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Using REU Program Evaluation to Foster Learning through Reflection

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In this work-in-progress paper, we suggest that the evaluation of undergraduate research experiences can be adapted to serve as a useful tool for supporting student learning. Specifically, we argue that undergraduate research can foster transformative learning, but one key element of this experiential learning–reflection–can be difficult to integrate into the programs[1], [2]. Indeed, even for programs that foreground experiential learning, such as service-learning and study abroad, it can be difficult to integrate reflection effectively[3]. Yet the National Science Foundation's (NSF) Research Experience for Undergraduates (REU) programs do require a process that, surprisingly, could serve as a tool for doing this work: program evaluation. In a previous paper we explored the possibility of using evaluation as a tool to collect valuable research data about the experience of marginalized and minoritized students[4]. In this paper we ask if we can design evaluation methods to do more than evaluate and provide research data; we suggest that they can encourage student learning through reflection.

It seems worthwhile to try, both to make multi-purpose research more efficient and to make student participation in these evaluations beneficial for them. All REU PIs aim for their programs to provide a rich learning experience, but measuring the learning from that experience can be difficult to integrate into the program itself. Evaluation is an administrative requirement usually outside of the expertise of the PI, and therefore it risks becoming a bureaucratic add-on. Further, for the students the evaluation process might be no more than a loss of precious lab time and can even pose the privacy risk of their data leaking. We suggest that evaluation could do more to serve the learning goals of the program in ways that would directly enhance student learning.

This paper raises this question, situates it in existing theories and frameworks of reflective learning, and offers suggestive data of the effects of evaluation methods on students from an evaluation and study of an undergraduate research program in engineering. We wonder if a reflection-focused evaluation process could help students connect their learning with their sociotechnical experiences of working in a research group.

Evaluating Learning in REUs

The NSF's official statements about REUs emphasize retaining students--especially the "missing millions" of students from underrepresented groups--in order to create a STEM workforce[5]. And much of the discussion and evaluation of these programs similarly emphasizes those goals, especially the admirable goal of diversifying STEM, by surveying how the research increased students' sense of belonging in science and their science identity[6]. These experiences, however, can also be even more transformative learning experiences, allowing the students to fundamentally reshape not just their science identity but also their understanding of science and the world. To do this, students not only need to have rich experiences of practicing science and engineering, but they also have to learn from those experiences: "to integrate evidence from their research experiences to strengthen views of their identity as scientists, the range of science practices, ways to learn science concepts, and the nature of science."[7, pp. 1261757–4] Different kinds of activities lead to this growth, including active mentoring, designing and

carrying out experiments, collecting data on field trips, presenting their work, and even writing peer-reviewed articles, but reflection has long been seen as central to experiential learning[8].

Reflection as a Tool for Learning

Dewey and others argued that reflection is one of the fundamental components of experiential learning[9]. The model of reflection we use starts with some bounded instance, whether an event/experience, an idea, or a way of thinking (tied to some context, real or imagined). Next, the person is distanced from that instance by time, space, or context. Finally, the person interprets that instance, comparing their prior knowledge or feeling, their understanding of that instance, and their current analysis. Through this process, an individual draws connections between experiences, synthesizing new understanding that can be applied going forward.

From a different perspective, Schön argues that engineers and other professionals should be "reflective practitioners", i.e., that they should think through their decisions rather than only going through routine actions[10]. More specifically, professionals should conduct "reflection *in* action", i.e., an ongoing process of questioning decisions *during* their work, as well as "reflection *on* action", i.e., assessing the results of the action *after* it's completed and thinking about how to act differently next time[11]. Our post-program evaluation methods invite students to reflect *on* action by thinking back across their experiences in the REU program. Similarly, scholars in science and technology studies have developed methodologies for encouraging scientists and engineers to reflect on their ongoing research and design practices to better achieve ethical and socially beneficial outcomes [e.g.,[12], [13], [14]]. Those methodologies may be useful for designing future strategies for reflection as part of engineering education.

Methods

In brief, we served as evaluators for a three-year NSF REU program at a medium-sized public research university, at which we are faculty in a different department from the REU program leaders. We conducted pre and post-program semi-structured interviews and pre, post, and one-year-later surveys with 35 students, and we received IRB approval to study these data for two summers' cohorts (n = 24 students). This study analyzes interview responses from those 24 students. Our methods design and interview questions are reported in [4].

This group is an unusual cohort of engineering students by educational background, gender, and race. 17 of the 24 students (71%) were attending or had graduated from community college, which was a recruiting focus of the REU program. Women were a slight majority (14/23, 61%, 1 student did not respond). 43% identified as students of color (9/21, with 12 White or Asian students, 57%, and 3 students who did not respond).

We did not expect that participating in an evaluation could influence student learning by encouraging reflection. This observation arose from our experience interviewing students. For example, several of the program's students remarked how interesting the interview questions were, or how the questions made them think. One student even requested a copy of the interview questions after the pre interview, because he wanted to keep thinking about them. So in 2024, we decided to explore this observation by adding a question to the post interview about students' experience of the evaluation itself: "What did you think

about answering these questions? What was it like to answer them? Did anything stick with you?" Then we coded the 2024 post interviews (n = 12) for evidence of reflection in general, across all question responses. In the coding, we drew from the frameworks discussed above to conceptualize reflection as students differentiating their own past and present ways of thinking. Specifically, students reflected in their interview responses by comparing their expectations to what actually happened, or thinking out loud about what has changed for them academically, personally, or professionally during the REU program.

We conducted interviews during the first and last weeks of the REU, talking to students individually in a separate room. Interviews are not common in REU evaluations, perhaps because they are more labor-intensive than surveys. We had designed our evaluation methods to produce data that were useful for both research and evaluation, so we asked students more reflection-related questions than is typical for program evaluation[4].The data were anonymized and were solely available to us. We had no other role in the REU and therefore did not introduce sociotechnical thinking outside of the interview sessions. Indeed, this limited intervention is why the student's request for the questions was intriguing.

The most reflection-relevant questions we asked, drawn from the Views of Nature of Science instrument[15], called attention to the social aspects of research, such as how researchers choose research questions and methods, how they interpret data to propose theories, why multiple theories can co-exist based on the same data, etc. Reflecting on the realities of how people do research, both in students' expectations and assumptions (a pre-interview) and in their own experience of working in a research group (a post-interview), may be a powerful way to help students recognize engineering research as a sociotechnical endeavor.

Results

Here we discuss preliminary analysis of the 2024 post interviews, coded for evidence of reflection. We found reflection in every student's answers. This is in part because we were asking them directly about their past experiences in the program, arguably demanding reflection. However, students gave thoughtful and introspective answers that went beyond merely telling a story of their summer experiences, adding a level of analysis and self-awareness that, we surmise, helped them recognize their own learning and perhaps thereby solidify it. We identified themes within students' reflective responses of 1) comparing expectations and experiences, 2) assessing one's own skills and abilities, 3) recounting an experience as a story to demonstrate learning, 4) how social relationships affect reflection, and 5) students' perceptions of the emotional and learning effects of answering the evaluation questions. We illustrate each of these themes with interview data below.

Comparing Expectations and Experiences

Several students phrased their reflections in terms of their own expectations and then what they actually experienced in their research. One common lesson for these students was the prevalence and importance of reading research papers. One student explained, "this is what's really unexpected, when I learned that people who are doing research read a lot of literature. Like a ton." In this form of reflection, students frame the learned information in reference to a prior - and now rejected - belief or assumption. Similarly, a student thought out loud about the experience of uncertainty and failure in research:

> “A lot of it was kind of trial and error, kind of just seeing maybe this might work out, maybe it might not. We should have expected that, but actually having to be like, ‘oh, I'm not sure if it's gonna work out’ was a very interesting experience. Like having things actually not work out, and it's like, ‘oh, what do I do now?’”

The student “should have expected” that research is experimental and isn’t always successful, but that they didn’t learn that lesson until they experienced it themselves. Several students mentioned this feeling of not knowing what to do, and feeling uncomfortable about the uncertainty of research. Being comfortable with uncertainty and knowing how to respond to it is a key lesson for students moving from undergraduate to graduate education in science and engineering, in that students face open-ended research questions and methodologies, perhaps for the first time[16].

Self-Assessment

Students also discussed their own skills and abilities in reflective ways. For example, one student offered an assessment of their own communication skills and accountability for their research:

> Maybe I could have read more through the process, but maybe I just needed to push for more communication, as well, … but that is not a bad thing [that] personally I could have done to improve the experience. And another thing about research is that it does take a lot of patience and using your free time well and asking others.

Several students similarly described their own skills reflectively, in terms of wishing that they felt more comfortable communicating with their mentors and/or being self-directed. Recognizing one’s areas for growth is crucial for learning in any setting, beyond research skills in particular.

Storytelling

Another form of reflection is telling a personal story to illustrate what students have learned. In response to an interview question about how scientists can propose different theories to explain the same data, one student recounted what their mentor had told them about this situation:

> This is also something that my professor said a lot, about how you can get data and you can draw different conclusions from it, and that was actually something that he talked about when he used to review papers. Like they would say, “okay, this happened, so,” but then he'd be like, "Well, how do you know it's not this or this?" And then they have to have a reason for why it's not those, or [else] it's not a very good conclusion. So yeah, I just know that you can analyze data differently and even if you analyze it the same, I mean, you could still... come up with different ideas for why it looks like that.

This is a complex idea about the conditional nature of knowledge as not obvious and never completely proven. The student is more comfortable with this idea because they heard about it from their mentor, in the form of a story about the mentor’s personal experience. This real-life example from a trusted source was a powerful lesson for the student, and arguably more powerful than just being told that knowledge is conditional[13].

How Social Relationships Affect Reflection

As shown above, relationships are important sources of new information and new ways of thinking. They can also encourage reflection and self-awareness, through external validation and assessment of a learner's knowledge and achievements. One student told us: "I realized yesterday how much I've actually done from what my professor has told me. So, I think that's an accomplishment on its own." The mentor's assessment of the student's work made the student feel valued and pleased, and also provided an external measure of what counts as good work. Then the student adopted the mentor's reflective assessment of their progress rather than their own less-satisfied view of their work. As an expert and their boss, the mentor plays an important role in informing students' sense of good work, which is a key lesson of professionalization. Specifically, an expert's feedback on a learner's work is a powerful way to teach a profession's values, skills, and goals[17], [18].

Students' Perceptions of Answering the Evaluation Questions

The question we added about students' experience of the evaluation yielded positive reports of the questions' impact on students' thinking - much more so than we had expected. Students were talking to us face-to-face, which means it's unlikely they would have shared any negative perspectives on the evaluation. However, they could have chosen to give minimalist answers to this question; instead, their responses were thoughtful and detailed. Many said they remembered the interview questions and thought about them during the 10-week program, to our surprise. As one student put it, "I definitely was thinking about these questions, maybe not consciously, but definitely subconsciously. I was definitely thinking about these questions throughout all of my research." Another student said,

> As I was going along the internship, I would think back at the questions and kinda put it into perspective at that time, because I would be in - like, you know, I was a researcher. So I could really relate to it. Prior to the first interview where I hadn't really done much research, I guess like then I couldn't really say much because I hadn't experienced it compared to as I was going along.

This ongoing self-questioning aligns with Schön's concept of "reflection in action"[9], in which professionals think through their work to identify and solve problems rather than doing it merely by rote.

Students appreciated thinking about the interview questions. One saw it as a way to create time for recognizing their learning:

> I think the introspection has been good, because sometimes things are going so quickly, you're not really like stopping to say, 'Okay, how is this actually helping me?' type of thing. So I think it's been good to actually say, 'Oh, this has actually helped me grow in some way,' you know, actually thinking about the different experiences I've had, because it's been so much, even though it's only been a short period of time.

The student felt proud of learning a lot in just one summer, and might have struggled to realize this achievement without being asked to think about it. Another student took their changing views on the questions as a sign of learning and self-confidence: "I do feel like I know more about what I'm talking about with research because I actually did it… It's good to have that experience of, 'Wait a minute, I've learned something.' Right? Before you do the presentation, maybe that helps the anxiety that everyone has with making presentations." The student was glad to recognize their learning, in particular a few days

before they would share their learning in a final presentation to the REU program's students, mentors, and staff. Another student found the questions grounding and motivating:

> I think answering the "what is research" one is inspiring, because sometimes it's hard. Sometimes you can lose focus of what you're really trying to achieve in the day-to-day. It can feel so stressful to like, 'Oh, I'm not getting this result. What's happening? What's happening?' But zooming out and looking at the big picture of, "this is for science, this is for humanity," it's very inspiring and wholesome.

This is remarkable self-awareness for an undergraduate. This kind of response suggests that reflection - sparked by program evaluation - can have benefits for students' self-confidence, motivation, and sense of achievement and purpose.

Discussion

What implications do these findings have for how we design evaluation? At this point, these results are merely suggestive, supporting our initial insight that a student wanting a copy of the pre-REU interview questions demonstrated something unexpected about the evaluation process. Can evaluation interviews that spur student reflection be more than a measure of learning, serving as an actual tool of learning? How then should we design such methods? [See [19] for examples of reflective questions and activities.] And for our disciplinary purposes, can such methods cultivate students' sociotechnical learning about the conduct of research and the nature of scientific and engineering knowledge? Like other scholars who study sociotechnical thinking [*e.g.*, [20], [21], [22], we see possibilities and limits.

A key purpose of REU programs, we argue, is to immerse students in the sociotechnical nature of research practice. Becoming a researcher requires learning the social roles, cultural norms, and ethical values that underlie the practice of science and engineering. Further, research requires developing and appropriately applying extensive tacit and explicit knowledge. This learning is typically not taught directly, so it tends to be overlooked in REU program objectives and evaluations. These sociotechnical elements might, however, be elicited through the evaluation process. In our case, we asked questions and impromptu follow-ups about students' interactions with faculty and graduate mentors, about how they interpreted failure in their work, and about the process of conducting research. In other words, these interviews gave us the chance to elicit those sociotechnical elements explicitly. Diekman and coauthors have found, for example, that reflection activities can particularly benefit minoritized STEM students, such as by improving their motivation[23].

But how much can students actually learn from reflection during pre and post interviews? Further, because we were not directly involved in the conduct of the REU and were not a regular presence in the REU activities, we could not periodically reinforce the issues we raised. We had no role in determining the content of the REU. Likewise, we were not the authoritative REU staff, so it would be easy for students to dismiss our questions as an unimportant subject not worth dwelling on.

At the same time, the interviews took place in a quiet conference room, away from the students' labs and office spaces, with an older authority figure's guiding questions and close listening. In other words, we can see it as a distanced, liminal social situation that allows the student to reconsider and reconstruct their own knowledge[24]. It would be a stretch to compare it to an important rite of passage where initiates

gain crucial cultural knowledge, but nevertheless, this encounter might have more impact than we would initially expect.

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