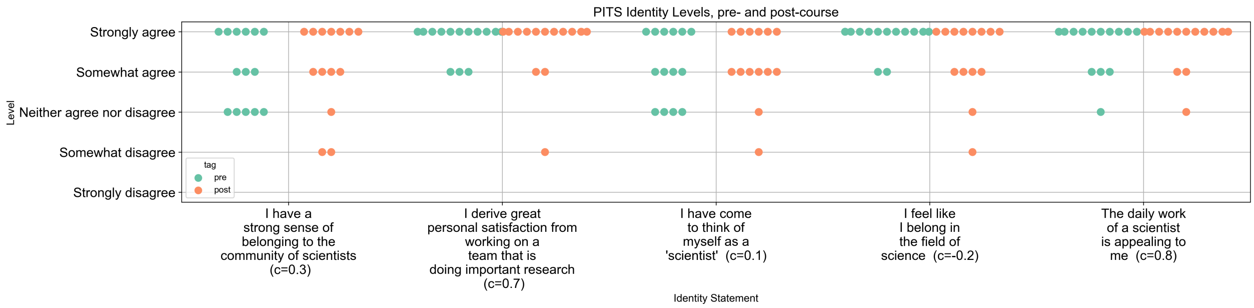

FIG. 3. CURE participants' responses to PITS survey statements regarding self-identity as a scientist, pre- (turquoise dots) and post-course (orange dots).

TABLE 1. Relative advantages and disadvantages of the traditional URE format and the CURE format

	Traditional URE	CURE
Advantage		
Mentee:mentor ratio	1:1	1:many
Potential project complexity	Low	High
Potential for publication	Low	High
Mentorship model	Mentor → Learner	Mentor → Learner, Learner ↔ Learner
Student contact hours	Low	High
Equity	Challenging	Implicity
Disadvantage		
Planning required	Simple to moderate	Complex
Risk associated with project failure	Low	High

contact information from student participants, who may graduate before the publication cycle completes.

2. **The baseline learning objectives of the course should still be met.** Paraphrasing the hippocratic oath, an educational intervention should do no harm to students' learning. The instructor may deploy previously used, non-CURE knowledge and skills assessments in the CURE to compare CURE students' gains to those of non-CURE students.

3. **It is recommended that the CURE be deployed in courses that have appeal to students from a range of knowledge and skill levels. Peer mentoring should be openly encouraged.** Our results suggest that students who enter a CURE with relatively low skill and knowledge levels stand to gain the most from the CURE, while those who enter with relatively high skill and knowledge levels gain valuable peer mentoring experience. These peer mentoring activities emulate those of real-world research groups.

4. **Calibration is required to ensure consistent quality research results.** If the task involves applying the same analysis technique to a large data set, have all the students analyze the same subset of the data first, in order to check that the analysis is being performed correctly.

5. **Collaborative tools (such as online documents, spreadsheets, and messaging systems) should be employed.** The instructor should retain and preserve these materials as a record of the project and relative contributions of all participants.

6. **Reflection should be incorporated into class activities at regular intervals.** Such metacognitive activity that ensures students understand *why* the research activity is worthwhile and the scientific questions being answered.

7. **The objectives of the research, including the hypotheses to be tested, should be made clear at the outset.** If possible, advertise the CURE format in materials during enrollment. Make it clear to learners that the format is experimental, and things may not go as planned.

8. **Because the CURE format is likely to be unfamiliar to students, transparency in grading is of paramount importance.** The students' grade should not be tied to whether the scientific research project produced the hypothesized or desired results. Instead, the students' grade should be based on their contribution to the project and demonstrated knowledge and skills gains.

9. **In developing a CURE, the instructor should be mindful of inclusive course design.** In particular, we recommend adherence to the principles of Universal Design for Learning (UDL; Meyer et al. 2016; Miller and Lang 2016) which emphasizes multiple modes of engagement, representation, action, and expression. A UDL-based can ensure that all students

are equitably included in the project in ways that play to their respective strengths.

10. **Students' sense of belonging in science requires particular attention.** While the course format implies and creates equity across skills, our results suggest that instructors should make concerted interventions to participants' sense of belonging in science, particularly if the CURE is their first "real" (not canned) scientific engagement. This finding reinforces those of Deci and Ryan (2000, "relatedness"), Hunter et al. (2007, "socialization"), Walton et al. (2023, "belonging"), and others.

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