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“Where could this take me and what kind of interesting stuff could I do with that?" The role of curiosity in undergraduate learning

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“Where could this take me and what kind of interesting stuff could I do with that?”: The role of curiosity in undergraduate learning

ABSTRACT: This qualitative research paper explores how undergraduate research experiences impact engineering students’ curiosity and responses to uncertainty. Curiosity occurs when a student encounters uncertainty and seeks to close a gap in knowledge [1], which can lead to deep and meaningful learning [2]. In research labs, students can extend and apply content they learn in class and pursue independent lines of inquiry. We ask whether engaging in research experiences can therefore support and promote students’ curiosity. Eight undergraduate engineering students working in research labs participated in a semi-structured interview about their research and class experiences. These interviews were coded for themes related to uncertainty and curiosity. This paper specifically investigates causes of students’ curiosity and their responses to uncertainty. Students were curious about a wide variety of topics both within and outside of engineering and appreciated that research provided opportunities to apply and deepen their knowledge. They frequently encountered uncertainty and responded by independently seeking resources or consulting a mentor, most often a graduate student. These findings can help inform how professors in both classroom and lab settings can cultivate and encourage their students’ curiosity and help them respond to uncertainty.

Keywords: Curiosity, undergraduate research experience, motivation, active learning

This qualitative research paper is part of a larger mixed-methods study that investigates the role of engineering research experiences in undergraduates’ education, and how students’ curiosity influences and motivates their learning. As engineering is a “practicing profession” [3] where theories from mathematics and physics are applied to solve real world problems, experience in a research lab can serve as a vital component of an undergraduate’s education. Through research, students learn how engineering knowledge and applications are created and develop skills that are not learned in their courses [4]. Engineering students report that engaging in undergraduate research greatly increases their technical skills and knowledge [5] and helps elucidate career goals [6]. Moreover, undergraduates report that their research experiences deepen their engagement in learning, amplify their motivation to learn, and increase independent thinking [7].

These admirable outcomes may be due to research experiences cultivating curiosity. Curiosity can lead to deep, meaningful learning, especially when in response to uncertainty or information gaps [2]. In engineering, students can explore topics they are curious about through research outside of their classes, providing experiences that help to bridge the content from class to real-world applications. Exploring one’s curiosities within college classrooms can be detrimental to class performance [8] as it can distract from the specific content that will be assessed. Yet, as students gain knowledge about things they may or may not already be interested in, this perceived knowledge gain leads to higher curiosity [9]. Traditional courses focus on specific content and learning experiences, which might limit autonomy for learning and curiosity as a result [10]. In comparison, research experiences can provide an important outlet for supporting and promoting student curiosity.

Based on the Information Gap Theory of curiosity [1], a curiosity promotion framework suggests that when students are given the chance to engage in thinking about and exploring uncertainty, which commonly occurs in research labs, curiosity is supported [2]. Curiosity is rooted in uncertainty, which occurs when an individual is aware of a lack of knowledge, information, or understanding [11]. Uncertainty is different from ignorance where an individual is not aware that they lack knowledge, information, or understanding [12]. Stretching students to think about what it is they know and don't know and *how* to get the missing information helps them to become curious. When more senior lab members or professors model comfort with uncertainty students develop their own comfort with uncertainty and likelihood of acting on curiosity [2]. This type of learning is constructive and interactive, leading to deeper, more meaningful learning [13]. Undergraduate engineering research experiences can provide opportunities to develop curiosity by providing learning environments that are focused on exploring questions rather than performance.

In the current study, we explored undergraduate Materials Science and Engineering (MSE) students' curiosity through qualitative interviews about their experiences with uncertainty and curiosity in their classes and research experiences. This paper presents an initial exploration into what experiences lead to student curiosity and how students approach situations in which they feel uncertain or curious about something. The goals of this work are to identify the themes around students' experiences of curiosity in their engineering education and to use this information to consider ways that engineering programs can promote student curiosity.

Methods

We are a team of faculty and students in education, social science, and engineering, with expertise in quantitative and qualitative methods. This paper draws data from a larger overall mixed-methods study of undergraduate engineering student research experiences focusing specifically on the characteristics that are related to students' curiosity and motivation. The data collection of this study was conducted in the 2021-2022 academic school year, consisting of three measures: interviews, surveys, and observations. Differentiated interviews were conducted with both professors and students in the Engineering School including questions regarding class and lab experience, curiosity, uncertainty, and motivation. Observations were conducted in both the class and laboratory settings, with observation notes focused on curiosity and uncertainty promotion and suppression. This paper analyzes data from the student interviews from fall 2021. All authors developed the interview, survey, and observations measures together. Author 1 conducted the interviews, and Authors 1, 2, 3, and 4 coded them.

Participants

We were particularly interested in recruiting students from the Department of Materials Science and Engineering (MSE) at our current institution, a flagship state university on the East Coast. The current undergraduate cohort includes twenty (2^{nd} through 4^{th} year) students with a near term department goal of increasing this number to 75. Materials science and engineering departments' student numbers are typically small relative to other engineering majors, for example MSE has only about 5% the enrollment compared to mechanical engineering. As such, the department is in a position to offer customized and hands-on research experiences in both laboratory coursework as well as in sponsored research activities. The department's goals are *i)* to encourage active engagement of every materials science undergraduate student in sponsored research within our research laboratories; and *ii)* to promote learning and interest in research through laboratory courses. The department has 23 research active faculty in the areas of structural materials; electronic, magnetic, optical materials; electrochemistry and corrosion; and soft materials that support active involvement of undergraduate researchers.

For the interview portion of the study, participants were invited from the population of undergraduate engineering students working in research labs using two methods. First, an announcement was made in a MSE course about the study with a link to the survey, and at the end of the survey students could include their information if they wanted to participate in an interview. Of 22 students, 9 responded to the survey, of which 2 expressed interest in the interview, but neither chose to participate. Second, the research team contacted students who had current positions working in MSE faculty research labs. Of 43 students contacted, 11 students responded. Due to scheduling issues, not all students who wanted to participate in interviews did, resulting in a final sample of 8 students completing interviews, which were conducted either in person or via zoom. Two interviews collected in the summer as pilot data were included in this data set (after student consent was granted) because no substantial changes in the research protocol were made. All students participating in interviews were actively working in an MSE faculty member's research lab at the time of the interview and answered questions about both their classroom and lab-based learning experiences.

Students self-reported their race, gender, class year, and major. Student responses will not be separated by demographic to protect their confidentiality. Of the 8 students who participated, 5 identified as female and 3 as male, 3 identified as White/Caucasian, and 2 as Black/African American. Two students identified with multiple racial backgrounds including Asian, White, and Native Hawaiian or other Pacific Islander. Students were in their 2nd to 4th year, and all students were either Materials Science and Engineering (7 students) or Mechanical Engineering (1 student) majors.

In this study, we explore whether participation in hands-on activities in both research laboratories and our lab-based coursework can promote students' curiosity, and what specific characteristics of research experiences relate to positive student perceptions so that we might improve both our laboratory course offerings and research lab experiences.

Interview

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 interview guide was pilot tested during the summer with three student participants and then revised, although substantial changes were not made. The interview included 35 questions (plus relevant follow-up questioning), was approximately forty-five minutes in duration, and was audio recorded and transcribed.

Coding

Once interview data were collected and transcribed, the team met 3 times and used several rounds of open coding and collaborated to discuss results. The research team then created an appropriate code book that encompassed the goals outlined in the research questions and the themes identified in the data. After the code book was created the data were coded by Authors 1 and 3. Consensus coding was then used to resolve any conflicts and then codes were reviewed by the team as a whole.

Results

The initial interview coding process resulted in seven categories of responses, which are described in Table 1. After coding all the data and identifying the seven themes, we selected quotes as exemplars for each theme and each subcode within the themes. In considering the themes that emerged, two aligned with a recent framework presented for how to promote curiosity in education contexts, the Curiosity in Classrooms (CiC) framework [2]. The CiC framework describes how curiosity can be promoted both by promoting students becoming curious, which aligned with our code of “causes of curiosity” and by supporting students’ responses to uncertainty or curiosity (i.e., information seeking), which aligned with the code of “strategies of approaching or responding to uncertainty”. Although the CiC framework describes methods that instructors can use to promote curiosity in prek-12 education, the two themes discussed here align with the two main categories of curiosity promotion, so we thought it would be interesting to understand students’ perceptions of their own curiosity developing in education and their responses to it.

TABLE 1: List of major codes

Code	Definition
Recognition of uncertainty	Citing an example of, describing, or displaying understanding of uncertainty in any context or situation.
Causes of curiosity	Acknowledging or explaining something that makes or made the respondent curious; this may be a situation, a topic or question they have.
Motivation	Actions in response to curiosity, whether explicitly defined as a motivation for action or not. Subcode: Demotivation
Strategies of approaching/ response to uncertainty	Responses and/ or strategies engaged when experiencing uncertainty, described either explicitly or indirectly.
Lack of uncertainty	Certainty; Explanations or displaying certainty or the desire for certainty through

	words or actions.
Affect related to uncertainty	Emotions or connotations expressed relating to uncertainty.
Changes and/or reflection about own curiosity	Personal examples of curiosity and/or the change in their curiosity.

"Present a little bit and I'll try to pursue it further": Causes of curiosity

Within the code of causes of curiosity, several sub-codes were identified, discussed below. These include topics of curiosity, or what students report being curious *about*, influences on curiosity, and deepening and applying curiosity, which is related to students' developing or changing curiosity.

Topics of curiosity

As would be expected with a group of engineering majors, many students expressed curiosity about subjects related to Science, Technology, Engineering and Math (STEM). One type of response given involved naming things that students were curious about. Sometimes this theme was expressed as being curious about broad topics such as chemistry, math, and engineering, whereas some students named more specific subjects of curiosity such as cement phases, mechanical processes, corrosion, aluminum alloys, additive manufacturing, electricity, and polymers. In some instances, students elaborated to describe how their curiosity about a particular subject inspired them to work in a research lab:

"What piqued my interest was the additive manufacturing portion of the research. I got probably my earliest engineering type interest and material science interest was in just regular desktop 3D printing, which deals with plastics, but … as soon as you start tinkering with it and troubleshooting, you've got to understand like, all right, how are these things heating and cooling down and sticking together . . ."

At other times, students expressed that they were curious about engineering subjects outside of the scope of their research:

"I guess it's not really pertaining to this research, but I have a really big interest in, polymers, and recyclability of polymers . . ."

Students' curiosity also extended beyond STEM and included topics ranging from foreign policy to the Roman Empire and World War II. Several students mentioned that they wanted to know more about psychology, specifically what motivates people, how people interact, and how people interpret information. One said, "I like learning about motivation and, you know, how other people think, and stuff like that."

Influences on curiosity

Several students named their parents as major influences on their curiosity. At times students described this support generally, e.g., “my parents really encouraged curiosity and education,” and in other instances they described how their parents’ influence led them to develop specific interests. For example, one student described how their current research focus aligns with a long-held fascination related to their father's occupation. Students also mentioned that professors fostered their curiosity in both class and lab settings. For example, a student described how a professor’s engaging explanation of course material at the students’ level encouraged their interest in the class:

“Professor [X] was, I mean, you can tell that he's very engaged in the subject, which is hard, because a lot of the better professors at [university] who are going to be more advanced, are going to be focused more on their graduate students and getting their graduate research, because having their publications is where there's more prestige, I guess, and so I'm seeing a teacher who is interested in teaching a subject about concepts that he has known for very long, very basic for his field of research and just being able to be lively to the first year undergrads was very influential.”

In the lab context, students were encouraged when PIs valued and were welcoming of questions, “something that I really appreciate about Prof. [X] is she doesn't think any question is not worth asking”. Students also reported that they were curious about other projects in the research group, “it's always really neat to hear what other people were doing in the lab since my project is completely separate from everyone else in the group”.

Deepening and applying curiosity

Although there was variation in students’ perceived prior knowledge related to engineering, they reflected that they arrived at class or their research lab already curious about an engineering topic and that their experiences helped them to deepen their curiosity. Students recognized that they often knew very little about the specialized topic of research they became engaged in and reflected on how their growing curiosity:

"I knew next to nothing about this specific part of it. I knew conceptually, like the idea of making a chemical solution and then coating it onto something, but I know nothing about zirconium oxide...I'm really getting invested"

Interestingly, students also reflected on seeing similar changes in research interests in PIs:
"I knew very little about what was actually going to be happening in the lab. I knew generally the areas that Dr. [X] focuses in, however it's a wide variety of topics and he switches every few years"

More generally, students’ reflections on changes in their own curiosity also touched on the general dynamic nature of research. One student commented that engaging in research was like entering a “spider web”, where the answer to one question branched off into a series of new questions:

“the more I learn, the more I see opportunities to kind of spin off and do new cool stuff with it. So that's just how I am in engineering. I'm always kind of tracking out trajectories, like, where could this take me and what kind of interesting stuff could I do with that?”

Students also described how class and lab experiences helped them to recognize areas of uncertainty in topics that seemed simple on the surface, and this recognition led to greater curiosity:

“We were talking about, essentially, how we don't fully understand the processes involved in why ice is slippery. So, we're learning about essentially how pressure can increase melting temperature but then there's also friction and such. And so, that just really made me curious as to what other processes like that seem simple on the surface that we still just don't understand today.”

Students noticed that a particular benefit of working in a research lab was the opportunity to see connections between scientific principles and real-world applications. They also had the chance to explore subjects that they had not encountered in class.

“I think corrosion is super cool, I've never had a class with corrosion before, this is my first experience dealing with it, it's just super interesting. Second of all, just how a lab setting can relate to a real-world example every single time I make a different salt solution.”

“I’m going to Google this later”: Response to uncertainty

Within the code of strategies of approaching or responding to uncertainty, several sub-codes were identified, discussed below. These include seeking answers from others, seeking answers independently, responses to unexpected results, and accessing many resources.

Seeking answers from others

When encountering uncertainty, students frequently reported that they sought out other people for help. In the lab, this included the lab’s principal investigator (PI) and graduate students, “my PI and the grad student I worked under were very available, so I can always go to them, ask the questions I had,” as well as postdoctoral researchers and other undergraduate lab members. Notably, most students (6 out of 8) reported that they went to their PI for help, and all mentioned that they received help from graduate students, with many reporting that graduate students were their first point of contact when they encountered uncertainty.

“And then the cement project, things are breaking, things are going wrong, and the graduate student that I'm working with, I feel like I've learned a lot just watching him change directions based on what’s working. We have weekly meetings where we set the focus for the next couple of weeks, and that can just change on a dime.”

For uncertainty encountered in class, students reported that they sought help from teaching assistants (TAs) and professors during office hours in addition to other classmates.

Homework was often mentioned as a source of uncertainty that would prompt a student to reach out for help.

“I think, homework is to help you develop mastery and considering, you're not going to have that [certainty] going into the homework. It's going to be all that uncertainty where you'll hopefully be learning the content. I think, if there's uncertainty within how a question is phrased or whatever, then I'll reach out to the teacher directly and just be like okay, what concept are you challenging us with here?”

Seeking answers independently

Students mentioned that they utilized a variety of information sources when they encountered uncertainty. These included print sources such as textbooks and lab manuals, as well as online resources such as Google Scholar, YouTube, and online articles. One student noted that they turned to these resources when they felt like they needed to work something out for themselves:

“Sometimes working through a problem on your own is how you convince yourself of the solution and you know how that solution is going to work. . . if I'm really looking to increase my understanding of it, I might slog through a textbook or a manual or something or a YouTube video - so much is on YouTube.”

Most students gave broad descriptions when mentioning these sources, as in “alright, now it’s time to consult the internet,” although one student commented that they were particularly concerned about finding credible sources, “so trying to distinguish which sources were the most credible introduced a lot of uncertainty into the final result”.

Responses to unexpected results

A common source of uncertainty for students working in research labs was unexpected results from experiments. Some students described that this was a common occurrence and described how they approached these situations:

“Unfortunately, it is very hard to get your data to look the way you want the data to look. And so I think every time, opening up on what I'd say the majority of times it was not what we wanted it to look like and then it was with that surprise you had to figure out, okay, what could have gone wrong here. Why'd we end up with this.”

One student described that in situations of uncertainty they would redo an experiment to check for human error. Another student described corresponding with a graduate student and postdoctoral researcher in an unexpected situation and expressed their pride in being included in the process of problem solving:

“I told [grad student] and the post doc in the lab everything about it and we went over the possibilities of things that could have gone wrong, like he literally texted me and he was like okay, what do you think, could have gone wrong with the furnace and he was like, why don't you make a list and we'll talk about it, which I thought was really a fun thing…I just thought it was really cool that he trusted me to think about it, and think my way through it, and so I came up with a list of things."

Accessing many resources

As the example above illustrates, students often utilized several resources at once when they encountered uncertainty. In research labs, this involved speaking with several different members of the lab as well as searching for sources independently:

"I feel like the entire department's pretty easy to rely on. Obviously, my main boss is the research scientist, the grad students can also help a lot, considering they're always asking each other questions because they're doing their own research. So, they'll work together, they're used to getting us questions and asking them themselves. I think that's a good community. And then Google Scholar."

In class settings, one student stated that, "the teacher, your classmates, online, or the textbook," are, "the four go-to's for any student". Another student described how they independently reviewed a question to address gaps in their knowledge using YouTube to feel prepared to ask questions during office hours:

"Firstly, I'm consulting YouTube videos, because I know once I go to office hours it's still going to be a little bit of a jump between someone who really knows their linear algebra and me who knows nothing."

Discussion

Understanding the causes of student curiosity can inform instructional practices and knowing how students approach and respond to uncertainty can provide strategies for scaffolding students' information seeking and identifying useful resources to provide for student learning. In exploring student causes of curiosity, students described being curious about a broad range of topics and that curiosity increased with opportunities to apply and deepen their knowledge. When encountering uncertainty, students most often responded by reaching out for help from a mentor, usually a graduate student, or by independently searching for resources.

Causes of curiosity

Students in this study were curious about a variety of different topics ranging from broad STEM subjects to specific interests in materials and engineering processes, as well as topics outside of STEM all together. While some students mentioned that their curiosity about a certain topic led them to join a particular lab, many had not studied the lab's subject matter extensively before entering the lab or had other curiosities outside of the lab's focus. This suggests that students have different motivations for joining a lab. Some may be interested in pursuing a specific line of research on a certain topic while others may be looking for more general lab experience or are unsure of what they are most curious about. Students' level of knowledge about the lab's research focus can affect their experience, as some may be ready to generate research questions of their own or build upon questions currently being examined in the lab, whereas others may need to engage in tasks that help them build a knowledge base about the lab's research and protocols.

Students reported that one of the benefits of working in a research lab was the opportunity to deepen and apply their knowledge on topics they were curious about or were introduced to in class. One student used the metaphor of a spider web to describe the iterative nature of curiosity as one question branches off into new questions or lines of research. Research labs can provide students with more opportunities to pursue these questions than a traditional class that is constrained by time, subject requirements, and human resources. Investigating a new question carries a degree of risk-taking because the idea may take time away from other work and ultimately not be useful. Students may be less likely to take this risk in a class if they think it may impact their grade. Working in a research lab also encourages students' curiosity by allowing them to apply theoretical engineering knowledge they learned in class to real world problems and situations. Almost every student interviewed worked in a lab that examined a practical issue, from investigating how ceramics can be used to make more effective aircraft engines to how corrosion can affect the copper used in COVID tests, bringing meaning to the more basic content they were learning. Ultimately, all students entered the lab with some degree of curiosity and engaging in a research experience provided an opportunity to explore new questions and deepen prior knowledge.

Response to uncertainty

Every student interviewed in the study reported that they sought the help of a graduate student when they encountered uncertainty, and most also mentioned the lab's PI as a source of help. In many cases, students worked directly with a graduate student in the lab and assisted them with their projects, therefore, it is likely that grad students were often physically present in the lab when uncertainty arose or were available to call or email. It is also possible that undergraduate students felt more comfortable expressing uncertainty and asking questions [14]. Grad students are students themselves, and in many cases, they are not too far removed from the undergraduate experience. They may be able to take the perspective of an undergraduate and explain things in an accessible manner more easily than a PI whose years of experience can create an "expert blind spot".

Principal investigators and professors also certainly influenced students' curiosity by using engaging pedagogical techniques, such as meeting students at their level, through creating a culture of welcoming and valuing students' questions, and in scaffolding information seeking by providing resources to help answer their questions. PIs and professors also have the experience needed to help students recognize what they do not know and to model comfort with uncertainty. One student gave the example of a professor who pointed out that it is not fully understood why ice is slippery during a lesson on melting points and pressure. By making students aware of their own uncertainty, the professor was able to engage their curiosity. Professors' and PIs' knowledge and experience may also make students hesitant to ask a question if they believe it might be too simple. One student described that they felt the need to prepare for office hours by watching educational YouTube videos. This student may simply be conscientious, but this example highlights that students can feel self-conscious about asking a question when they feel uncertain. This is relevant in class settings where students may not have time to fully form a question while keeping up with the class or may be apprehensive about asking in front of peers.

When encountering uncertainty, several students reported that they took the initiative to consult resources in print and on the internet. It was notable that students did not discuss how they searched for resources on the internet or how they chose which ones to use.
Only one student mentioned that finding "credible" sources was a priority. This suggests that PIs and professors should both direct students to useful online resources and dedicate time to teaching students how to discern credible resources themselves.

Implications for engineering education

The themes identified and explored in this paper aligned with the recent Curiosity in Classrooms framework used to understand how prek-12 teachers can support student curiosity [2]. The responses from students within the themes of causes of curiosity and responses to uncertainty were consistent with the practices identified to support curiosity in educational contexts and suggest that similar practices could promote curiosity and learning in engineering undergraduate students. For example, for promoting students becoming curious, learning experiences can be designed to scaffold students' recognition of things they do and do not know, and professors and PIs can model being comfortable with and valuing uncertainty, helping to identify open questions that can be explored and making connections to real-world meaning of what students are learning. Related to students' responses to and strategies for approaching uncertainty, scaffolding for finding and evaluating relevant information can be provided. Mentors at different levels can also be available for students to bring questions to. More generally, a culture in both classrooms and research labs can be cultivated that welcomes students' questions and provides opportunities for students to engage in work that relates to things they are curious about.

Limitations and Future Directions

The sample size of the study was small, and only 19% of the students that were contacted volunteered to be interviewed. All the students we interviewed seemed to be curious about their research and described an overall positive experience with their lab and mentors, but this could reflect a self-selection bias. Students who did not feel curious about their research or did not have a productive relationship with their PI or graduate student may have felt uncomfortable discussing their experiences with the research team even with the promise of confidentiality. Interestingly, the demographics of the current study are not representative of the university's engineering school or engineering more generally, with 62.5% of study participants identifying as female and 37.5% students historically underrepresented in engineering (i.e., racial, and ethnic backgrounds other than White or Asian). It could be that students from underrepresented groups are especially motivated to pursue engineering and/or research experiences because of their curiosity, which is why they participated in this study and had so much to say about the role curiosity plays in their classroom and research experiences. While we are cautious in drawing conclusions from this pattern, as it is a small non-representative sample, we do see this as an area of importance for future research. Specifically, we hope to further explore how promoting and engaging students' curiosity can provide support for students from backgrounds historically underrepresented in engineering, perhaps by making the content more meaningful for them or by creating a more welcoming culture where they feel they belong. Research experiences might be especially effective in achieving these goals, so further research to test these ideas is needed.

We plan to invite all students who were interviewed to participate in a second interview after they have spent at least one semester in a research lab. This will allow us to ask whether their curiosity has changed as they have spent more time in the lab and become more familiar with the research. It may also be important to expand the study and interview graduate students given that they influence undergraduate research. Grad students would be able to reflect on how their curiosity in their research focus has changed over time and how it may have led them to pursue a higher degree. Grad students also serve a dual role as a student to the PI and a mentor to undergraduates. It would be useful to know how grad students approach working with undergraduates and whether they feel prepared to work with them during encounters with uncertainty. Finally, it would be valuable to interview engineering undergraduates who have chosen not to work in a research lab to understand how their curiosity develops through coursework alone and to compare their curiosity and comfort with uncertainty to students in research labs.

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Appendix

Interview Script

"Hello! Thank you so much for participating today. My name is [interviewer's name], so nice to meet you. [interviewer introduces self]

"Before we start, I want to make sure that it is okay if we record this session so that we can remember what you tell us during our interview today. We won't post the video anywhere that people outside of our research team can see it, and if you change your mind and want us to delete it at any time, we will do that. Is it okay if I start the recording? [wait for confirmation].

"**Okay, we are recording. Thank you for filling out the consent form already! We are trying to learn more about the experiences of engineering students in classes and/or research positions with hands-on learning. Universities tout their undergraduate students' access to laboratory courses and research experiences, which are credited with increasing students' likelihood to choose careers in science and engineering, improving their curiosity and critical-thinking and problem-solving skills, and developing their sense of personal identity as engineers. In this study, we will try to identify the specific factors of laboratory courses and undergraduate research experiences that tend to create these admirable outcomes.**

"We'll start with a few warm up questions then I will ask questions about your research experience and/or course experience and three questions about curiosity.

I have prepared some follow up questions to check for understanding to help us develop these questions to be sure they are explicit and comprehensible. We anticipate that this interview will take less than an hour. Do you have any questions at this point?

Check for understanding:

- **“Do you need me to repeat anything or say anything differently to help you understand what we're about to do?**
- **“Can you repeat back to me what I’ve said we’re going to do?**
- **“Does this feel like topics that you’ll be able to talk about in detail?**

<u>Warm Up:</u>

1. **What’s your major?**
2. **Why have you decided to study engineering?**
3. **What year are you?**
4. **Have you ever done research?**

Yes -> Research section.
No -> Classroom section

<u>Research: topic, tasks, community</u>

R1. **Why did you decide to do research?**

Follow-up if needed:

1. **Did you have something you were hoping to learn that led you to want to do research?**

R2. **Tell me about your research experience.**

Follow-up if needed: *Make sure to ask about any prior research experience in other labs*

a. **Who do you work with?**
b. **What tasks do you do?**
c. **What are you trying to find out?**
d. **What have you learned?**
e. **What do you want to learn** – save this question

R3. **Before starting your research experience, how much did you know about your research topic? Tell me more about that.**

R4. **What about your lab's research do you want to know more about, if anything?**

R5. **Tell me about aspects of your research experience that are less interesting to you?**

R6. **Tell me about a time you encountered uncertainty or ambiguity in your research experience.**

a. **What did you do?**
b. **What resources have you used in times of uncertainty?**

c. **How did you feel?**
d. **Do you think that uncertainty or ambiguity is important in research?**

R7. **Tell me about a time when something surprised you while engaging in your research activities.**

a. **What did you do?**
b. **How did you feel?**

R8**. Do you anticipate that your curiosity about [topic of research] will change as you continue research throughout the (year/semester)?**

a. **Why/why not?**

R9**. What are some specific aspects of doing research that motivate you to continue in this subject area at the moment or in the future?**

R10**. What are some specific aspects of doing research that DO NOT motivate you to continue in this subject area at the moment or in the future?**

R11**. Has anything from your research experience led you to try and learn something that went beyond your assigned research tasks, such as finding and reading information, signing up for a workshop or class, or asking someone questions?**

1. follow-up probing to get specific examples if needed

R12**. In your own words can you tell me what research is or what it means?**

a. **We have decided to define a research experience as "taking a systematic approach to gathering data and producing new knowledge. It typically takes place in an academic institution, a government agency, or a company**" (Wylie et al., 2020)

Classroom Experience

CE1. W**hat have been your favorite courses thus far?**

a. **Why?**

*CE2. **What has been your favorite class assignment? What motivated you to complete it? What influenced the effort you put into the work?**

Follow-up prompting questions:

a. **Prefer more goal oriented (right answer) or mastery oriented (projects)?**
b. **Try to get at whether this was driven by students' own goals or instructor's goals, structure of class, etc.**

CE3. **If you had the opportunity to sign up for a class on any topic, what would it be?**

a. **Is this a topic that you already know about or would be new learning?**

*CE4. **In your lab classes, do you prefer doing labs that have a single right answer, or labs that have many possible answers? Tell me more about that.** Is the most important part of lab arriving at the answer or getting to the answer?

1. **Generally, do your professors focus more attention on the learning process or the single right answer?**

If haven't done lab classes yet:

a. **Imagine you were in a lab class, would you be more excited about a lab that was structured to have you figure out a right answer or to do one that had many possible answers or outcomes? Tell me more about that, why?**

CE5. **Tell me about a time when class made you feel curious.**

(Follow up re environment/context and interactions.)

a. **What did you do in response?**

CE6. **Tell me about a time when class did not make you feel curious.**

(Follow up re environment/context and interactions.)

a. **What did you do in response?**

CE7. **Tell me about a time you encountered uncertainty or ambiguity in class.**

a. **What did you do?**
b. **How did you feel?**

CE8. **Tell me about a time when something in class surprised you.**

a. **What did you do?**
b. **How did you feel?**

CE9. **Have you taken MSE 2101 or 3101**? or- **what MSE courses have you taken? What other courses have you taken that you feel prepared you for the MSE major?**

<u>Curiosity:</u>

C1. **Can you explain to me in your own words what curiosity is?**

C2. **What is the opposite of curiosity?**

C3. **Do you think it is important to be curious? Why/why not?**

C4. **Tell me some examples of what you're usually curious about.**

a. **in life**
b. **In college**
c. **In classes**
d. **In research**

<u>Conclusion</u>

1. **How have your labs, class experiences or area of research influenced whether or not you anticipate choosing a career in science and engineering?**

2. **Is there anything else you want to share about curiosity, classes and labs, or your topic of research before we conclude?**