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# Student curiosity in engineering courses and research experiences: ”I’m kind of torn between being a decent student and a decent engineer.”

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# Student curiosity in engineering courses and research experiences: “I'm kind of torn between being a decent student and a decent engineer.”

**Abstract:**
This mixed-methods research paper investigates how classes and research experiences affect undergraduate engineering students' curiosity. Students become curious when they recognize a gap in their knowledge and seek to resolve this uncertainty [1]. When students are curious about a topic, their learning better generalizes to new material and contexts [2]. Both the classroom and the research lab are spaces where students regularly encounter uncertainty and new information and are ideal contexts to examine student curiosity. In the current study, we examined how students' experiences in classes and research labs may foster and/or suppress their curiosity. Twenty undergraduate engineering students completed a self-report survey of curiosity and responded to questions about how different instructional elements impacted their curiosity. Eleven of these students also participated in a semi-structured interview about their class and research experiences. Survey responses suggest that hands-on activities and labs were most likely to make students feel curious and exams were least likely. In the interviews, students expressed that they experienced curiosity when their instructors were engaging and made connections to real world applications, whereas they felt less curious when they were overscheduled and when class content was redundant. Students noted that working in a research lab gave them more time to process information, develop questions, and build relationships with peers and mentors compared to their class experiences. We discuss the implications of these findings and offer suggestions for encouraging students' curiosity in both class and research lab settings.

## Introduction

This mixed-methods research paper presents findings drawn from a larger study that examines how undergraduate research and class experiences impact student curiosity. Curiosity occurs when an individual encounters uncertainty and seeks to fill this gap in their knowledge or understanding [3]. According to the Information Gap theory of curiosity [1], this is most likely to occur with a "medium" amount of uncertainty, that is enough uncertainty that an individual feels motivated to seek information, but not so much that they feel overwhelmed. This curiosity leads to more deep and meaningful learning [2] and is linked to desirable academic outcomes in K-12 students [4,5]. Despite these findings, there is little evidence that curiosity is promoted in schools [6,7]. Children also do not perceive that school is a place to be curious. Dutch children interviewed about their experiences with curiosity reported that school was not a place they were supposed to be curious [8]. It is possible that focus on performance and grades, which may begin as early as kindergarten [9], may discourage children from being curious. When performance goals are emphasized in educational contexts, it can imply that the students should focus on learning the information tied to the performance metrics (i.e., tests), and expressing curiosity or engaging in information might hinder this goal.

Most research has focused on K-12 settings and very little work has examined how undergraduate educational experiences may impact their curiosity, although there is some evidence that higher curiosity is associated with better academic outcomes in undergraduate students [10]. Curiosity is also linked with crucial engineering skills, such as creativity, the ability to generate new and original ideas, and innovation, the successful implementation of creative ideas [11]. In prior work, we examined how research experiences might impact curiosity in undergraduate engineering students [12]. Research experiences can promote curiosity because students often encounter uncertainty and opportunities for exploration and question-asking, and they are associated with increased independent thinking and deeper engagement in learning [13]. Research experiences are especially important for engineering students because engineering is considered a “practicing profession” in which theoretical STEM concepts are used to solve real world problems [14]. As such, participating in research experiences provides hands-on training that can help students in their later careers. Despite the benefits of participating in research, not all students have the time or opportunity to experience working in a research lab during their undergraduate careers. In comparison, all students will participate in classes as part of their engineering majors, and thus it is important to also understand how class experiences may impact student curiosity and learning.

In the current study, we utilized a qualitative interview and survey to investigate undergraduate engineering students’ experiences with curiosity in class and research settings. We also interviewed faculty who work with undergraduates in both settings to understand professors’ perceptions of how these educational settings may impact student curiosity. The goal of this paper was to examine factors in undergraduate engineering classes that may contribute to or obstruct curiosity and how classes compare to research experiences.

## Methods

Undergraduate engineering students completed a survey, with some also completing an interview about their experiences with curiosity in class and research settings (see [2] for a detailed description of the methods). We also interviewed faculty about their perceptions of student curiosity in their classrooms and labs. The current study used a qualitative approach to analyze the student and faculty interviews to explore the ways that classroom experiences might influence student curiosity and how this can look similar to or different from students’ experiences working in faculty research labs. The broader aims of this work are around identifying factors that influence student curiosity, to raise questions for future research and to inspire recommendations to encourage and support students’ curiosity in both courses and research experiences, for which this paper describes our initial steps.

### Participants

Undergraduate engineering students were recruited from Materials Science and Engineering (MSE) classes and labs at a flagship state university on the U.S. East Coast. Students were told that participation was optional and that their decision whether or not to participate would not be reported to their class instructor or lab PI or affect their grade. We invited students from two engineering classes to participate in the survey, and 11 students completed the survey. On the survey, students were able to indicate whether they would be willing to complete an interview, and 3 students indicated interest. Of these students, 1 student participated in an interview. We also reached out to students working in engineering labs and visiting students who were working in research labs as part of an NSF REU experience. Twelve of these students (9 full time students, 3 visiting students) completed interviews, and 10 completed the survey. Overall, 11 students completed only the survey and 2 completed only the interview, and 11 completed both (24 participants total). Participants received a $10 gift card for participating in the interview and an additional $10 for completing the survey.

Students self-reported their race, gender, class year, and major on the survey. Student responses will not be separated by demographic to protect their confidentiality. Of the 22 students that participated in the survey, 12 identified as female and 9 as male, 14 identified as White/Caucasian, and 5 as Black/African American. Two students identified with multiple racial backgrounds. About half of students (13) reported they were Material Sciences and Engineering and/or Mechanical Engineering majors. Other students reported majors in chemical, electrical, aerospace, and general engineering, as well as chemistry, and physics. All students were undergraduates in their 2nd to 4th year.

Two faculty members from the MSE department participated in an interview. Both professors regularly teach classes and work with undergraduate students in research labs. These professors taught the two classes where we recruited students.

**Survey**

The survey consisted of a set of demographic questions, a self-report measure of curiosity [15], a self-report measure of intellectual humility [16], and a set of questions asking students to rate how curious various elements of class made them feel. Besides the demographics, students responded to these questions using a 7-point Likert scale. The survey was designed to take less than 20 minutes to complete and was administered through Qualtrics. In the current paper we focus on the class curiosity questions.

**Student and Faculty Interviews**

The study interview is the same as described in [17]. The semi-structured student interview consisted of five sections: a warm-up, classroom experiences, lab related experiences, curiosity, and conclusion questions. Each section consisted of questions and sample follow up questions that were asked on a need basis. The student interview included 35 questions (plus relevant follow-up questioning), was approximately forty-five minutes in duration, and was audio recorded and transcribed. The faculty interview was written to parallel the student interview and included the same five sections. There were 18 questions (plus relevant follow-up questioning), and the interview took approximately thirty minutes to complete. Both student and faculty interviews were transcribed for analysis.

**Interview Analysis**

In this paper, we focused on student responses about classroom experiences section of the interview to identify factors that contributed to and opposed student curiosity. To understand factors related to courses that contributed to student curiosity, we examined responses to questions where students were asked to describe their favorite courses, what made them feel curious in class, and their experiences with uncertainty in class. Interview questions also asked questions related to curiosity, such as asking about what they wanted to know more about during their research experience, their experiences with uncertainty, and their motivation and information seeking. In analyzing the responses across all students interviewed, four sub themes emerged around students' experience of feeling curious during their learning: Information seeking in response to uncertainty, real world applications, effective instructors, and useful assignments. These themes align with prior research that suggests ways of promoting both *becoming* curious (e.g. task demands and introducing uncertainty) and *being* curious (e.g., seeking information, providing opportunities for hands-on exploration) [18]. When considering barriers or obstacles to curiosity in students' responses, four sub themes were identified: covering redundant information, overwhelming classes, time constraints, and conflict over getting the right answer or understanding. These responses most often emerged when students were asked to describe what did not make them feel curious in class and encounters with uncertainty, and align with prior research around curiosity suppression, such as emphasizing performance, but also get at barriers to promoting curiosity that do not actively suppress it [18]. We did not explicitly ask students to compare their class and research experiences during the interview, but we present examples of students making such comparisons. Below we provide representative quotations from students to illustrate these themes and examples. The two faculty interviews were examined after identifying examples and themes in the student interviews. We selected quotes from these interviews that offered faculty perspectives on student experiences.

Table 1. Themes and Sub Themes

| Theme | Sub Themes |
|---|---|
| Contributions to Curiosity | Information seeking in response to uncertainty |
| | Real world applications |
| | Effective instructors |
| | Useful assignments |
| Obstacles to Curiosity | Redundant information |
| | Overwhelming classes |
| | Time constraints |
| | Conflict over getting right answer or understanding |
| Comparing Class and Lab Experiences | *Examples* |

## Results

### Survey

Students' ratings of their curiosity across different class components showed significant variability ($F(1, 19) = 28.75$, $p < .001$). Specifically, students rated lab sessions and hands-on activities, as well as lectures, as leading to significantly higher levels of curiosity than the readings, homework, and exams (all $p$ values < .02). While hands-on experiences had the highest curiosity rating, this was not significantly higher than lab-sessions ($p = .204$) but was rated significantly higher than lectures ($p = .026$); see Table 1 for all means and standard deviations.

Table 1 displays averages of student responses to class curiosity questions.

| Question | Mean (SD) |
|---|---|
| Lectures make me curious about the class material | 5.30 (1.34) |
| Lab sessions make me curious about the class material | 6.00 (.86) |
| Readings make me curious about the class material | 3.95 (1.50) |
| Hands-on activities make me curious about the class material | 6.25 (.79) |
| Homework assignments make me curious about the class material | 4.05 (1.82) |
| Exams make me curious about the class material | 3.25 (1.83) |

Note: 7-point Likert scale; 1=Strongly disagree, 7= Strongly agree

### Student and Faculty Interviews

#### *What contributes to students' curiosity in class?*

One of the sub themes we identified across student interviews was that students **sought information in response to uncertainty**. Several students remarked that the content they encountered in class led them to recognize uncertainty in their knowledge and understanding of related content, leading them to seek information independently, often by looking through class materials or going online.

> "Um, pretty much all the time in my Intro to Engineering class- or Intro to Aerospace Engineering class. I was confused, like, all the time in that class. I would have to like- I would just read the textbook after class or like at the end of the week or something, and try to learn from there. And then the same thing would happen next week, I'd be like, 'what?'"

> "it made me feel like I need to do more in this class, or I need to seek out more I need to put more hours into it I need to understand this because if I can find joy in this one bit, I should be able to find joy in like the other parts as well."

Many students noted that they felt more engaged and curious about class material when the instructor was able to make connections to **real world applications** and examples. Students discussed these applications as specifically supporting their understanding for how the information learned could be useful in real-world contexts, and as a foundation of knowledge to build on in future learning.

> "There's lots of, in engineering courses, the good ones, well they take what you're learning, and be like, here's real world events, and this thing that we learned played a role in it. I love looking at that because I now have like a seed to start understanding that event, and you know all real world things are faster and more complicated than a textbook or class"

> "You can see . . . how those assumptions you're making in class affects a real world situation. Because, you know, even the people designing stuff in the world are taught to make assumptions. So you want to understand what impact those assumptions have so you can only do that by comparing it to a real world things so having that kind of comparison, really kind of stokes my curiosity as to . . . the underlying mechanisms of the situation."

**Effective instructors** helped promote student curiosity in class, and students described several different ways that instructors were effective in engaging their curiosity. For example, students appreciated when instructors challenged them and also their acknowledgement of students' effort to understand the class material. When describing why certain courses were their favorites, one student explained:

> "Well they've [the favorite classes] all had really good instructors, and they've all been really challenging. . .with my classmates, It's like, how are we going to do this homework, we gotta figure this out kind of thing. And collaborating and working together and stuff like that and all of the classes have had, instructors were understanding and sympathetic and great to work with. And they knew we were, you know, trying really hard and they worked with us and that's kind of it."

Students similarly valued scaffolding and guidance from instructors, such as pointing them in the right direction in terms of what they needed to work on or where to find information.

> "And, but I thoroughly enjoyed the class, because I was being pushed like every single week . . . and I went from getting like consistent like 80s, on my essays to getting a 95 on the final and I was just like oh, my goodness, like this is the real champion story. But I just that was really rewarding because I was constantly learning and constantly pouring myself into and I found that extremely mentally stimulating."

Students appreciated when professors acknowledged that they do not know everything and that there are questions in engineering that do not have concrete answers.

> "there are occasional instances where it is at the forefront of human knowledge currently, and someone in the class asks a question that the professor doesn't know, and the professor doesn't think anyone in the department knows, and he will ask his colleagues

and come back with a we don’t know, and that is one of the less avoidable instances of ambiguity.”

Different types of **assignments** promoted student curiosity. Some students expressed that they preferred assignments where multiple answers could be considered correct, especially in group or collaborative settings. Removing the need to find a single correct answer reduced student stress and provided more autonomy in the project. Other students stated that they appreciated having clearly defined goals in a project as it gave them more structure. This was especially true on graded assignments.

> “I like projects more. They're less stressful because you get to like, one, do something you want to do, if it’s like, an open-ended project. And two, you don't have to worry about like, being wrong kind of, cause like, it's bigger than just the answer to one question.”

> “That depends on the format in which its delivered. Usually homework’s, that kind of graded assignment, I would prefer the single answer, very objective, yes no, correct incorrect. But if it’s a discussion-based assignment, or collaborative, then I would prefer mastery.”

> “I like goals, because if it's too abstract I tend to overthink things and I want to, like, but what if they're looking for something like this or, you know, if I have to like make a thing that works. That's a, that's a nice concise set of parameters that I can shoot for, and get really into the nitty gritty of it. If I can have an answer that I can draw a circle around and be like, that's my answer or have a thing that I can turn in and be like, here's this thing that does the thing that you wanted it to do, or almost as what you want it to, then that's, you know, that's my kind of assignment right there.”

Interviews with professors in the program provided examples of the thought-process behind some of these observed student examples/themes, such as identifying ways that instructors tried to support students’ experiences of and comfort with uncertainty. For instance, one professor commented that they encourage students to ask questions as a way to check their understanding and admitted that they do not always know the answers. Instructors also commented on the balance of challenging students with questions beyond their understanding, while also presenting information at an appropriate level for students along with recognition that mistakes happen, should not be feared, and how to address them.

> “Um and I stop periodically and ask them questions. And I ask a lot “do you guys follow this?” “Does this make sense?” and I’ll just ask them open-ended things sometimes. Um and oftentimes they’ll ask me questions that I can’t answer.”

> “Yeah. They are collected data for example and mistakes are made, and mistakes happen and that's fine, um that's research. But I think with me being involved and being able to help them identify where the mistakes are made and how to correct them”

> "And I don't shy away from it and yeah you know, its, okay so like when I teach an intro level course, and the [research] lab really is an intro level course too, but I definitely do in some ways try to present a sanitized picture sometimes because they're learning a new concept and if there are 50 fuzzy outcomes that an expert could say "well, but this" or "well, but that" boy that's so hard to learn for the first time."

***What obstacles to curiosity do students perceive in classes?***

Students described several different types of obstacles or barriers to becoming curious in their responses about when they don't feel curious. A recurring sub theme that was observed is students' descriptions of feeling less curious in classes where they felt the **information they were learning was redundant** with material they previously covered in past courses.

> "There are a few classes that I am currently in that have a large degree of overlap with other classes that I have. So there will be lectures on it, where it will be stuff that other classes I am taking at this point are assumed to be trivial knowledge, and they are teaching it in other classes to be novel and new which in that class it is"

Similar to the effective instructor theme above, instructor practices also negatively impacted curiosity, both in terms of the content presented and the ways it was covered, but also noted the influence of factors outside of the course. One student noted that **overwhelming theory-heavy classes** with an unengaging instructor made it difficult to be curious.

> "I'm taking [CLASS], . . .Um, so that the class is very theory heavy. And he just kind of spits theories at us, and so it can become very like mind numbing and it like I do not think about that class when I don't have to".

Students also reported that they felt fellow students sometimes **did not have time to cultivate curiosity** because they were overscheduled and had too many demands on their time.

> "I often just don't have much time at all for just seeking sheer curiosity. And I think that's something felt amongst a lot of students. So, it really comes down to what I have time for it just comes down to, If I have an assignment due tomorrow I'm not going to be researching this other thing that is just like that I'm just currently interested at the moment."

Students expressed that they felt **conflicted over getting the "right" answer and understanding class material.** They mentioned that they sometimes felt conflicted between different goals of being a good student vs. engineer, and that they had to choose between incompatible ways of approaching their learning based on these different goals.

> "So, whenever I'm kind of torn between being a decent student and a decent engineer, like, you know, the student in me wants me to get a good grade and do this but the engineer wants to like, you know, Google these 10 things to get more background information to have a better understanding of what's going on."

> "The other aspect of that, the dichotomy, is the concern as to whether it will be included in the homework or the tests. Whenever ambiguity arises, almost first though is, if I don't understand this, I very much hope it isn't on the test or a homework. And that thought is usually before the second half of that, the part that I started with."

These feelings of getting the incorrect answer also impacted students' willingness to engage in the course, with one student noting that a professor's practice of cold calling and criticizing incorrect responses made them change the way they engaged in the course.

> "At the beginning, I attended on Zoom just because I had a weird class schedule on those days, and he is a cold caller and he is not necessarily kind to people who do not get the correct answer and like getting the answer wrong in front of people just sort of sent me into style where I wasn't paying attention in class so I just started going in person, since he wasn't cold call on the people in person since he didn't know names."

Professors' responses again showed recognition of the experiences students described, such as acknowledging the busy lives students have outside of courses and homework and the conflict between motivation for grade-based performance and curiosity.

> "It would be incredibly motivating for students to come in every morning to their 9 am class or whatever it is right and say "I'm going to learn something really new about science or engineering today, isn't that cool!" Of course it doesn't quite work out that way, especially if you only had three hours of sleep last night, while getting your big huge homework assignment done. Um but yeah ya' know, uh, curiosity is something I think is in rather short supply [pause] um and even honestly in grad students not just, under, true sort of joyous curiosity does seem to get kind of ground out of them by the grind itself right?"

> "It is, yeah [pause] I don't know I mean you know we [pause] I go around and around on this probably one of the big obstacles is grades, right? I mean the fact that they're not just here to kind of explore and try things and fail and there's no consequence to failure, try's, try it again or try something different. Um grades are a consequence and they are consequences that they feel will affect their subsequent careers and they are not wrong about that. It may not be quite as important as they put it, ya' know the GPA, it may not be the be all and end all of whether you are ever going to get a job or be a success but they perceive it that way."

***How do students compare class work and lab classes to independent research?***

Students' discussion of differences between independent research with courses showed similarities to what they reported as impacts to their curiosity, such as the real-world relevance for their futures, and the structure of the learning experiences. Students reported that their time working in a research lab had a greater impact on their long-term goals than their classes, and working in the lab made them consider graduate school.

> "But like, [PROFESSOR]'s lab I think, makes me- it like, put the idea of graduate school in my head, even though that was like never in my- I never thought about it before. I was just kind of going to get my degree and then start doing something I was more interested in. But now, like, since I'm interested in research, it's opening up different doors in my mind. I'm like, 'I could do that, in materials science' or get master's in materials science and then work still in aerospace, just on the materials side, which would be like, very cool. . . But I still think any job I do get in engineering, I definitely want to work in engineering and be hands on, I think everything I've learned in [PROFESSOR]'s lab will help me with my job, so yeah."

Another student expressed that time constraints were a disadvantage of class-based labs where students are expected to accomplish a specific goal in a short time frame. They mentioned that during independent research they had the opportunity to step away and return to the work when a challenge arose, which helped them process what was occurring.

> "I feel like I am able to ask more questions and, like, pursue my curiosity in the lab than I ever was in class . . . not a single minute could be wasted. Whereas in the lab I feel like everyone has the ability to slow down because again science is slow, so if someone were cutting something I could just be like hey so, can you explain why are using the low-speed saw instead of the high speed saw? Like and I could easily ask those questions and more comfortably"

Similarly, another student noted that there were more opportunities to pursue questions in a research lab because there were fewer students and a more flexible time frame.

> "So, ours are actual classes, a little under four hours, and that that can be a lot, because we have so many things that need to get done in four hours . . . first day I was like getting fatigued, its like okay, when I got tired like over the summer especially I just like okay, I'm going to stop do something else, and come back later that evening or tomorrow, and that's fine, and you can't really do that in a class setting, you have to get it done in those four hours. I feel like That kind of takes away a little bit from the experience."

While the students we interviewed described that lab experiences promoted their curiosity, one professor noted that working in a research lab didn't guarantee student curiosity. They described that students can work in the lab as a "technician", only doing what they are asked or required to do, while others ask questions and seek additional information.

> "I think that if they are not curious then they are just acting as a technician doing what I tell them to do. um I've been lucky in my career to have students that seem generally interested. They ask questions; "can you point me where to get literature so I can read up

on this?" and things like that. And I think students that aren't curious won't do that. They'll just come in and punch the clock and do what I tell them to do."

Professors were more likely to discuss the limitations of research than students when considering competing motivations, such as balancing curiosity with hitting milestones and goals set by funders.

> "I so, my students do work on funded work. And funded work has goals and milestones that they have to hit. And I don't like goals and milestone driven research, but the government doesn't just give you money to go play. So in many ways there's an end goal that I instruct them to go after. But if what they are doing isn't working then um we'll tell them "well try this". Or they'll say hey I did this and look this resulted."

## Discussion

Curiosity is associated with learning and academic achievement [2], but little is known about how undergraduate educational experiences may impact student curiosity. Prior work has examined how undergraduate engineering students' research experiences may promote curiosity, but not all students have the opportunity to participate in these experiences. Understanding the role of both class and research experiences can help to motivate policies around making research opportunities accessible and also suggest what can be done in class instruction to provide similar benefits to student curiosity. In the current study, we found that students reported that classes encouraged their curiosity when the students encountered uncertainty that led to information seeking, were able to see connections to real world applications and when they had engaging instructors. Redundant content, overwhelming classes, time constraints, motivation to get the "right" answer, and critical professors were described as obstacles to students' curiosity in classes. Students also reflected on how their experiences of curiosity in research compared to their classes in ways that aligned with the identified supports for and barriers to curiosity.

### Causes of curiosity in classes

We were interested in understanding students' experiences with uncertainty to understand their curiosity based on prior theoretical and empirical literature demonstrating that curiosity results from an intrinsic motivation to seek information in response to uncertainty and knowledge gaps [1]. All students interviewed reported encountering some degree of uncertainty during their classes, which often occurred when they were learning about an unfamiliar subject or revisiting a prior subject and learning novel information. For example, when class was "confusing" some students were motivated to take time outside of class to review or look up new information, and this information seeking was described in ways that suggested an intrinsic motivation rather than extrinsic motivators like grades. Students also felt more engaged when they saw connections between class material and real-world events and applications. Engineering is a "practicing profession" in which basic science and math concepts are utilized to solve applied problems [14]; undergraduates already seem aware of this problem-centered approach and appreciate it. When students have the opportunity to make connections and apply their learning, such as by building assignments on a 3D printer, the course content is more meaningful because students can envision how they may utilize their knowledge in future careers.

We propose that instructors can foster curiosity in their classes by encouraging exploration, scaffolding real world applications, and recognizing students' learning processes both through their direct interactions with students in their instruction and also through the assignments they ask students to complete. Students reported that professors were most helpful when they were "challenging" but also "understanding and sympathetic". Faculty commented on the importance of presenting students with the right amount of uncertainty so they would be challenged but still able to learn new information. For instance, one professor noted that in introductory courses they try to present a "sanitized picture" and not overwhelm students with the possibility of "50 fuzzy outcomes", which aligns with students' appreciation for effective scaffolding of their learning. Students also appreciated when professors modeled uncertainty for their classes by admitting when they do not know the answer to a question or had made a mistake, which professors discussed as well in their reflection of their interactions with students. When professors scaffold the right amount of uncertainty, that is enough that students are not bored but not so much that they are overwhelmed, and model comfort with uncertainty, students may feel more able to be curious [18]. Because students are often at different levels of prior knowledge and experience, this can be challenging, but providing hands-on, experiential learning opportunities gives professors the opportunity to monitor and step in when they see students who need more support and can also create a sense of prioritizing the learning process over performance.

**Obstacles to curiosity**

In alignment with Lowenstein's Information-Gap theory [1], students reported that they were less likely to be curious when they encountered too little or too much uncertainty in their classes. One student described a course with too much uncertainty as "theory heavy" and "numbing," which suggests that these types of courses require students to take in so much new and abstract information that they do not have the capacity to pursue additional questions or information. More commonly, students complained that their curiosity was low when courses were redundant and repeated information from prior courses without adding new information. If students feel that they are already overly familiar with the course material, they can become disengaged and be less likely to pursue a topic further. These responses indicate that students want to be challenged with new information in their classes, aligning with their explanations of what makes them become curious, but not provide so much new information that they are overwhelmed.

Students also expressed that they felt they did not have time to be curious due to the pressure of their schedules and need to get good grades. A student's explanation that they felt a conflict between being a decent student and a decent engineer and that taking time to pursue a question or explore information might get in the way of a good grade clearly demonstrates the conflicting goals around curiosity and performance emphasis often observed in educational contexts. These concerns were apparent to professors as well. They described that curiosity can be "ground out" of students and that students were concerned that every test or assignment could impact their GPA and ultimately their career. These responses reveal that students perceive a cost to being curious and feel they must focus their efforts on tangible outcomes such as graded assignments.

### Survey results and student perceptions of assignments

Student responses on the curiosity survey echoed what was learned from the subset of students who completed the interview. The highest levels of curiosity were reported for hands-on activities and lab sessions, which are the types of experiences that allow for more real-world connections and have less of an emphasis on getting a specific correct answer. Similarly, graded exams, which are explicitly focused on extrinsic performance outcomes, had the lowest ratings for curiosity. It was interesting that homework assignments were not rated more negatively, as they typically involve similarly structured activities designed to elicit a correct answer. This may indicate that students sometimes see homework as an opportunity to dive deeper into what was learned in class, and as more of a learning opportunity than a summative assessment. Students seemed to favor homework assignments where multiple possible answers would be accepted, potentially putting more priority on the processes of thinking and learning over performance. These assignments may also be given with credit for completion, which can alleviate some of the stress that grades impose and encourage students to be more engaged in the assignment. Students were relatively neutral about assignments such as readings, which is somewhat surprising given that students report seeking out additional readings when they are curious about a topic [12], but they were likely also responding in relation to readings assigned with expectations for completion, relating to course performance and learning assigned content over what a student might be curious about or the specific questions they have. Because curiosity results from uncertainty and knowledge gaps, the readings and lectures both can be opportunities to provide information that can then lead to questions of things students don't know but are curious to find out, and if these are done in engaging ways that involve real-world connections they could be effective means to promote curiosity. Similarly, all course components can be constructed in ways that promote metacognitive reflection on what one does and does not know to help identify things students might be curious to find out.

### Class compared to research experiences

All students participate in labs as part of their engineering courses, and many students also take part in research separate from their courses. Research experiences outside of class are clearly impactful for students, with one student citing that their involvement with a lab was more impactful than class experiences on their decision to pursue graduate school. While class labs allow for hands-on experiences, students reported that they often felt constrained and rushed by the limited time available to complete lab assignments. In contrast, students reported that it was understood in research labs that science could be slow sometimes, and it was acceptable to take time to reflect and ask questions of other lab members. A student also noted that they were more able to pursue their curiosity in a research lab because there were less people, which meant it was easier to ask questions without being concerned about wasting others' time. Professors perceived different levels of curiosity in undergraduates that worked in their labs and noted that particularly curious students ask for opportunities to learn more about the projects and sometimes take responsibility for their own role or project in the lab after they have gained enough experiences. Professors were also more aware of the challenges associated with conducting research. While students perceived that there were less constraints in lab settings compared to class settings, they did not seem aware of other factors that impact research such as funding requirements and milestones.

**Implications for faculty**

Both student and faculty interviews revealed that professors can have a major influence on students' curiosity in class. These findings indicate that there are tangible practices professors can put in place to promote curiosity. Professors can make sure that the level of uncertainty is appropriate for the class so that students feel challenged by the material, but not so much that they are overwhelmed. Students appreciate when professors model comfort with uncertainty and acknowledge that they do not know everything and make mistakes. This may help students feel less vulnerable when they encounter uncertainty, and more open to uncertainty as opportunity to learn. It is also important, particularly in engineering courses, to make sure students are able to see real world applications and take part in hands-on experiences that allow them to implement what they learn in class.

Whereas professors clearly identified curiosity as important and were able to identify factors that promoted and obstructed student curiosity, it was not clear that they felt they had a huge influence on curiosity. They described that it would be ideal if every student came to class curious, but that they found this was often forced out of students due to busy schedules and pressure to get good grades. Noticeably absent from the discussion was the role professors can play in setting expectations about grades. Professors have the opportunity to assign homework and projects that allow students to demonstrate their knowledge rather than arrive at a single answer and to decide how much exams impact student grades. When teaching, faculty members could also be mindful of other demands students have on their time, which can inspire empathy that helps students feel supported and encouraged while they're learning. Students and professors commented that working in a research lab promoted curiosity more than class experiences, but not all students are able to fit research in their schedule. Others may not look into pursuing research out of concern for how the time commitment might impact their grades. Many undergraduate students need to work and may only be able to participate in research experiences if they are paid. While some aspects from research experiences related to curiosity might be possible to bring into classroom contexts, some may not due to the nature of classroom learning. Thus, given that research can influence student career goals and job prospects, it is necessary to think more about which students have access to and opt into research experiences and why others do not.

**Future Directions**

Undergraduate research experiences can promote students' curiosity, but not all students have the opportunity to participate. Future work should examine why students chose to participate in research experiences, and whether there are potential barriers to participating in research. We should examine what universities and faculty can do to make sure that all students who want to participate in research have the opportunity. In the current study, we were not able to interview students who only had class experience. Several students from the classes we surveyed did not take part in undergraduate research, but none of these students volunteered to be interviewed. In our previous work, we have noted that our participant sample may be limited by a self-selection bias in which only students with positive experiences in class and/or research are choosing to take part in our interviews [12]. In future research we could use a more anonymous tool, such as a survey with open ended questions about student experience, to gain a broader understanding of student experiences.

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