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Running A Virtual Summer Undergraduate Research Program: Lessons learned

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Running A Virtual Summer Undergraduate Research Program: Lessons learned

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Abstract

Undergraduate research is a fundamental part of the research activities in most laboratories at institutions of higher education. Undergraduate students serve a wide range of functions and perform critical lab work with significant impact on a lab's research output. These tasks range from bench work, literature surveys, data analysis, and writing. In turn, students are exposed to new learning opportunities and gain complementary skills highly suitable for their later careers. Moreover, undergraduate research is a particularly meaningful opportunity to engage students from underrepresented groups and create increased equity in preparation of their professional career. In light of COVID and resulting distanced-learning guidelines, many of these undergraduate research opportunities are eliminated and call for the development of novel programs to adequately replace previous activities. As part of our response to COVID, we spontaneously created a remote Mechanical Engineering Summer Undergraduate Research Program. Here, we report on our experience and summarize our key learnings from our successful 12-week program.

1. Introduction

Undergraduate research is a fundamental part of the research activities in most laboratories at institutions of higher education [1]. Integration in ongoing research work is a unique learning experience and typically compliments a student's academic curriculum. According to Bloom's taxonomy, see Figure 1, analyzing, evaluating, and creating is the most effective way to achieve desired learning outcomes [2]. Participating, contributing, and reflection on research is particular powerful in building on basic knowledge acquired during course work. This hold true in general but requires particular consideration and rethinking in terms

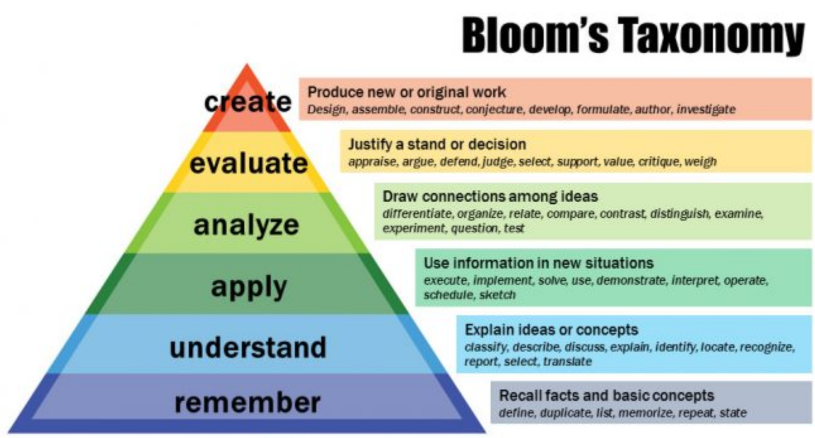

Figure 1 Bloom's Taxonomy outlines educational learning objectives into levels of complexity and specificity [2]. Our research program builds on memory and understanding from our participants academic curriculum and aims at training and engaging in creative and analytical activities.

of distance learning environments. The primary goal of our undergraduate student research program was to engage students in active research and to provide a mentored experience for independent research work. Due to a comprehensive COVID-related campus closure starting in March 2020, including a majority of the research labs, we conducted this program fully virtual with all participants working remotely. Students were matched with faculty based on their primary fields of interest, had to work a minimum of 20hrs per week, and were actively involved in their host lab routines [3]. We organized a series of workshops on research methods, scientific writing, and career planning discussed in detail in subsequent sections. The program ended with a virtual conference which gave all students the opportunity to present their work and to participate in a research presentation contest. We had a total of 21 participants working in 10 different labs. The program was designed to address fundamental gaps in the engineering undergraduate curriculum: project-oriented coding experience, scientific writing, and merit-driven presentations which include project narrative development and application-oriented thinking. We conducted pre- and post-program surveys and evaluated learning outcomes for each workshop.

In the following, we review the structure of our program as well as the goals, content, and outcomes of our workshops and the virtual summer research conference. Lastly, we summarize key learning from our students and the program in general.

2. Program Structure

We selected 21 mechanical engineering undergraduate students to participate in our 12-week summer research program. Students were expected to work for a minimum of 20hrs/week and to participate in our workshop series in order to qualify for a program stipend of $1200. The program was not associated with a credit-bearing course, but we required participants to have a GPA of 3.2 or higher to qualify for participation. Our student population ranged across all for years and included 9 female students. On their applications, students were asked to rank their three most preferred research fields, which included Additive Manufacturing, Biomechanics and Biomechatronics, Control Systems, Design and Manufacturing, Mechanics and Materials, MEMS/NEMS/NANO, Neuromechanics, Robotics and Autonomous Systems, Sustainable Energy, and Thermal/Fluids Systems. Robotics and Autonomous Systems ranked highest most frequently followed by Additive Design, and Control Systems. We aimed at matching students with a faculty advisor active in their preferred research field and placed our participants in a total of 10 host-labs. The program started with a kickoff meeting with all participants and their research advisors. We used multiple curated Zoom breakout room sessions to facilitate advisee-advisor interactions for introductions, information about advisor-specific lab culture and lab activities (such as weekly lab meetings, journal clubs, and bilateral research discussion), and ultimately to determine the project goals for each student. Based on a post-kickoff meeting survey, 70% of our participants had no prior research experience, 80% of students were going to conduct original research (20% literature review), 78% had never done a literature search before, 61% had not written a scientific report before, and 35% of our participants plan on pursuing a PhD (57% plan on going into industry, 8% undecided).

During the 12-week program, we conducted three half-day workshops to convey basic research skills ranging from research methods, scientific writing, and personal and professional development. Format and results are discussed in the following section.

3. Educational Initiatives

The objective of our summer research program was to engage our participants in research work in active research groups in the mechanical engineering department and to offer educational experiences that are outside of their regular academic curriculum. To achieve these goals, our program incorporated direct mentorship via faculty advisors, a series of three workshops, and a virtual research conference as discussed in the following.

3. 1 Mentored Research Work in Active Research Groups

Students were matched with faculty in our department in order to obtain direct mentorship and guidance on their research projects defined in collaboration with their mentors. Most students reported, that they were actively integrated into their host-lab's community and able to participate in regular lab meetings, journal clubs, and direct research discussions with stakeholders in their research project. Most students had the opportunity to regularly interact with their faculty mentor and obtain direct feedback on their work. Students ranked the quality of their faculty engagements a 4.5/5.0. 86% of our participants reported to have had an authentic impression of the work and culture in their host lab. 79% of our participants indicated that they were going to continue working with their advisor for the rest of the summer. 50% of our participants reported a weekly effort of 20-25hrs (required minimum for the program), 36% worked between 25-30hrs per week, and 14% worked up to 40hrs every week.

These numbers clearly indicate a strong integration of program participants in our research labs and sustained exposure to the working environment in research-active groups. This level of integration led to impressive research results from several participants which was clearly visible in their work reported during the concluding research conference, see Virtual Conference. Students reported biggest learning outcomes with respect to coding, data analysis, data visualization, and significant improvements in the reading and analysis of research papers based on preparing a literature review.

3.2 "How to Research?" Workshop

The "How to Research?" workshop aimed at establishing a basic understanding of commonly used and highly relevant research methods. The workshop took place in the second week of the summer program during which time our participants, in consultation with their faculty advisors, were asked to commit to a project goal, derive specific aims, and define project milestones. The workshop consisted of three elements: presentation, breakout rooms with active group work, and a faculty panel session for questions and answers. The presentation we covered central elements of research work. Specifically, we addressed:

- Purpose: Research is either purely exploratory driven by open-ended inquiries or aims at addressing a concrete problem relevant to basic science, engineering, medicine, or society
- Advancement: Research should aim at answering existing knowledge gaps in order to advance our basic understanding; or to advance our abilities to maximize utility, minimize resources, or improve efficacy of the newly developed solutions. Identifying knowledge gaps is a critical first step in any research project and requires the thorough review of existing literature. We reviewed available tools to search, annotate, and manage literature, as well as how to correctly incorporate references in our own research work.

- Hypothesis: Research work should aim at gathering repeatable and reliable data to either accept or reject your underlying hypothesis. We reviewed several examples to practice writing a good hypothesis.
- Planning: The development of a research plan is another fundamental step in designing research work. Defining specific aims, milestones, and control points that guide the development of experiments, simulations, literature searches, reviews, and product design require practice and are key to successful project completion. Unguided research work leads to long project times, dissatisfaction with project outcomes, and unintended use of resources. In the workshop, we discuss how to define project goals that will enable answering the overarching research question.
- Project Management: Part of becoming an independent researcher is the development of project management skills. We discuss techniques to structure research work to ensure that there is sufficient time for learning (reading papers and reviewing literature), accountability with respect to milestones, and exchange with peers.
- Data Visualization: Data visualization is an immensely critical part of scientific work. Communication of results and interpretability of data hinges of well-conceptualized visualization. A good figure or illustration may convey data much more effectively than text. Good data visualization requires thorough identification with your results and should be driven by a narrative, i.e. a train of thought that conveys your path towards arriving at concrete conclusions. In the workshop, we review data representation styles, the meaning of graphical abstracts, the importance of figure captions, and basic plotting etiquette with respect to font sizes, legends, and labels.
- Writing: Successful research projects result in a scientific report, e.g. paper, thesis, or article. How to narrate your work, how to present your data, how to discuss your work in the context of other work, and what conclusions to draw is one of the most important tasks in research. In light of a separate workshop on scientific writing, we briefly discussed relevant steps in documenting research work and showed examples of scientific writing in preparation of defining the student's own reports.
- Peer Review Process: Peer Review is a fundamental part of any rigorous scientific process. In the workshop, we present how to assess the strengths and weaknesses of a publication with respect to properly defining the work's objectives, the suitability of their methods, the representation of their results, and the validity of their discussion and conclusion points. We outline the impact of a supportive feedback culture in the scientific community and the relevance of considerate and inquisitive review of the work of peers.

We conducted a total of four breakout sessions, 15 minutes each, and 3 students per room. In the first breakout room, each group discussed their previous research experiences, any previous projects they had worked on, methods they already were familiar with, and their impressions of the research culture in the labs they were matched with. The second breakout session aimed at students formulating the overall objective of their summer research project. Each student prepared a three-sentence summary of their project goal and was then asked to present their work to their peers. Each breakout room reviewed the proposed goals and provided feedback that aimed at clarifying and specifying their peer's project goals. The third breakout room was used to specify three immediate tasks that would allow each student to begin working on their project. After writing them down, each group reviewed, discussed, and improved their lists in separate breakout rooms. The fourth breakout session was aimed at identifying three key references linked to each of the students' projects. In groups of three, students were tasked to find three publications relevant to their first goals and to generate a proper citation. Students submitted their results from all four breakout rooms via a google form which were subsequently reviewed by their faculty advisor and the program director. Each breakout room session was followed by a 10-minute feedback session were one representative from each room reported on their discussion and their most important take away lessons. This allowed us to create a rich feedback culture that practiced presenting results and putting them in the context of the workshop's overall goals. The workshop ended with a faculty panel to answer questions by our participants.

Based on our post-program survey, students ranked the relevance of the "How to Research?" workshop a 4.4/5.

3.3. "Scientific Writing" Workshop

"Easy reading is damn hard writing" - Nathaniel Hawthorne

Scientific writing takes practice and a continuous effort in order to improve. Moreover, writing is an iterative process that involves feedback and editing. Most of our undergraduate students graduate from college with only very little writing experience and a poor understanding of basic guidelines for a report, thesis, or paper. In this workshop, we discuss central elements to a scientific paper or report, i.e. structure, style, and presentation, how to develop a narrative, and how to write for clarity. Specifically, we discussed:

- Successful writing is guided by the following principles: have a clear understanding of the content, avoid unnecessary jargons, develop in-depth knowledge of your subject, use innovative ideas and ways to justify your work, explain your scientific terminologies and provide a track of bibliography, thoroughly proofread your manuscript, and develop a unique writing style through practice.
- Paper/report structure: Most publications have an abstract, introduction, materials and methods, results, discussion, and conclusion section. We outlined the relevance of each section and presented established writing styles. In a 10-minute breakout session, we asked students to discuss a reliable order in which to write a report and gathered their input in a subsequent feedback session.
- Narrative-driven writing: A very important concept in scientific writing is the "narrative thread". Each report, article, or paper should follow a clearly outlined narrative thread that is tangible to the reader and allows them to follow the authors train of thought. A tangible narrative thread is very powerful in conveying complex lines of argument and is a convincing method to introduce new ideas and research results. It guides the author during their writing process and allows them to tie their findings to an overarching theme.
- Writing for Clarity: Writing is a multi-step process. We touch upon the individual steps that lead to a well-written report. Each paper starts with a first draft that is purely for yourself and transforms into a coherent and clear summary of your work through multiple revisions and editing by yourself and your co-authors. Following the ideas of Joseph M Williams on writing for clarity, we discussed the following 4 key principle: clearness, cohesion, coherence, and concision [4]. Through examples and task-based group discussions in breakout sessions, we reviewed Williams' simple guidelines for the writing process, which include (1) make main characters the subjects of sentences; (2) make important actions the verb of sentences; (3) get

to the main verb quickly; (4)create connections between sentences with common themes and common subjects; (5) provide old, familiar information at front; new, complex information at end; (6) begin sentences in a passage with consistent topics and themes; and (7) omit needless words. In a last active learning session, we reviewed George Whiteside's paper on scientific writing [5]. We then split up into breakout rooms to discuss assigned sections of the paper. In a subsequent feedback round, each group presented their key discussion points and taught their peers about their respective sections.

Based on our post-program survey, students ranked the relevance of the "Scientific Writing" workshop a 4.1/5.

3.4 "Career Development" Workshop

Career planning and professional development are important components of undergraduate studies. This includes not only a rigorous academic education, but also personal development and preparation for the job market. In the career development workshop, we discussed successful steps towards choosing a profession, evaluation of personal strengths and weaknesses, and concrete steps to towards career readiness. Specifically, we discussed:

- Career Development Model: As shown in Figure 2, the Career Development Model includes initial assessment of personal interests, values, and skills, followed by research and inquiries into possible career paths. Once applicants have concrete options, they systematically evaluate their priorities and commit to a path. By pursuing hands-on experiences such as internships, CO-OPs, and part-time positions, applicants will gain valuable data for their career decision. This process requires continuous reflection on one's experiences and is a gradual process that goes beyond the first professional job after college.
- Personality Test: We asked all participants to perform the High 5 Test, a free online assessment tool to identify ones top 5 personal strengths, prior to the workshop [7]. We collected the participants' results via a google form and prepared an overview of the groups outcomes. Problem Solver, Philomath, and Analyst were the most frequently reported strengths which is characteristic for a group of engineers. In a 15-minute breakout session into rooms with 3 participants each, we asked all participants to use the STAR method to describe a situation in which one of their key strengths was particularly relevant. The STAR method is a communication tools to establish relatability with your narrative [8]: "S" stands for situation, "T" for task, "A" for one's action, and "R" for result. Following this setup, you will be able to engage your audience, convey your story, and create empathy.

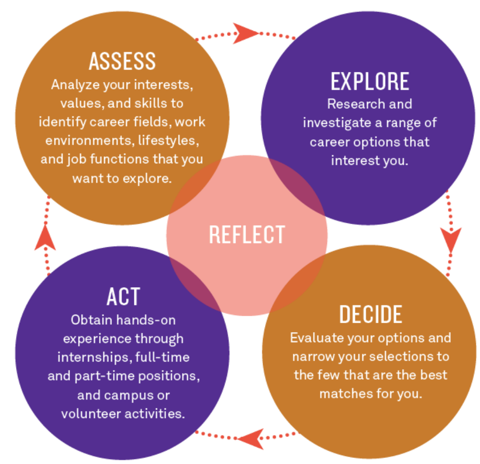

Figure 2 Career Development Model developed by Northwestern Student Affairs [6]. Through continuous reflection on new experiences and strategic pursuit of diverse hands-on experiences, students prepare for their future career paths.

- Career Readiness: In this last theme, we aimed at outlining critical steps towards preparing for their professional careers. Many skills can be developed and trained during their academic training. Therefore, we wanted to create awareness for critical skills and important tools towards becoming a valuable asset. These include work towards becoming a critical thinker and problem solver, practice oral and written presentation skills, gain teamwork and collaborative experience, pursue leadership opportunities and peer mentorship, develop a professional work ethic, and study basic project management skills [9].

Based on our post-program survey, students ranked the relevance of the "Career Development" workshop a 4.4/5.

3.5 Virtual Conference

At the end of the 12-week research period, we ended the summer research program with a virtual conference and provided all program participants with the opportunity to present their work. As part of the program, all students had to submit a research poster of their project. During the conference, each student had 3 minutes to present their work. After every 5 presentations, we broke up into breakout sessions in order to discuss the presented work and to allow participants to interact with the respective students. The regular interruption of the presentations proved particularly useful to maintain sincere engagement from the audience and to foster lively discussions of the presented work. The three-hour long virtual conference was also well-visited by our faculty body that participated in the breakout rooms and provided encouraging feedback to our program participants. Based on the poster submissions and the student presentations, we asked all participants to rank their three favorite presentations and to provide constructive feedback in order to practice peer review. Moreover, we inquired with the faculty mentors to rank the three most impressive student projects. The top three projects were selected as winners of the summer research program award and received a money prize of $500, $300, and $200, respectively.

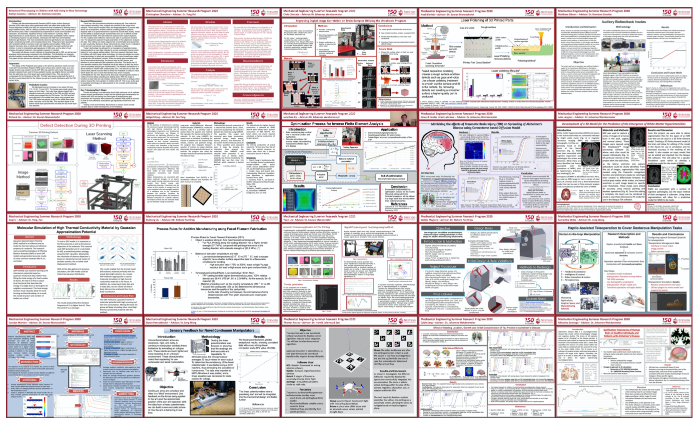

Figure 3 Posters from our participants of the Virtual Summer Undergraduate Research Conference. Each student had 3 minutes to pitch their work; after every 5 presentations, we split the audience into breakout rooms to discuss the individual projects and to provide constructive feedback to the presenters.

4. Learning Outcomes for our Students

Based on our post-program inquiry with our faculty advisors and students for assessment of perceived learning outcomes and newly acquired technical skill levels, we made the following observations:

- Engaging in research labs enriches the skill sets of our undergraduate students
- Intentional mentorship through a faculty advisor fosters personal growth
- Visibility of one's own work increases commitment, effort, and professionalism

- Sharing concrete work output with peers and mentors uncovers strengths and weaknesses and allows for guided feedback and growth
- Accountability for progress creates appreciation for one's own accomplishments
- Social networking- even if virtual- stimulates identification with own work
- Independent, albeit guided, review of literature and the participation in scientific exchanges during lab meetings and presentations, fosters basic understanding and memory associated with the least complex learning outcomes of Bloom's taxonomy, see Figure 1; the development of a research project and identification of project goals trains the application of existing or new knowledge; coding, simulations, data generation, data analysis, and the derivation of founded conclusions inherently train and expose students to complex learning objectives at the top of Bloom's taxonomy. In summary, independent research work leads to engagement with new materials on multiple passive and active learning methods.

On the technical level, students reported a diverse list of newly acquired skills. Most frequently, students reported that they made significant gains in coding and programing, i.e. python, C/C++, and html. The second most frequently mentioned learning outcome is the search, review, and annotation of relevant literature. Other skills range from project management, presentation skills, new statistical methods, data analysis, data visualization, and soft skills as part of their group work. These skills are truly valuable for our participants and are in many ways complimentary to their academic curriculum [10]. Interestingly, many of these skills were acquired despite fully virtual research work and speak to the impact of mentored project work. Face-to-face interactions might increase the learning effect and we will assess differences in future years.

Major limitations listed by students ranged from the lack of access to experimental spaces, physical interaction with experiments/manufacturing, and in-person meetings. A critical component of research work is the presentation and discussion of one's own work which is particularly difficult to practice and train in a fully remote setting.

5. Learning Outcomes from the Program

The summer research program was very successful in engaging our participants in active research work and we were able to match our students with enthusiastic faculty that provided regular mentorship, guidance, and training. Despite the purely virtual format of the program, we achieved high integration of students in their individual labs and received very positive feedback with respect to perceived authenticity of their research experience (85% of students reported that they had an authentic experience). Moreover, 79% of our students reported that they would continue working with their faculty advisor for the rest of the summer. This is truly indicative of the positive experience and enthusiasm that was generated through this program.

Undergraduate research is a key contributor to the research culture. In the mechanical engineering department, we are now building a permanent Student Research Program, with the goal to provide continuous mentorship to our students. This includes mentorship through a dedicated faculty member, independent research opportunities with group mentoring, and a workshop series on research methods.

During our workshops, we explored different active learning techniques in order to create engagement and audience participation in the otherwise purely virtual setting. The use of breakout rooms and independent research sessions during the workshops interrupted the passive screen time and took advantage of all participants having immediate access to their computers and the ability to looking things up on the internet. The virtual summer conference was a success and the chosen format with frequent discussions was effective in engaging students and faculty on a continuous basis.

5.1 Observed Limitations of the Program

We surveyed our students and faculty with regards to perceived limitations of the research program. We identified three frequent comments:

- Few students commented on the amount of feedback and facetime they received from their faculty advisor. The more integrated the students were, the higher their enthusiasm for their project and the higher their performance was [11]. Future programs could explore incorporating increased accountability from the faculty advisor side for increased interaction with their mentees.
- Students consistently expressed a preference for in-person, hands-on research experiences over a purely virtual program. Especially those students that matched with faculty advisors working in an experimental field, additive manufacturing, robotics, amongst others, would prefer physical access to research lab and workspaces which would allow them to design, build, and test parts, objects, or materials for their project. That being said, many students generally appreciated the engagement in research work even if fully virtual. Frankly, all research groups faced the challenge of accommodating to remote work with many innovative working styles being explored. Faculty reported that participants frequently contributed to their labs' efforts of finding news way to communicate and share their work, discuss projects and challenges, and to interact with peers under new circumstances.
- On the faculty side, most commented on a lack of prior coding skills among many of our participants. Furthermore, most participants had no prior experience in literature review methods and typically showed limitations with respect to proper citation of other work.

6. Conclusions

Based on student and faculty surveys we consider our first iteration of a summer undergraduate student program a success. Going forward, we intend to build a continuous student research program to provide faculty-student matching and group-mentored research opportunities to provide students additional learning opportunities that focus on scientific methods, coding, and hands-on experiences. Even if virtual, engagement in research work provides significant new learning opportunities for undergraduate students.

7. References

[1] Thiry, H. and Laursen, S.L., 2011. The role of student-advisor interactions in apprenticing undergraduate researchers into a scientific community of practice. *Journal of Science Education and Technology*, 20(6), 771-784.

[2] Krathwohl, D.R., 2002. A revision of Bloom's taxonomy: An overview. *Theory Into Practice*, *41*(4), pp.212-218.

[3] Wilson, Z.S., Holmes, L., Degravelles, K., Sylvain, M.R., Batiste, L., Johnson, M., McGuire, S.Y., Pang, S.S. and Warner, I.M., 2012. Hierarchical mentoring: A transformative strategy for improving diversity and retention in undergraduate STEM disciplines. *Journal of Science Education and Technology*, *21*(1), pp.148-156.
[4] Williams, J., 1990. Toward Clarity and Grace. *Chicago: The University of Chicago*.
[5] Whitesides, G.M., 2004. Whitesides' group: writing a paper. *Advanced Materials*, *16*(15), pp.1375-1377.
[6] Career Planning: Career Development Model, viewed 10/05/2020, *Northwestern Career Advancement*, https://www.northwestern.edu/careers/job-intern-prep/career-planning/index.html
[7] Free Strengths Test: Find Your Unique Talents and Character Traits, viewed 10/05/2020, *High 5 Test*, https://high5test.com/
[8] "STAR" Method for Behavioral Interviewing, viewed 10/05/2020, *Lehigh University, Career & Professional Development*, https://careercenter.lehigh.edu/node/145
[9] Career Readiness Defined, viewed 10/05/2020, National Association of Colleges and Employers, *Center for Career Development and Talent Acquisition*, https://www.naceweb.org/career-readiness/competencies/career-readiness-defined/
[10] Lopatto, D., 2007. Undergraduate research experiences support science career decisions and active learning. *CBE—Life Sciences Education*, *6*(4), pp.297-306.
[11] McKinsey, E., 2016. Faculty mentoring undergraduates: The nature, development, and benefits of mentoring relationships. *Teaching & Learning Inquiry*, *4*(1), pp.1-15.