Mentored student research: A case study evaluation of benefits and best practices

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JASA ARTICLE

Mentored student research: A case study evaluation of benefits and best practices[a)]

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ABSTRACT:
Efforts to mentor undergraduates in research require time, energy, and resources but can yield significant benefits. A review of education research on undergraduate research is presented followed by a case study of how technical and educational principles from the literature have been implemented and practiced in a new underwater acoustics lab. This case study involves the students who have joined this lab over its first three years. The results highlight the importance of several key factors that mentors can implement to improve their students' research experience. In order to meet the steep learning curve that new students face, faculty mentors should establish a culture of research (i.e., well established norms, expectations, and practices associated with being a part of a research group) through clear expectations, open communication, and student-led peer mentorship supported by carefully selected or designed resources (i.e., scaffolding). This paper seeks to share these education research resources with the acoustics community while providing a case study for review as a specific application of these key principles into an acoustics laboratory setting. https://doi.org/10.1121/10.0014348

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I. INTRODUCTION

One of the best ways to prepare undergraduate students for the next steps in their careers is to provide experiential learning opportunities (Kolb, 2014). In particular, mentored research can provide students with experiences beyond the classroom that not only improve their connection with coursework (Lopatto, 2004, 2007) but also prepare them for future opportunities. While many studies have shown tangible benefits (e.g., co-authored publications, conference presentations) from mentored research, these benefits are often tied to the definition of mentored research and the degree to which a culture of research is established. A culture of research indicates that an institution has well established norms, expectations, and practices associated with being a part of a research group. For example, Brigham Young University has an expectation that undergraduates will be engaged in experiential learning which, in the Physics and Astronomy department, translates to involvement in research groups, an expectation to contribute to scholarly work, and to engage with the professionals in your area of expertise. The benefits of this culture of research depend on establishing clear expectations, open communication, and an efficient model for transferring knowledge and skills to support student growth. This paper shares these education research resources with the acoustics community while providing a case study of how key principles were applied in an acoustics laboratory setting. A review of the current literature on undergraduate research is presented, and key findings are highlighted.

Mentored research experiences for undergraduate students have proven to yield benefits such as better preparation for the professional world and enhanced cognitive and personal skills (Petrella and Jung, 2008). Undergraduates who engage early in research become better students with improved ability for independent thought and problem solving (Lopatto, 2010; Russell *et al.*, 2007). For example, they are more confident and likely to pursue graduate degrees. The benefits of undergraduate research is consistent and lasting among all demographics (Lopatto, 2004). This paper reviews these benefits, common concerns of undergraduate research, and resources to better understand how to define and improve undergraduate research in Sec. II. Section II also contains a brief history of the expectations for undergraduate research in the Department of Physics and Astronomy at Brigham Young University (BYU). In part, these expectations give students the autonomy to engage in the research process at varying levels of rigor and to develop the intellectual independence that typifies true scholarship.

Applying these expectations, the authors developed an underwater acoustics lab in 2019 (Vongsawad *et al.*, 2021), by carefully considering how to build and structure a student centered experience. These considerations led to an emphasis on scaffolding, which is an educational metaphor describing the support a mentor offers to provide a framework and resources for successive levels of understanding and skills to help students gain increasing independence. Scaffolding is important because it allows new research group members to grow at their own pace with the support

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necessary, giving them checkpoints to ensure they are progressing in the desired direction. We took care to design a lab culture conducive to mentored research including clear methods of communicating, mentoring, and training. The goals for the lab were to provide a positive mentored research environment in which each student could (1) develop technical research skills safely with sufficient scaffolding, (2) improve communication between students and mentors, (3) experience peer mentoring, and (4) prepare for their next opportunities (e.g., graduate school or the workplace). Key elements in the design of the lab are discussed in Sec. III along with how they contribute to these goals.

This work evaluates the effectiveness of the efforts to establish a beneficial mentored research experience for undergraduates through a case study. The methodology for evaluating student experiences are described in Sec. IV, followed by the results in Sec. V. The results confirm key recommendations from the education literature, such as the need for open communication and clear expectations (Kolb, 2014; Brew and Mantai, 2017), building students up to the level of instigating and leading their own independent research within the group (Brew and Mantai, 2017; Kolb, 2014; Neilsen and Gee, 2011; Weimer, 2002; Zydney *et al.*, 2002), and the need to start research early (Lopatto, 2010; Russell *et al.*, 2007; Wayment and Dickson, 2008). The findings also note that faculty mentors should establish communication and student-led peer mentorship should be supported by scaffolding through carefully selected or designed resources. This structure enables students to become independently driven research scientists with the technical and professional skills to support the program and become more successful in the professional world.

II. BACKGROUND

In 1998, the Boyer Commission issued a report entitled, "Reinventing Undergraduate Education: A Blueprint for America's Research Universities" (Kenny *et al.*, 1998). In this report, they recommend that research-based learning should become standard practice at the undergraduate level. Those authors state that "Learning is based on discovery guided by mentoring rather than on the transmission of information. Inherent in inquiry-based learning is an element of reciprocity: faculty can learn from students as students are learning from faculty." The report also says that undergraduates should end with a culminating capstone experience, meaning students should participate in a final experience which helps provide a bridge between coursework and either graduate school or the professional workspace under the guidance of a faculty mentor and with collaboration with other students where appropriate. The report encourages universities to provide mentored research experiences to undergraduates. Since the Boyer report, research studies have explored the difficulties and benefits of mentored undergraduate research and offered recommendations for how to provide good mentored research experiences.

Around the same time as the Boyer Commission report, the faculty of the BYU Department of Physics and Astronomy dedicated themselves to the goal of providing mentored research experiences to each student, as described in Sec. II E. While survey feedback has been used to guide internal practices, the results of the faculty's efforts have not been studied generally. This paper shows a case study where a new underwater acoustics lab was designed with student-centered learning principles in mind and reports on the experiences of the first five undergraduate students and first graduate student who worked in this lab. This case study forms the basis for the authors' contribution to the Special Issue on Education in Acoustics. The following familiarize readers with key research regarding undergraduate mentored research experiences (summarized in Table I), followed by a description of how these ideas have been applied in the BYU underwater acoustics lab.

A. Why mentored undergraduate research?

Because of the time and energy required to mentor undergraduate students on research, the objectives and outcomes for the students must be clear. For their future careers, each of these students will need to develop the skills to think critically, analyze problems and make complex decisions.(Kenny *et al.*, 1998; Brew and Mantai, 2017) While college courses provide one avenue for learning these skills, mentored research provides a more realistic experience for how these skills are used in authentic science

TABLE I. Key research regarding undergraduate mentored experiences.

Key Attribute	Description
Clear Objectives	Undergraduates need to be provided with clear and meaningful objectives (Kenny *et al.*, 1998)
Authentic Work Space	Research groups should provide undergraduates an authentic space to learn skills relevant to the discipline that models the work they will do as graduate students (Russell *et al.*, 2007; Hunter *et al.*, 2007)
Complimentary Experiences	Departments should work toward establishing research experiences where the classroom and research experience of undergraduates are complimentary (Brew and Mantai, 2017)
Inclusive Experience	Research opportunities should be made available to many students (Brew and Mantai, 2017)
Atomistic to Wholistic	Undergraduate research experiences should move them through a progression from an atomistic approach (task based) to a wholistic approach (development and contribution based) (Brew and Mantai, 2017)
Multimodal Learning	Undergraduate research experiences should engage students in multimodal learning (Gardner and Hatch, 1989; Vongsawad *et al.*, 2014)
Student Centered	Mentored undergraduate research is student centered and incorporates elements of the learning cycle (experience, reflection, abstraction, experimentation) (Weimer, 2002; Kolb, 2014)
Open Communication	Mentored undergraduate research has open lines of communication between the students and mentor that develops a constructive relationship (Gee and Popper, 2017)

spaces. In coursework, the questions have already been formulated and the correct answer is known; whereas, in research, careful thought is required to ask good questions and the answers are unknown. Participation in mentored research allows the students to learn about and appreciate how science works. Mentored research provides opportunities to learn how to formulate questions, develop approaches for addressing those questions, and deal with the uncertainty inherent in the research process.

B. Common concerns with mentoring students

Most agree with the idea that mentored research experiences can benefit students, but many are skeptical that the gains are worth the costs. Brew and Mantai (2017) found that almost all universities have one common goal when it comes to undergraduate research: universities want to see research and teaching come together. They also mention the difficulties an institution can encounter in this endeavor. Some of these difficulties could be a lack of general resources like time, funding, and space, limiting the number of students that can participate. Some professors may not want to mentor undergraduate students, preferring more advanced graduate students. Some universities struggle with advertising research opportunities, leaving many students unaware of the option to do research as an undergraduate. Both students and professors are already busy, so undergraduate research can appear to be an additional burden, especially if the definition of undergraduate research is not well established (Brew and Mantai, 2017).

It is likely that institutions have different definitions about what constitutes undergraduate research. A spectrum of institutional definitions could range from loose to strict in the following way: At one extreme, a loose definition would not substantially differ from regular coursework (e.g., reading articles, writing papers) (Brew and Mantai, 2017). In a strict or rigid definition, students could be required to contribute knowledge to the scholarly community (e.g., publishing first author peer reviewed journal articles) (Brew and Mantai, 2017). Both of these cases can complicate the implementation of undergraduate research. Caution is always needed when defining critical student experiences like undergraduate research. An institution could look for a place in between these extremes where more students can participate in research experiences that allow them to develop authentic skills. These approaches work best when faculty time and effort are supported by institutional policies and procedures.

C. Benefits of mentored undergraduate research

This section is a summary of the benefits found in implementing mentored undergraduate research. The benefits discussed are grouped into influence on student career path, student character development, uniting research and teaching, and advantages to graduate students, faculty and the institution.

Students who participate in undergraduate research have an advantage in preparing for their career. They obtain a stronger understanding of the research process (Hunter *et al.*, 2007; Petrella and Jung, 2008), they report an increased interest in STEM careers (Petrella and Jung, 2008; Russell *et al.*, 2007), and they "feel more like a scientist" (Hunter *et al.*, 2007). While some undergraduate students indicate research helped them discover a new career path (Seymour *et al.*, 2004), many say the experience clarified, confirmed, and/or refined their predetermined career or education paths (Hunter *et al.*, 2007; Petrella and Jung, 2008; Seymour *et al.*, 2004). An increased probability of going to graduate school is often seen (Seymour *et al.*, 2004) along with an enhanced preparation for graduate school. Students are able to get a feel for what research in graduate school would be like (Hunter *et al.*, 2007; Russell *et al.*, 2007), and they are also more likely to see themselves working towards a Ph.D. (Russell *et al.*, 2007).

Undergraduate researchers also develop or enhance personal characteristics necessary for graduate school or the workforce. For example, many students boost their problem solving skills (Hunter *et al.*, 2007; Petrella and Jung, 2008), increase their sense of responsibility, become more confident (Hunter *et al.*, 2007; Seymour *et al.*, 2004; Thiry *et al.*, 2012), improve their communication skills, work more independently (Hunter *et al.*, 2007; Seymour *et al.*, 2004), and gain a higher tolerance for obstacles (Petrella and Jung, 2008). These benefits are some of the reasons that mentored undergraduate research programs can provide a pathway to scientific careers for some minority students (Lopatto, 2004).

The aforementioned goal of uniting research and teaching can also be achieved. One study reported "enhanced educational experiences" in terms of general satisfaction and learning gains after students began mentored research (Lopatto, 2004) and another found that research influenced classroom behavior (Lopatto, 2007). A positive research experience leads to more motivation and active engagement in the learning process (Lopatto, 2007). Students report shifts in their attitude toward learning and working as a researcher (Hunter *et al.*, 2007; Lopatto, 2004). Students often integrate the theories they learned in class and the practice of utilizing those theories in a research setting (Petrella and Jung, 2008). Students who are interested in research often help promote the culture of research. For example, they were found "attending conferences, mentoring other students, authoring journal papers" (Russell *et al.*, 2007).

The above mentioned benefits are not limited to the undergraduate students, but can also extend to graduate students, faculty, and the department. For instance, graduate students can receive valuable experience in mentoring and teaching (Zydney *et al.*, 2002), also benefiting them in future careers. Implementation of mentored undergraduate research has been found to increase the visibility of faculty and graduate students to the scholarly world (Petrella and Jung, 2008), especially as they help establish the culture of research at their institutions (Russell *et al.*, 2007).

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D. The pedagogy of effective mentoring programs

Brew and Mantai (2017) found that the definition or guidelines an institution adopts for undergraduate research largely impacts its ability to implement it. They define a spectrum of definitions that ranges from atomistic development to wholistic. The atomistic approach fails to marry research and teaching fully. The opportunities given to students to perform research are typically disjointed and vary on level of involvement during the research process. These opportunities include activities such as reading published literature, data collection, and data analysis. In the atomistic part of the spectrum, one or more of these steps is often assigned to the undergraduate outside of the context of the other steps. The wholistic approach utilizes all parts of the research process in an organized and goal-oriented fashion. This approach should allow students to clearly see the connection between their coursework, research responsibilities, and the project's overall purposes and outcomes. The wholistic approach also allows students to contribute to the scholarly community in a meaningful way. If an institution's approach is unintentionally too atomistic, then students might not learn about their school's research opportunities and fail to make connections between their contributions, to coursework, and the goals of the research group. If research opportunities are advertised as too wholistic, they might reach fewer students and require more time, space and material resources that involve both the faculty and the student. Both extremes could provide roadblocks to the main goal of generating the right amount of "scaffolding" depending on the needs and potential of interested students. Brew and Mantai (2017) suggest that students can be offered more atomistic research opportunities in their first semesters as an undergraduate and then a shift to the wholistic approach can be made as they advance. They claim that this shift over time allows students to develop an aptitude for research and produces positive results for both the undergraduate and the research group.

Mentored research programs should also provide undergraduates with unique opportunities to engage in multimodal learning that uses principles from Gardner's multiple intelligences (Gardner and Hatch, 1989). Multimodal learning is active learning that emphasizes different sensory inputs and learning styles. Some examples of multimodal activities for introductory acoustics are given by Neilsen and Gee (2011) and Vongsawad *et al*. (2014). They provide multimodal examples for hands-on acoustics outreach, and contain examples of effective multi-sensory learning in the context of teaching acoustics to the deaf and hard of hearing Vongsawad *et al*. (2016). Studies [e.g., Anderson (1997)] have shown that multimodal learning increases the likelihood that information gets stored in the brain in a way that is accessible for reconstruction later—this is particularly useful when undergraduates need to apply their coursework in the lab. Such interactive engagement increase conceptual understanding (Hake, 1998).

Mentored research programs need to be "student-centered." Weimer (2002) describes five characteristics of a "student-centered" environment: (1) Students must engage in the hard, messy work of learning and research; (2) skill instruction must be explicit to help students build the required scaffolding; (3) students must reflect on what they are studying in the lab; (4) student motivation should increase as they are given control over the research process; and (5) collaboration is essential. All five of these should occur in a student-centered mentored research environment and have been emphasized in this case study. Weimer (2002) found that this student-centered approach leads to more long-term understanding, lifelong learning, increased motivation to learn, and better assessment outcomes. A focus on how students learn and develop is essential in a mentored research environment (see example of this in Sec. V D).

Another resource for implementing undergraduate research is to consider the stages of the experiential learning cycle defined by Kolb (2014). In this learning cycle, the learner is expected to engage in all four stages to maximize learning gains:

(1) concrete experience (new or reinterpreted),
(2) reflective observation of the experience,
(3) abstract conceptualization,
(4) active experimentation.

These four stages correspond with different learning modalities: feeling, watching, thinking, and doing. In addition, the mentored research environment is an ideal setting for implementing the experiential learning cycle because the four stages (Fig. 1) effectively capture the research process. In the BYU underwater acoustics lab, for example, undergraduates perform acoustic measurements in the water tank environment (concrete experience), analyze the data with guidance from their mentors (reflective observation), develop new questions to answer with further experimentation (abstract conceptualization), and create a plan for improved measurements (active experimentation) and then repeat the cycle. Another common example would be when students learn related principles in their acoustics coursework (abstract conceptualization), determine how to apply these principles to their research in the laboratory (active experimentation), collect data through experimental measurements (concrete experience), and then analyze the data with guidance from their mentors (reflective observation).

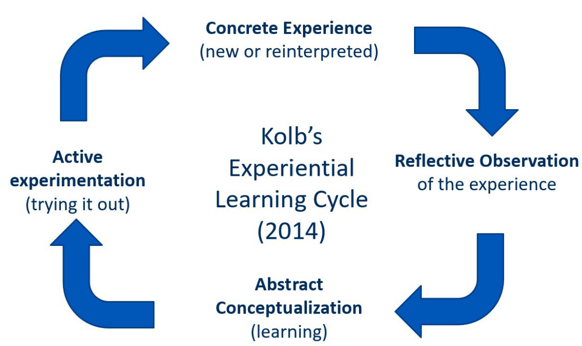

FIG. 1. (Color online) The four stages of the Kolb learning cycle.

On a personal level, the undergraduate research experience is enhanced when the mentoring relationship between the faculty and student is a constructive one with open communication and clear expectations. For ideas on improving mentoring relationships, the reader is referred to the Acoustics Today article by Gee and Popper (2017).

On a departmental or institutional level, Brew and Mantai (2017) identify strategies (outlined below) that contribute to successful mentored research for undergraduates (e.g., well defined research and a culture of research based on that definition). An important step to reach that goal is to establish a culture of research by making an undergraduate research experience "the norm." Universities need to institute policies, procedures, and structures that support mentored undergraduate research in the following areas: (a) application procedures, (b) advertisement, (c) assessment and communication, (d) establishment of a departmental newsletter, and (e) restructured faculty teaching assignments (Wayment and Dickson, 2008). For example, in the Physics and Astronomy department at BYU, undergraduates are required to join one of the various research groups (ideally by or before their junior year) and make meaningful contributions to their research group that is documented by the completion of either a senior thesis or capstone detailing the work they accomplished. To help accommodate this, college funds and external grant money are used to fund undergraduate research assistantships to many students. For example, on average 4–5 undergraduates receive research assistantships each semester to work in the BYU underwater acoustic group These undergraduates each work approximately 10 h hours per week during the main semesters (August–April) and up 20–40 h per week during the summer. In addition, students have the opportunity to earn up to six research credits as they prepare for and write their senior theses.

E. Implementation at BYU

Prior to the release of the Boyer report (Kenny *et al.*, 1998), the BYU Department of Physics and Astronomy recognized the importance of mentored undergraduate research. The department made changes to their programs to make mentored undergraduate research available to students before the first senior thesis was completed in 1990. About five years later, the faculty decided to make a mentored research experience a requirement for the B.S. in Physics beginning with the freshman class of 1998. Approximately three years later, a research requirement was also adopted for the B.S. in Physics and Astronomy and the B.S. in Applied Physics. Figure 2 shows the increase in the number of senior theses and capstone reports completed each year as a result of the added expectation.

As the last two decades have brought increased emphasis from the university and accreditation boards on student-centered learning outcomes, the department included the mentored undergraduate research experience in its program outcomes:

- Physics theory and application
- Experimental and computational skills
- Effective communication
- Professional ethics
- Research and professional preparation

In addition to being listed specifically in the last outcome, the mentored research experience contributes significantly to the first four as well. More details can be found on the department web page (BYU, 2022b) and the BYU electronic course catalog. Each faculty member is expected to mentor several undergraduate research students and have, on average, one or two of their students complete a senior thesis or capstone report each year.

The Physics and Astronomy department has also recently made changes to the required lab course work for the undergraduate majors. For example, the Introduction to Experimental Labs course (PHY 225) was recently rebuilt to focus on elements of experimental design, constructing models, and leadership. These changes should prepare the undergraduates for the kind of work they will do with their faculty mentors and for future lab coursework. The department also offers a course to support the undergraduates while they write their senior thesis. Courses like these help the department to build a culture of mentored research by helping the undergraduates to gain autonomy in the work they do as well as signaling the importance of developing research skills.

With regards to the definitions of undergraduate research described by Brew and Mantai (2017), the BYU Department of Physics and Astronomy requires active participation in research but leaves it up to the individual students and their mentor to decide how much progress will be made during the experience. This flexibility is one reason why open communication is an important feature of an undergraduate mentored research experience. This communication and relationship is

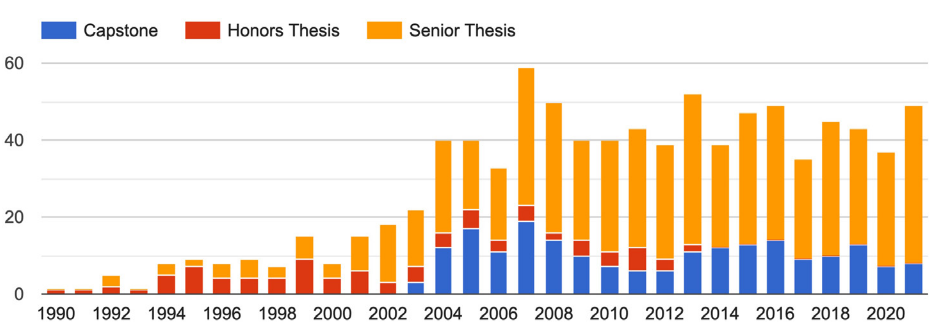

FIG. 2. (Color online) Number of theses and capstone reports completed by students in BYU's Department of Physics and Astronomy. Retrieved from internal data.

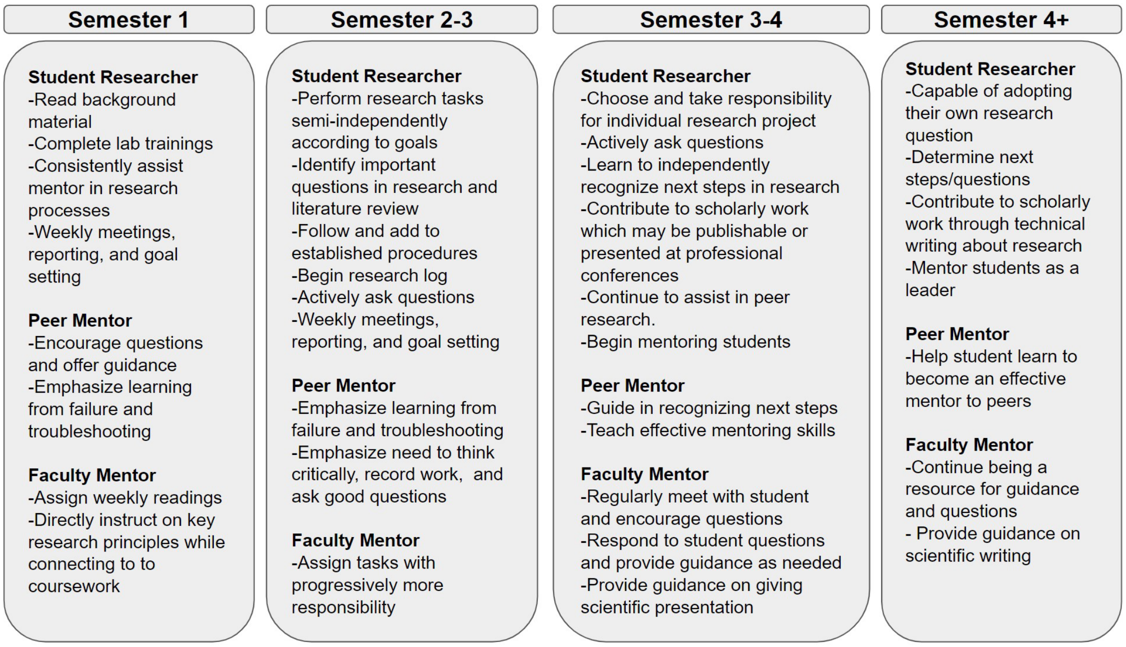

FIG. 3. (Color online) A generalized timeline for mentored undergraduate research in underwater acoustics at BYU. The timeline includes scaffolded responsibilities of student, peer mentor, and faculty mentor. This is an idealized timeline of a student's progression and does not represent all cases. The duties of the faculty member and peer mentor listed in each column also apply to different semesters but are not repeated for conciseness.

significant at BYU because an undergraduate's research advisor becomes their academic advisor and counsels with them on what courses and experiences (e.g., conferences, internships, etc.) will best help them to meet their goals. In this way the mentoring experience becomes a wholistic approach to help align the academic and research decisions the students are making while targeting outcomes that are meaningful to the students. Blending the academic and research mentoring for undergraduates gives students at BYU a unique experience with guidance and access to the faculty that many undergraduates at other institutions do not have.

A generalized timeline for the mentored undergraduate research experience for a student who begins after their sophomore year is provided in Fig. 3. After appropriate training and shadowing (e.g., working with other experienced undergraduates or graduate student in the lab), the new students are assigned their own projects, or parts of larger projects, to work on. This leads to the research they are expected to write about in a senior thesis or capstone report. Student experiences differ based on their individual interests and level of commitment. Students are shown the possibilities and have some say in how involved they are (for instance, while a minimum of five hours per week on research is expected, the exact number of hours worked is decided largely by the students). The options that are open for the students are summarized in the thesis grading rubric for the mentored research requirement, displayed in Table II. This grade is assigned to a two credit hour senior thesis "class" at the time of the student's graduation.

Although contributions to the scholarly community are not required, dedicated students have that opportunity. Particularly in BYU's Acoustics Research Group, undergraduate students are encouraged to perform research that can be presented at a national meeting of the Acoustical Society of America in either a poster session or published abstract and often are co-authors on proceedings paper and/or peer-reviewed manuscripts.

As described above, the costs for this added load of mentoring research students is significant. The faculty are dedicated to the goal of providing a mentored research experience to every undergraduate, but the mentoring requires a great deal of time and energy. For more than a decade, substantial support for undergraduate research assistantships has been and continues to be provided by BYU's College of Physical and Mathematical Sciences. The College also helps fund travel for undergraduate students to present at regional and national conferences. While the time to mentor students has not been explicitly included in the faculty expectations at a university level, that appears to be changing.

The president of Brigham Young University, Kevin Worthen, began emphasizing the critical nature of experiential learning in 2016. The office for Experiential Learning

TABLE II. Grading rubric for the senior thesis requirement in BYU's Department of Physics and Astronomy. More information online (BYU, 2022c).

A−, A	The student has completed a quality thesis.
B−, B, B+	The student has produced a significant written report on his or her research that falls short of a quality thesis.
C−, C, C+	The student has documented his or her research but failed to produce a thesis.
D−, D, D+	The student has been involved in meaningful research, appropriate for the number of credit hours (i.e., 15 x 6 hrs = 90 hrs for 2 credits). However, the student has failed to produce a written report.

and Internships was established. The Experiential Learning outcomes are (1) discipline specific skill and knowledge, (2) transferable competencies and knowledge, and (3) experiential learning literacy that leads to life-long learning. (More information can be found at BYU, 2022a.) These learning outcomes are to be accomplished within a framework built on Kolb's Experiential Learning Cycle, shown in Fig. 1 (Kolb, 2014). These institutional practices and expectation are enabling even more participation in mentored undergraduate research, such as the underwater acoustic research group discussed here or the recently formed physics education research group within our department.

In summary, many universities have taken on the challenge of giving students added opportunities to develop their understanding and skills through research since the Boyer report suggested research-based learning should become a standard practice. Though it may feel like an added burden to personal research and teaching responsibilities, with a well defined research program and clear expectations an effective culture of research may be developed. This culture of research should include effective pedagogy and apply principles that relate the chosen definition of the research, the hypothesis and research goals, and include Kolb's learning cycle. Establishing a research program based on these principles can yield great benefits to students as well as faculty and the institution, as has been seen by BYU's Department of Physics and Astronomy establishing a requirement of student research and a focus on experiential learning since the 1990s.

III. DESIGN

With the emphasis on mentored and student-centered research, careful consideration was taken to construct a new underwater acoustics lab at BYU in ways that are conducive to mentored research. This construction consisted not only of the equipment purchased for the lab but also in designing scaffolding for training students to use the equipment and follow lab protocols. In this section, the methods of communication, mentoring, and training to support the lab goals are described. The lab goals are to provide a positive mentored research environment in which each student can (1) develop technical skills safely, (2) have sufficient scaffolding to facilitate learning and build confidence, (3) improve communication skills, (4) experience peer mentoring, and (5) prepare for their next opportunities. Key elements in the design on the lab are now discussed along with how they contribute to these goals. Further details on the lab design can be found in Vongsawad *et al*. (2021).

A positive mentored research experience begins with clear expectations and lots of communication, especially during the onboarding phase. The faculty mentor sets the tone for the communications. Suggestions for how faculty mentors can communicate in ways that allay rather than exacerbate common fears, feelings of inadequacy, and impostor syndrome are given in Neilsen (2017). Strategic decisions were made to help students meet the initial steep learning curve including a project management platform, standardized means of communication, individual and group mentoring, and scaffolding through lab-specific resources (e.g., "getting started" tasks, communication software like Trello and Slack, and live lab documents).

For new students, scaffolding such as a list of "getting started" tasks and resources helps them know where to begin. In our group, Trello was selected as our project management platform to store and pass-on information and improve student onboarding. Trello is a web-based, Kanban style software that allows for digital sticky notes and checklists. The exact software application is less important than the functionality of having all key information available in one place that is easily accessible by all. On Trello, new students have access to a "card" of "getting started" items with tasks and materials to get familiarized with our research group, the research process, and the content area in which we are doing research. Here, they find step-by-step tasks to help them become trained on using the measurement equipment, learn procedures for gathering data, and gain experience with computer codes needed for data processing. Resources for understanding the big picture of the research are also included, such as major journal articles. We create cards for each student and project in the group to keep a record of key resources and prior results. The cards also contain common problems students encounter to help pass on knowledge to the next generation. As a member of the group's Trello board, each student may be assigned tasks, short and long-term goals can be tracked, and schedules may be shared.

Use of a project management platform like Trello is important because one of the key ways to increase inclusion is to ensure that everyone has equal access to the same information. The sense of belonging is increased when students have an easy way to communicate with each other and the professor. Students, especially new ones, need to feel comfortable asking questions and communicating with others. Students generally appreciate a timely response from their faculty and peer mentors. These kinds of communication can be facilitated using business communication software. Our group uses Slack, but many other options are available. The messaging environment provided by Slack is often a more efficient way to communicate with students than email, in part because current students report less hesitancy in sending a message than an email. Slack allows you to add and delete members from "channels" such that information can easily be sent to all students involved in a certain project or event (e.g., attending an ASA meeting or participating in an outreach show). The use of Slack also allows the faculty member to limit distractions by turning off email notifications and yet be easily contacted by their research students. A business communication messaging platform is preferable to texting students' phones for several reasons: (1) When striving for work-life harmony, student and faculty should have the option to turn off work notifications in the evening and on weekends; (2) some students do not want to share their phone number with people they work with; and (3) the difference between their work communication platform and personal texting serves as a subtle reminder about how they should conduct professional communications. The exact platform used is less important than the principle of creating a quick way to ensure that all group members receive accurate and timely information and have a simple means to ask questions as they arise.

While these electronic resources greatly increase the efficiency of sharing information, they should complement, not replace, in-person communication. Regularly scheduled individual meetings for specific projects and group meetings are both important. During group meetings, students review current literature, discuss new laboratory updates and procedures, learn basic physical principles governing our area of research, or review a reading assignment on ways to improve our practice as research scientists. When appropriate, this time may also be used for students to update the group as to where they are in their individual research, and the group can help address any questions the students may have in regards to their research. The group meetings may also be used for practicing and getting feedback on upcoming conference presentations (as seen in Fig. 4) or paper drafts. These group meetings can be led by the faculty advisor, graduate students, or senior undergraduate students.

While effective faculty mentoring is important, peer mentoring has many benefits including increasing a sense of belonging (Gee and Popper, 2017). As part of a research group, students are encouraged to be involved in each other's work and help one another. Though students have different projects they are working on, they regularly discuss questions about research with each other and help one another take measurements, review code, or set up for experiments. Particularly, all graduate students are expected to mentor all undergraduate students in the group in order to actively establish a collaborative culture (see Fig. 5). Graduate students regularly follow up with undergrads on their research as well as offer feedback during formal weekly meetings as well as informally while working in the lab together. As such, graduate students have the

FIG. 4. (Color online) Research group meeting with faculty advisor. In this figure, students are reviewing their research and practicing conference presentations.

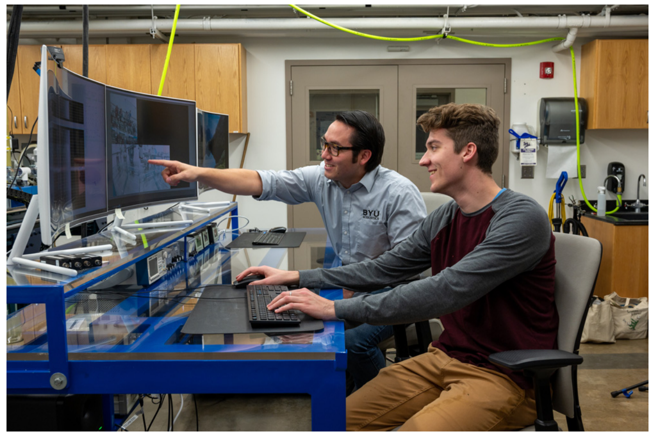

FIG. 5. (Color online) Graduate student peer mentor assists undergraduate student in computational aspects of the lab.

opportunity to build their presentation and teaching skills as they become an expert in their field of study. Through these collaborations, students learn to become regular resources for each other in their research duties and a comfortable open line of communication is established. As a tool, Slack has been integral in providing an effective means of informal communication that assists in peer-to-peer mentoring.

Students are involved in creating and updating laboratory resources—another important element of scaffolding—that help guide new students and facilitate the transfer of knowledge that is needed in an academic setting. These resources are shared via Trello as well as in an active general laboratory document. These resources contain details regarding equipment, measurement protocols, general laboratory procedures such as cleaning and maintenance, as well as software and code developed for effective experimentation. With this resource, students may lookup answers to many questions they have or ensure they are following lab protocols. The general laboratory document also contains links to additional materials including equipment specification sheets, pictures of equipment setup and maintenance, figures demonstrating how to take measurements or what to expect from measurements, as well as past presentations and publications that are organized into a shared cloud-storage folder. Data analysis and modeling codes and custom data acquisition software are tracked and shared via code tracking repositories (e.g., Git) for all to access and update.

Data analysis and computational modeling are major components of experimentation and students are expected to become proficient in PYTHON, MATLAB, and on occasion, LABVIEW. Although learning these languages is a part of the standard curriculum in physics at BYU, the new research students often have not had these courses. Resources are needed to scaffold student learning (either before they finish the computational coursework or supplement it afterwards) to enable them to obtain skills and begin contributing to the group. For this we have gathered online tutorials for students to become familiar with PYTHON. Libraries of PYTHON functions are contained in Git repositories that can be imported as packages to allow for processing data. Such code

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TABLE III. Scaffolding steps experienced by all students. These steps generally take students 3-6 months, but the exact timing depends upon student motivation and availability.

Set up communication on Slack and Trello
Begin reading introductory material about underwater acoustics
Complete training for UR10e (robot) certification
Complete robot motion tasks
Learn how to run filtration system
Learn how to clean the tank
Learn about the elements of the measurement chain
Learn appropriate settings for experiments
Use the log sheet to record details about the experiments
Learn how to use the custom lab-view software package to perform an experiment, which includes signal generation, transmission, reception, and recording the signal
Begin learning PYTHON, if needed—Practice data analysis using the group's codes
Make plots of the data in time and frequency domains
Throughout: Assist senior student with measurements
Throughout: Participate in group meetings
Throughout: Read literature about current projects

resources must be well documented with each section of code thoroughly commented so a new student with little coding experience can follow the process of what is being done so they know how to use or manipulate the code. This approach allows students to gradually "learn" mathematics, physics, and computational skills as they get involved in research.

Our scaffolding approach allows undergraduates to make step-by-step progress in the following way: first, students concentrate on learning how to take measurements according to established protocols. Second, they focus on learning conceptually what must be done to analyze the data and learn to evaluate data through examining plots of the data or other metrics. Third, they grasp the computational aspects of the data analysis. Finally, they can be assigned a new part of the project that requires independent thinking, designing experiments, and writing their own or improving previous codes for additional analyses. Specific steps and tasks involved in building the scaffolding are listed in Table III. These key principles of effective regular communication, student-led and faculty supported peer mentorship, and careful scaffolding can be applied to any undergraduate lab as a structure for research.

IV. METHODS

To investigate if the goals of the research lab are being implemented, a case study was conducted to evaluate student perspectives on their research experiences. This section contains a description of the participants, an explanation of the surveys and interviews that were conducted, and an explanation of our methods and analysis. The codebook, created through open coding (Maxwell, 2013), is also provided.

A. Description of respondents

The survey respondents consisted of six students including: one 3rd year Master's candidate (involved in research for just over two years); three 3rd or 4th year undergraduate students (involved in research for 9–10 months at the time of the survey); one 1st year undergraduate student (involved in research for six months); and one undergraduate alumni (who was involved in research for over two years and was currently in a graduate program at a new institution). These participants include every undergraduate and graduate student that was actively involved in experimental underwater acoustics (a minimum of five regular hours per week) at Brigham Young University since the lab's beginning in 2018. At the time the survey was conducted (September 2021), the undergraduate participants had not yet presented research in a professional setting. Students who had shown mild interest in this research group but did not actively pursue research were not involved in this study. As such, this case study lacks an experimental comparison to a designed control group [similarly to many others of its type, e.g., Lopatto (2004), Lopatto (2007), and Seymour *et al.* (2004)].

All student respondents come from Brigham Young University's Department of Physics and Astronomy studying physics or applied physics with an emphasis in acoustics. This department has a long-held requirement for student involvement in faculty-mentored research, as detailed in Sec. II E. All undergraduate students reported not having any prior research experience, and the one graduate student had moderate prior mentored undergraduate research experience. The graduate student is included in this study because of their role as a primary peer mentor.

Demographic information was not collected on respondents because this is a case study with a limited sample set offering no significant benefit to demographic evaluation. It is also important to note that a good amount of research, including that done by Lopatto (2004), as well as Seymour *et al.* (2004), saw no significant difference in gains between gender or ethnic groups.

Undergraduates are also expected to participate in research in order to fulfill the requirement of completing either a senior capstone or senior thesis, as discussed in Sec. II E. A list of the research projects these students were involved in at the time of the study are listed in the bottom half of Table IV. Undergraduate students have the opportunity to apply for a research assistantship funded by the College of Physical and Mathematical Sciences. These assistantships are granted based on valid research proposals, advisor consent, and available funding.

Each participant's research is in experimental underwater acoustics and related to the overall acoustic characterization and modeling of the acoustic water tank environment. These beginning steps are preparation for the larger goal of developing methods for testing and refining machine learning applications in SONAR within a controlled acoustic water tank environment. Each student's research plays a connected but separate role in building to that overall goal.

https://doi.org/10.1121/10.0014348

TABLE IV. Tasks (upper) and projects (lower) worked on by research students at the time of the study. For details about the construction and capabilities of the tank and specifications for the transducers, see Ref. (Vongsawad *et al.*, 2021).

Tasks
Constructing the tank
Installing the robots, determining coordinates, setting safety planes
Learning how to use the transducers
Testing measurement chain
Developing measurement protocol
Installing cameras
Enabling remote control of measurements
Determining tank maintenance protocol
Projects
Estimating acoustic vector intensity using the p-p method (Fronk, 2021)
Using Norris-Eyring equation to find reverberation time (Vongsawad, 2021)
Estimating the spatially averaged absorption (Vongsawad, 2021)
Evaluating echo reduction of anechoic panels (Dobbs, 2022)
Comparing measurements to Cartesian normal mode models (Terry *et al.*, 2021)
Comparing measurements to ocean propagation models (Hollingsworth *et al.*, 2021)

B. Data collection process

This case study consisted of a survey and an interview. The participants took a survey similar to SURE (Lopatto, 2004) or URSSA (Thiry *et al.*, 2012). Each participant was then interviewed to follow up on their survey questions and ask them for descriptions of their research experiences. Questions focused on student's perception of their relationship and communication with their faculty research advisor (Fig. 6) as well as primary peer mentor (Fig. 7). Additional questions focused on their perception of benefits gained as a result of research and the importance of those benefits, how they originally became involved in research, and what their future plans are after their current schooling program. Individual follow-up questions often focused on expanding on why they perceived various benefits.

The participants took the survey online and were interviewed in person when possible or over video chat where necessary. The researchers emailed the survey to each participant and collected their names only so the interviewer could connect survey and interview responses, which allowed for follow-up questions during interviews. A faculty member, outside of the research group, performed the interviews, which were recorded and then transcribed. The participants' names were changed in the data to pseudonyms to provide anonymity. A "Not applicable/Prefer not to answer" option was available for all survey questions, and respondents were invited to respond similarly during the interview process.

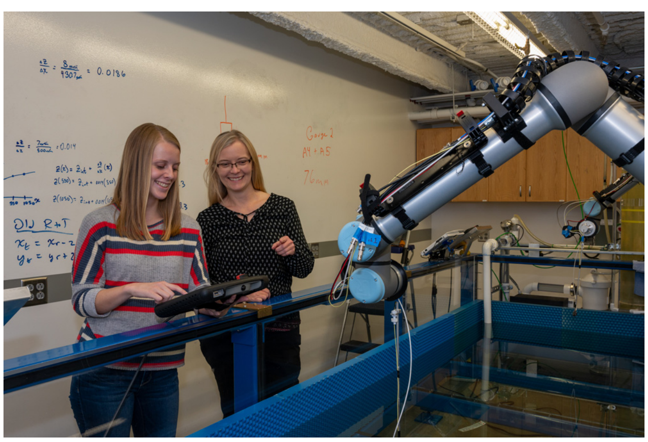

FIG. 6. (Color online) Example of interaction between a student and their advisor.

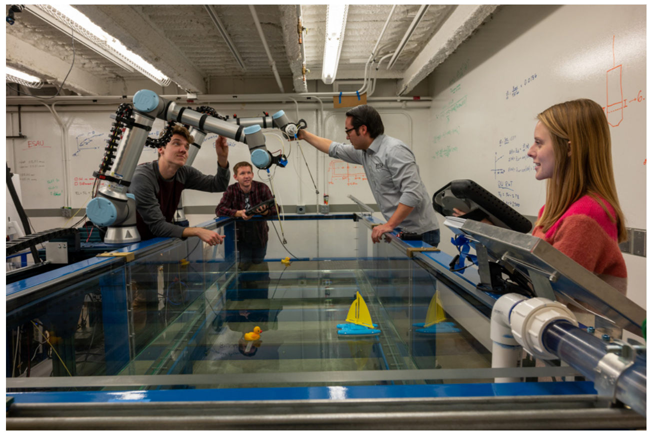

FIG. 7. (Color online) Students collaborating with their peer mentor.

C. Open coding analysis

Using qualitative coding methods (Saldaña, 2021), the researchers coded the data from the surveys and interviews into five major categories each with a given number of subcategories (see Table V for descriptions and examples of responses for each code). Each category and subcategory were developed through open coding (Maxwell, 2013), a process that involved building themes based on the respondents' comments and refining those themes into codes by the patterns found across the data. To test the legitimacy of the coding, a second reviewer coded a portion of the data using the developed categories. The initial comparison showed a high level of agreement (greater than 80%) between the two reviewers, and after a short discussion any differences in the coding were resolved to bring the agreement to 100%. The reviewers refined the categories as a result of the discussions and then applied the refined codes across all of the data.

The researchers used the patterns found in the refined categories to organize the qualitative findings. The results sections displays each of the salient themes with supporting data from the surveys and interviews. Direct quotes from interviews are provided to support findings relative to STEM interest, faculty interaction, peer interaction, learning and skill development, and self-identity.

V. RESULTS

The results are organized into the same categories as seen in the codebook in Table III. Each section further

TABLE V. Code book used for this study with description and an example quote from the interviews. Names have been changed to maintain anonymity.

Code/Subcode	Description	Example
Interest in STEM	**When interest started or how it was inspired.**	
High school	Time period in which decision was made. Maybe had a teacher who was amazing and inspired them.	"I would say probably our junior year of high school… It seemed like a cool field. Also, I had a phenomenal high school physics teacher." -Derrick
Relatives	A relative did STEM and they followed.	"When I was really little I think I was always focused on [STEM] because my dad was an engineer and all my uncles were engineers, so I thought that was really cool." -Casey
Way of thinking	Hinting toward appreciating the way of thinking that comes with being a scientist.	"I always leaned towards the idea of how things worked and why things work the way they do and I thought I'd get into some engineering-related field somehow." -Andrew
Fun/cool	General excitement and enjoyment in subject matter. Maybe they though the research sounded fun or cool.	"[Physics] is really cool, I have a lot of fun with it. I like the mix of direct physical applications and the computational aspects." -Ethan
Faculty interaction	**Reference to student interaction with faculty and their relationship.**	
Openness/ comfort	To ask questions, interact, or feel like can reach out anytime.	"[My advisor] is always very open to any questions or concerns that come up. She'll say, 'Just let me know. We'll, figure out a time to talk and figure things out.'" -Andrew
Personal level	Mention of getting to know on more of a personal nature aside from professionally with research.	"With research you get to work a lot more closely with [your advisor]. I can't really help but get to know them really well and develop a relationship with them which I think is really helpful." -Robert
Value	Description of the value provided by faculty. Could be referencing the importance of their relationship. Guidance they received professionally or personally. What they gained from their weekly meetings.	"[My advisor] is interested in what I'm thinking about my classes and how I'm going to move forward… That's been really helpful to see a clear path towards graduation." -Robert
Collaborative	Description of the value provided by faculty. Could be referencing the importance of their relationship. Guidance they received professionally or personally. What they gained from their weekly meetings.	"Even though my advisor knows a lot more than I do, I never feel that way when we're talking about a specific problem, even if it's something that I don't understand at all and she really understands it. I still feel like I'm on the same page with her as she's teaching me, whereas in class you don't get that vibe." -Casey
Peer interaction	**Reference to interaction with peers and their relationship (primarily in a mentorship context).**	
Who	More commonly mentioned peer mentor as graduate student or undergraduate student. Description of relationship.	"[My peer mentor] was very helpful in answering questions… More than just answering my questions, he helped me understand why those concepts were important to understand." -Derrick
Preference over faculty	Level of comfort with peer mentor. Maybe reference of going to peer before faculty for help.	"Sometimes there's a disconnect between wanting to be close with your advisor and how much easier it is discuss questions with a peer. It's nice to have someone at that level. They don't have the curse of knowledge like professors do." -Andrew
Criticality	Beneficial or enhancing of the experience. Mention that they are mostly or only beneficial initially.	"There's a lot to learn in a research group. I think I was capable of working on a specific task but I couldn't keep the project going. It makes it more exciting to have peers working in the lab." -Casey
Collaborative problem solving	Work together on solving problems and not just acting as a mentor who is always above them in understanding and just there to teach them.	"We meet as a small group of those students that are working on similar projects to discuss where we are at and how help each other move forward, which helps me be more accountable."-Casey
Skill development	**Reference to what students learned, skills they developed and what aided in that learning or development.**	
Research/ curriculum connections	Connections made between classwork and research. Gaining deeper understanding from research or learning more thoroughly	"Many classes have provided me with useful skills for my research. On the other hand, some classes gives me a deeper understanding of topics that I've learned the basics of through research." -Ethan
Overcoming challenges	What is done when you have questions/concerns. Go to	"Depending on the nature of the problem, I'll start by

TABLE V. (*Continued*)

Code/Subcode	Description	Example
	resources or to Mentors/Advisers. Other mention of overcoming. Pushing onself. Recognizing there are things outside of your typical control that you have to figure out how to solve or formulate a way to learn how to solve. Resources in the lab used to problem solve.	searching on my own for something that can help me. Sometimes there is an easy answer somewhere, maybe on the internet or in the resources we have in the lab. If not, it is more helpful to turn to my peer mentor or my advisor. If neither of them know, then we work it out together." -Ethan
Big picture	Connecting ideas to be able to see the big picture in their research. Look at something in a new way/perspective because of research.	"After acoustics classes, I'd go back to my lab and try and figure out how to apply those principles in that setting… The more application you have, the more passion you can get about it, and you can look at the situation more thoroughly." -Andrew
Scaffolding	Mention of need for/or how various things supported them initially to scaffold their entry into research and help them gain their independence as a researcher. Mention of Formal Group Meetings. Resources used in the lab to support learning.	"Trello has helped a lot because if students in the past run into a problem, then usually they put it on Trello… Also, our lab document… has an explanation for everything that you could be doing in the lab and that's really helpful." -Robert
Self-identity	**Reference to how students viewed themselves and their potential as a result of research involvement or mentorship.**	
Getting started	Mentality on when starting current research; excited, intimidated, scared, nervous, confident, etc.	"I was a hesitant because it seemed like something that was going to be new and difficult. I didn't know if I'd be able to offer anything to the group. But I was excited to learn about it." -Robert
Perceived growth	Mention of recognized personal growth. Recognition of how much more can still be learned.	"Sometimes I'm on my own on a project and I have to figure out what would be the best thing to do. In those cases I'm able to use what I've learned from previous work and solve the problem somehow that I wouldn't have thought of before being a part of a research group." -Ethan
Confidence in scientific contributions	Affirmation of scientific self-identity, taking ownership of research/learning. Understanding scientific process. Confidence gained in self-and recognizing ability to contribute. Retention of that identity if moving to another lab.	"I think that is one of the huge impacting factors of being a student, when you get the opportunity to present. Afterwards, people ask you questions and it's stressful, but you're able to answer them. People talk to you about your research and you gain a lot of confidence." -Andrew
Effect on career plan	Ways in which future plans have developed due to research. Recognition of more options open for future that they are capable of.	"[Research] helped me in the sense that it opened my eyes to what my options are… It was all super helpful for me and for figuring out my future." -Derrick

elaborates on the salient themes found in the data, providing additional examples and explanation.

Self-reported gains from the survey tend to match results seen in Table XI of Lopatto (2004) as well as those seen by Hunter *et al.* (2007), Lopatto (2007), Petrella and Jung (2008), Russell *et al.* (2007), Seymour *et al.* (2004) and Thiry *et al.* (2012). The only exception to matching gains found in other studies is with presentation and oral skills. A few of the students in this study reported not yet having opportunities to presented research in a professional setting, although at the time of the survey three of them were actively preparing to do so.

A. STEM interest

Each participant mentioned that their decision to pursue STEM began in high school. Their decision was often associated with a high appreciation for a teacher who taught physics well and helped them appreciate a challenging topic. One such student, Casey, said about their high school physics teacher, "He helped me find something [physics] I was interested in and understand the world around me…I think that made a really big impact on how I viewed myself, my ability to learn, and to understand the world."

Participants also mentioned how a relative working in a STEM field further bolstered their interest. For example, Casey had insight into what professional life could be like because her father and uncles are engineers. Others mentioned how physics connected with the way they thought, such as Ethan who enjoyed AP physics in high school because he felt "the subject material worked in the same way that my brain works." Sentiments like this give a little insight into the background of the participants.

B. Faculty interaction

The participants generally reported comfort in communicating with their research advisor stating that she made sure to be available to help them, actively worked with them, and showed genuine interest in their progress. Their comments suggested she created a comfortable environment where they felt welcome to ask questions and even receive guidance on their future plans. They expressed their openness and comfort in asking questions and interacting with their research advisor as the most common response within the code of faculty interaction.

The participants reported the value they placed in their interaction with their faculty advisor centered on gaining confidence. They mentioned several items that helped increased their confidence: altering the paradigm on research and faculty relationships, understanding the main goal of research so they could figure out the next step, guiding them in what coursework to take, and preparing for after graduation. Derrick said of their advisor, "at the beginning…I felt like I did not know anything. But in that regard [my advisor] is awesome. She's great in helping realize it is not about knowing everything to do, it is about learning what to do." One student, Casey, said during her interview,

> "At first it's a little intimidating because I'm used to my professors being in the front of the room and I don't really get to know them at all. So I was really scared of it for the first month or two. But my advisor is super kind and always makes me feel like I'm part of the team…I feel more open to asking questions even with a small group because we always are volunteering questions so it is an open space of learning. Even though my advisor knows a lot more than I do, I never feel that way when we're talking about a specific problem. Even if it's something that I don't understand at all and she really understands it. I still feel like I'm on the same page with her as she's teaching me."

Other participants also referred to this concept: The more they worked with their research advisor, the more they saw them as a collaborator, which they mentioned was very helpful.

Participants expressed an appreciation for their faculty mentor taking a sincere interest in their lives. Derrick said about their regular meetings that they would, "talk about what are the next steps in the project and what are we working on. And…I probably met with [my faculty advisor] once a month for some advisement; just thoughts about what classes I should take and where I am thinking I am going career-wise." From regular communications like these, students felt "a lot closer to a faculty member in a research setting, because of the personal weekly or twice-a-week meetings and all the other times I interact with [them]" (Ethan).

C. Peer interaction

In response to their peer interaction most students stated that having an assigned peer mentor was critical, particularly when first beginning research. In Robert's case, when he first joined the group, he felt more confident when working in the lab with his peer mentor. Casey also commented on the importance of the role of the peer mentor during the initial steep learning curve:

> "I think [when beginning] I was capable of working on a specific task but I could not keep the project going necessarily. So a peer mentor was really helpful for that…I feel confident doing research when there is someone there with the greater picture in mind. I could not come up with all these things by myself and further the project. But I am confident I can be helpful to someone that does have that bigger picture or that oversight…I think it also makes it a lot more exciting to have other students that are your peers working in there! It makes it a more lively atmosphere so it is an exciting thing to go and do and talk to them…I like being surrounded by people that are taking classes that I am taking and are just another normal student."

Adding to this, Derrick said of his peer mentor, "He was very helpful in answering questions…And more than just answering my questions, helping me understand why that concept was important to understand." The general findings from the survey about the benefit of peer mentors was confirmed by Ethan stating, "it is definitely a good supplement to having an advisor. I think it could be done without a peer mentor, but having a peer mentor enhances the process."

Each participant reported some level of accepted personal responsibility to mentor one another either formally or informally and that the peer mentoring relationship either moderately enhanced (33.3%) or was one of the best parts of (66.6%) their research experience. All respondents except one reported spending 2–5 h per week with their primary peer mentor, with one participant reporting 6–9 h per week. The participants reported that they would ask their peer mentor questions they were too afraid or embarrassed to ask their faculty advisor. It is common for students to realize they have more questions about principles discussed in weekly meetings and are often hesitant to ask their faculty advisor for clarification. One example of this is Fourier transforms: Students regularly need multiple explanations and reviews to develop intuition of connections between the time and frequency domains. While only one of them reported asking their faculty advisor questions they were too afraid or embarrassed to ask their peer mentor. They also reported that their peer mentor did not detract from the relationship with their faculty advisor whom they still spent 2–3 h a week with (in some instances along with their peer mentor or other students). In general, the participants reported that peer mentors provided a significant positive impact on their research experience.

D. Learning and skill development

Beyond the survey responses that matched the commonly observed benefits of learning and developing skill during undergraduate research, participants expressed in interviews that their overall learning experiences as students were enhanced significantly when both coursework and research supplemented each other resulting in greater depth of knowledge. Ethan stated in the interview,

> "They both reinforce what I learn in each one in a lot of ways…I feel like I usually…learn something better the second time that I learn it. So, in any class, the first time I'm exposed to something, it's pretty shaky. But once it comes back a second time in another class or in research, then I have an opportunity to learn it again, to learn it a lot better. And that's when it starts sticking."

Andrew supported this, commenting on how the application of content in research helped increase his interest and passion for acoustics. Several of the students took a senior level undergraduate intro to acoustics course which covered key elements of BYU underwater acoustics research such as sound propagation, reflection, refraction and absorption. For Andrew, there was a back and forth between understanding concepts in the classroom and deepening that understanding in the lab or seeing something in the lab for first time helped him be ready for the material when he encountered it in class. Robert specifically noticed how the concept of Fourier transforms were more deeply understood with application in their research. Of this experience he said, "In class I understood how they worked, a little about what they did. But then I started doing research, it just made a lot more sense why we need them…and just kind of a bit of a deeper understanding of how they work."

The participants also expressed that they used the understanding gained in classes to help take a more active approach in their research. They recognized ideas they could offer to the research group or concepts that "might be something that we need to keep in mind when we're taking measurements" (Robert). The relationship between coursework and research can also help students to grasp the big picture of what is being taught in the classroom. Andrew's experience in the lab helped him gain a deeper understanding of the big picture by giving him time (days and even week) to dig into the material through study and experimentation helping him to build a "very deep understanding" (Andrew). BYU's acoustics program teaches courses that emphasize data analysis (e.g., vibroacoustics) and mathematical modeling which are skill that transfer into the labs.

In response to questions about problem solving, participants reported that the provided resources (e.g., Trello, Lab Document, Slack) aided in finding solutions. Andrew said, "on Trello there's also a lot of 'getting started' to do lists…important papers to read,…websites you can go look to for a basic understanding of underwater acoustics." Robert used the resources to help him troubleshoot problems by looking at other students' past work. He would go to Trello or the Lab Document and search for similar situations. These documents also provided him a space to include his own work and solution to help future students. Casey saw the Lab Document as a "lab manual that is constantly being added to. I read through it when I first joined the lab, which was really helpful to understand what everything is. It is really scary to look at a room full of equipment and robots. But to realize what they do and their process was helpful."

In addition, the weekly meetings improved scaffolding by acting as an opportunity for students to learn necessary research skills and report on how they are meeting their goals. This benefit was described by Casey who said,

> "We'll do a weekly meeting with our whole little research group and it's almost like a class. We talk about a specific research topic…and we learn how to read research articles better. Sometimes we meet together as a smaller group of those that are working on very similar projects to discuss where we are at and what can we do to help each other move forward and set our weekly goals. Which help me be more accountable. We also do individual meetings with our advisor to follow up on the things…and I get the chance to ask questions about the project I'm working on. I think that gives good motivation by following up on our assignments. But it also helps me stay more connected and progress so I'm not just stuck on something for a long time."

The meetings showcase scaffolding by allowing students to help one another, ask questions, and be accountable for their progress while gaining important understanding or skills related to their progress. At these meetings, they set goals for conducting literature reviews, compiling and analyzing data, or producing a set of computational code to test.

Data in the surveys also show a possible connection with the findings of Harsh *et al.* (2011) that there are clear differences in novice and senior student researchers. Both the faculty advisor and primary peer mentor observed that these students have, on average, met the initial steep learning curve of this project within six months of being actively involved (five or more hours per week) in research. Once they reach this point, the scaffolding can be decreased because the students are well on their way with independent research. This observation is similar to the research progression discussed by Brew and Mantai (2017) where student start with an atomistic approach and transition to a wholistic approach of research.

E. Self identity

The participants expressed a lot of hesitancy and fear from being unsure of what to expect when getting started in research. Robert stated,

> "I was a little hesitant because it just seemed like something that was going to be very new and very hard…not anything that I was used to and I didn't know if I'd be able to offer anything to the group just 'cause I didn't feel like I really knew much about the topic. But I was excited to learn about it. And after meeting with everybody, I was definitely more on the excited side of things just because I could see that I was going to learn a lot of stuff."

As time went on, the participants found that their concerns became opportunities for growth. In Casey's experience, at first she was scared that she would do something wrong. After time, she learned that "you have to do a lot of wrong things to get to that right point" (Casey). She became confident in being wrong, because she knew she could learn from it and it was alright for things not to make sense as she struggled with new problems.

The participants who had not yet presented in prior professional conferences stated that their confidence in doing research and recognizing that they were becoming a scientist who could contribute to the scientific community was greatly increased by having an abstract accepted for presentation at a national conference. Ethan stated about this experience, "[the abstract acceptance] really puts it into perspective for me: how we are doing something that can contribute to the field of science, because a national conference wants to hear what we're doing." Robert also said, "just knowing that they thought that my abstract was worth hearing a presentation is kind of promising. And think that maybe I can actually provide some kind of insight."

As was commonly found among studies by Seymour *et al.* (2004), undergraduate research experiences confirmed most students prior plans (primarily focused on graduate school attendance) for after their undergraduate program. Only one participant reported a change in their immediate future plans after starting research. This participant had not considered options for post-undergraduate education and now plans to pursue a Master's degree in a STEM related field. All other participants maintained their original plans. In the interviews, they reported that their research experiences reinforced their plans or opened up more doors for their future. They also reported a large or very large gain in clarification for their career path. The participants mentioned that their research experience "helped me figure out what I like and what I do not like. It is a lot better than hearing about stuff in a class" (Ethan). The experience also, "helped me open my eyes to what are my options. Both things that I did not think that were possible and things I thought were possible…Both of those things were super helpful for me and for figuring out my future" (Derrick). Referencing "having their eyes opened," many of them explained they were more aware of what careers were available to them.

The results of the survey and interview confirm and add to what was seen in previous studies. The participants had prior experiences that established an interest in STEM fields. Faculty and peer mentors play an important role in providing communication and scaffolding. Undergraduates need resources to provide additional scaffolding as they begin research. Learning and developing new skills can increase confidence and help students to see themselves as researchers. These results are now discussed to highlight three major themes (communication, student-led peer mentoring, and scaffolding).

VI. DISCUSSION

From the background literature and case study, three major themes emerged. Students and faculty benefit from mentored research when a faculty mentor establishes a culture of communication and student-led peer mentorship supported by scaffolding through carefully selected or designed resources. In this effort, faculty and mentors must lead by example.

A. Communication

Beyond regular research meetings with students, the most important thing a faculty member can do to promote quality mentored student research is to develop a culture of effective communication (Gee and Popper, 2017). We found that elements of effective communication include: faculty interest in the students, discussing current work and connecting it to the next steps, and connecting coursework to research and then linking both to future career options. Effective communication helps the undergraduates to feel more comfortable and be more productive researchers. Participants found that all the forms of communication available to them (e.g., Trello, Slack, Zoom, in person) helped them to troubleshoot questions and gain confidence in the research group. A culture of open and regular communication between advisor and peers helped students gain confidence in their ability to contribute to the research project and overcome obstacles.

Beyond effective communication among the research group, the participants mentioned the importance of preparing for professional presentations. At the time of the survey, the participants had not yet presented their work at a national conference and this could have led to not seeing a change in presentation skills, this result differed from other research [e.g., Thiry *et al.* (2012), Petrella and Jung (2008), Wayment and Dickson (2008), and Lopatto (2004)]. To prepare for conference presentations, undergraduates can use group meetings to report on their research efforts and defend their work [e.g., Seymour *et al.* (2004)]. Currently, each participant is scheduled to present at local or national meetings, and they expressed excitement and validation of their status as a scientist to have their abstracts accepted for presentations.

Prioritizing professional conferences appears to improve scientific identity and validate what students are doing by providing undergraduates with smaller goals to work on as they progress. Andrew, who has presented at multiple conferences, summarized the importance of conferences: "I think that the opportunity to present research is definitely one of the huge impacting factors of being a student researcher…you get people asking you questions about your research, which is stressful, but when people talk to you about your research you just gain a lot of confidence." With improved scientific identity, as seen by Hunter *et al.* (2007) as well as Thiry *et al.* (2012), comes increased confidence in themselves, their research, and their ability to communicate effectively in a professional setting.

B. Student-led peer mentoring

Peer mentorship only happens in supportive research cultures. A supportive cultures must consist of colloquial

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communication that is mutually beneficial. Robert said, "[my peer mentor] definitely knows a lot more than me about the research that we're doing. But at the same time I've noticed that there are things that I can actually bring to table which is kind of encouraging and helpful." In this case, Robert might lean on the peer mentor for guidance, but he also feels that he can effectively provide a benefit to the peer mentor or the research group in meeting their own responsibilities.

The student's responsibilities consist of those given to them by their faculty advisor, those put on themselves, and those asked of them by their peer mentor. The feedback a student receives should help them to make connections to the larger themes of the research being done. This is supported by Derrick's statement, "we spent a lot of time trying to link the main goal to the specific steps we were taking. [this helps me] feel very confident in my ability to talk about it with my family or friends." By obtaining guidance that helps undergraduates focus on the big picture, they are better able to discuss these ideas with family and friends. Seymour *et al*. (2004) reported connections to understanding the big picture as one of the major benefits respondents identified.

Not only does this help undergraduates learn and become more effective researchers, the respondents all expressed how enjoyable it is to have other students to work with in the lab. They expressed that they were glad to have people in their research group that were also in their classes. They especially appreciated it when they felt comfortable asking asking questions to the other students. The ability of peer mentors to discuss students' questions is important, especially as a key part of providing scaffolding for new students.

C. Scaffolding

Carefully designed scaffolding is the glue that holds all these pieces together and maintains consistency as new students join the research group. The steep initial learning curve mentioned above is approached by having resources to provide guidance and patterns for the students to follow. A major goal of scaffolding is ensuring the undergraduates not only know what to do next, but also understand the "why" (Brew and Mantai, 2017; Thiry *et al*., 2012). Helping undergraduates understand the "why" behind the next steps can empower them accomplish their tasks and excel. Scaffolding can also be accomplished with the support of a peer mentor. Students typically felt more confident working with someone who had a better understanding of the greater picture of research. Concrete examples of scaffolding provided by the faculty mentor and peer mentor for the first few semesters can be seen in Fig. 3.

Resources other than the faculty advisor and peer mentor should also be carefully cultivated to help students gain more independence in research. The lab documentation manual is an active document that students are expected to update when major problems are overcome in the lab or new procedures or tools are put in place. This manual helps students learn to use and care for equipment in the laboratory safely and addresses common concerns.

Other resources are also available to students on the group's Kanban board (Trello). On this board, students have lists of things to do when they first join the lab, general papers to read, tutorials to watch, and training to begin. These beginning resources are "atomistic" in nature (Brew and Mantai, 2017). As the students progress, they can explore additional topics. The organization and availability of these resources is important. Students need easy access to resources that can scaffold their learning and training as they struggle with the initial learning curve often associated with research. These documents, resources, and repositories should be regularly reviewed and updated (by the research students) as active documents to continuously provide more effective tools for helping new group members succeed and become independent.

D. Observations/recommendations

Similar to what was found by Russell *et al*. (2007) and Brew and Mantai (2017) regarding increasing research involvement, a universal expectation of research is important. In addition to a departmental expectation for mentored research, the culture of BYU has shifted toward an increased emphasis in experiential learning (i.e., meaningful educational experiences outside of the classroom) as mentioned in E. This initiative, which began in 2016, established educational experiences like mentored undergraduate research as the norm. Institutions also should increase the transparency of what research is being done and what doing research looks like in their program.

In Ethan's experience, he had heard about research happening on campus, but did not know what to expect for himself. Even after taking the required "Introduction to Research" seminar, he still was unsure what his personal responsibilities would look like. Brew and Mantai (2017) argue that having clear expectations that are neither too atomistic or too wholistic, provide more students the opportunity to engage in meaningful research.

This concept can be broadened to improve transparency on what exactly can be done with STEM degrees and in particular with physics. Derrick mentioned that "physics might be a little too esoteric…compared to other STEM fields." Because of this, Derrick appreciated that mentored research helped him actually understand what he could do with his science degree as was also seen by Petrella and Jung (2008), Seymour *et al*. (2004), and Hunter *et al*. (2007). Some students may avoid this or other STEM fields, because they may not fully understanding what they can do with it or they may not know the expectations of a field of study or research.

From the undergraduate interviews, we found that the participants now understood the importance of beginning research early in their college career (during their freshmen or sophomore year) (Lopatto, 2010; Russell *et al*., 2007). Starting early also allows time for the initial learning process, which took on average 6 months before the participants began working on their own original research. This approach also follows Brew and Mantai (2017) recommendation to begin a student's early research with an "atomistic" approach for novices (Freshmen and Sophomore) and progress to a more wholistic research approach (Brew and Mantai, 2017; Thiry *et al.*, 2012) for experienced students. By treating it atomistically initially with well designed scaffolding, students can more effectively feel involved even as a freshmen when they often do not feel like they are as able to contribute.

It is important to help students quickly understand their responsibility as an undergraduate research student by providing a plan to guide them in their progress of becoming a research scientist, addressing the concerns they have about getting into research. The generalized timeline for undergraduate student research progression is seen in Fig. 3. This guide should be adjusted for every student's needs.

For example, Ethan began research as a 3rd year undergraduate and followed a plan similar to the one shown in Fig. 3. In the first semester of working in the underwater acoustics lab, he primarily assisted graduate students and more experienced undergraduate students in running experiments they had designed for characterizing acoustic environments in a lab setting. Some of Ethan's initial duties included: recording notes on concurrent experiments and setting up the water tank and hydrophones for measurements. In addition to general lab maintenance training, he completed official certification to operate the robots in the lab. While in the lab, the peer mentor was present to supervise Ethan's learning. Ethan practiced implementing Python skills and wrote a simple function used in reading data files more efficiently for processing needs. For this, he referred to the peer mentor as well as online Python documentation to implement and expand his coding skills. Over the course of the first semester, the peer mentor's role transitioned from walking Ethan through the steps of his tasks to being available as a resource when questions arose. In later semesters, Ethan worked on his own project, assisted by the advisor and peer mentor, characterizing the acoustic underwater tank environment (Dobbs, 2022) in ways his mentors had not previously done while also aiding in other group projects. Ethan had weekly meetings with the advisor to track progress and receive guidance. That guidance included a recommendation to take his first graduate level course on the fundamentals of acoustics which would benefit his overall understanding of the theory. Ethan reported that research encouraged more excitement for this course and that the course more effectively informed the learning process within research.

By the end of the third semester, Ethan was prepared to present on their research at the 161st ASA conference on taking intensity measurements in an underwater acoustic tank environment for use as an alternate means of characterizing the acoustic environment. In the fourth semester of working in the lab, he wrote his senior thesis and a proceedings paper with the assistance of his faculty advisor. The writing process helped Ethan become well-versed in the progress of the research as the project was refined. At the time of this writing, Ethan was preparing to begin their fifth semester in the research lab, making the transition to a new graduate student in underwater acoustics at BYU.

During this transition Ethan took part in a summer internship involved in machine learning in underwater acoustics. Ethan reported that this experience helped him realize that although the research topic was different than his undergraduate research, the same skills for learning and being mentored in research carry over in all areas. He also recognized that the specific field of undergraduate research does not determine his future career which was a concern which delayed his original participation in research.

Additional observations come from the faculty mentor's perspective. First, the opportunity to help students develop into young scientists who learn how to ask key questions and work hard to find answers through reading scientific literature, experimenting, analyzing, and discussing can be extremely rewarding. Some undergraduate students, such as those in this study, rise to the occasion and experience rapid growth that prepares them for internships, jobs, and graduate school. Other students discover they do not actually enjoy research perhaps because of the lack of concrete answers and creative and critical thinking involved in determining what to do next; their undergraduate years are a good time to make this discovery before beginning a research-based job or graduate program. The flexibility in the grading rubric (see Table II) allows students to opt out early if they wish and receive a lower grade on the senior thesis credit.

Second, by implementing practices supported by education-related research, such as scaffolding, open communication, and peer mentoring, the mentored undergraduate research experience can be, as stated in the Boyer report "Learning…based on discovery guided by mentoring rather than on the transmission of information." Students gain so much when they are engaged in the process of discovery, even the tedious parts like finding problems in measurement chains and debugging codes. The Boyer report also states that one of the key features of this "inquiry-based learning is an element of reciprocity: faculty can learn from students as students are learning from faculty." This principle of reciprocity has been very important in the establishment of this underwater acoustics lab as the faculty mentor has learned many things from each student. We have discussed ideas and made plans for how to proceed towards the larger research goals we have for our underwater acoustics measurements. Because we started from "ground zero," many decisions had to be made, preliminary measurements and analysis techniques had to be developed, and the lab protocols had to be developed. Students used their beginning experience with LabView and measurement systems to help build the computer interface for automatic robot positioning and temperature measurements. The graduate student used knowledge gained in a class about room acoustics to perform broadband characterization of the reverberation time and spatially averaged absorption and worked with an undergraduate on initial modeling of the tank in Cartesian coordinates with finite-impedance boundary conditions (Terry *et al.*, 2021). All of these steps have been essential for preparing for our investigations of how machine learning in underwater acoustics will perform when environmental variability is present. The students' participation in every step not only provided them with great experience but also assisted in creating a lab that is designed to welcome new students with sufficient resources for scaffolding and communication.

In addition to the methods for fostering open communication described above, one of the key lessons about communication that is reinforced each time a new student begins is the importance of sensing that person's communication style. Some are outspoken but many are quieter and hesitant, especially at first. Often the ones who are thinking the most deeply need more time to formulate their questions and are less likely to mention them if they feel they are interrupting or that their mentor is in a rush. To foster open communication, pausing to allow time for questions is key and small things can make a big difference. For example, when asked "Do you have any questions?" the almost instinctive reaction for most people is "no." If instead the question is framed as "What questions do you have?" followed by a patient pause, the students are feel more encouragement to ask their questions and understand that you expect them to have questions. Learning to ask good questions is one of the most important skills that needs to be fostered.

E. Next steps

This case study evaluated a new research group to better view what can be done to establish an effective culture of mentored student research. Despite having a small sample set, this report makes clear recommendations for faculty advisors and peer mentors who seek to build cultures of mentored research. The report also offers insight into what has been done and what could be contributing factors to a successful student research program, as well as giving guidance on how to develop a more complete approach to evaluating and addressing the concerns discovered.

The next steps could be to be refine the survey and interview process to better focus on the key points discussed throughout this paper (communication, student-led peer mentorship, and scaffolding) and to broaden the evaluation by including more research groups within the college and other universities. These include major factors that can be controlled by a faculty advisor in mentoring student research experiences and developing a culture for success. Additionally, future work could study what can be done to support undergraduates who do not participate in or do not persist in a research group, looking for scaffolds to help them have a better experience. These next steps aim to improve the mentored research experiences of undergraduates at BYU and at other institutions with a mandate to involve students in experiential learning activities.

F. Summary

In conclusion, this paper presents a case study of mentored student research experiences in an underwater acoustics lab. This qualitative study identified three key components to developing a positive mentored research environment. The first key is to establish a culture of clear and open communications between faculty and students and among the students. This foundation of good communications paves the way for student-led peer mentoring, which benefits both the experienced and inexperienced student researchers. The faculty and peer mentors build scaffolding for the new students to gain training and understanding through carefully selected or designed resources. These ideas are supported by larger studies in the education literature and can be applied to all mentored student research efforts.

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