Membrane Research Experiments for High School Students as an Introduction to STEM Research

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Abstract

A Research Experiences and Mentoring (REM) program was hosted for high school (HS) students by the Membrane Science and Technology (MAST) Center at the University of Arkansas. The students completed introductory membrane research projects designed to provide an introduction into the research process. Further, the students integrated into the MAST center research community that contains graduate students, undergraduate students from research institutions nationwide as part of a Research Experiences for Undergraduates (REU) program to connect with mentors who can offer guidance for their transition from HS to university. The students successfully separated watercolor pigment from food dye using tangential flow filtration and isolated the thiocyanate ion using membrane chromatography in two highly visual projects. Feedback from the students indicated the program gave them a tangible, realistic understanding of STEM that has left them significantly more likely to pursue a university STEM degree. On average, the students ranked gains from the program greater than 4/5 for both research self-efficacy and integration into the MAST center community. Overall, the goal of the program was to connect students to STEM and mentors that could provide future guidance. While only some of the students are passionate about continuing into STEM and research, all the students felt more confident entering university and pursuing ambitious goals. The authors recommend similar introductory research experiences and mentoring to organizations working with HS students as a means to prepare them for university and beyond.

Keywords High-School, Membranes, Research Experiences, Mentoring

Introduction

The Membrane Science and Technology (MAST) Center at the University of Arkansas seeks to provide students interested in STEM with research experiences and mentoring that emphasizes preparation for a career in STEM. The center has regularly hosted a Research Experiences for Undergraduates (REU) program and has recently extended these efforts to include non-traditional community college students as part of a separate Research Experiences and Mentoring (REM) program. The REM program includes a time-intensive research experience and further mentoring sessions during the following academic year only possible for local students [1]. Through a collaboration with Upward Bound, a program that hosts rising high school (HS) seniors on the University of Arkansas campus, an opportunity was identified to extend these research and mentoring efforts to HS students.

The program seeks to provide the HS students with experiences outside the classroom that prepare them for industry in ways undergraduate courses tend to struggle with. Students best prepared to

enter industry have refined industry-relevant qualities such as creativity, innovation, adaptability, etc., while forming a network of peers and mentors that can be leveraged to find opportunities [2,3]. These qualities and resources are not obvious to young students, and the sooner these students have experiences and connect with mentors that can provide the necessary preparation and guidance, the better prepared they are to enter industry after receiving their degree. **The goal of the High School Research Experiences and Mentoring (HSREM) program is to provide HS students with enriching introductory experiences in STEM research and quality mentoring relationships that inspire them to pursue an undergraduate degree and subsequent career in STEM**. The program was adapted from community college students to HS students by simplifying projects and concentrating the students in a single lab. It was our hypothesis that maintaining the research element of the experiments and allowing the students to contribute to the design of their experiments would instill a sense of ownership in their work that would encourage them to return to STEM. Further, connecting the HS students to the growing research community at the MAST center would give them many mentoring relationships that would continue to encourage them to pursue STEM.

Methods

The projects were designed to demonstrate relevant principles to membrane research. Membrane research is an effective topic for an introduction to STEM since students can easily visualize the process, the experiments are simple and efficient, and the field is highly interdisciplinary. Each project consisted of an introductory day where the instructors taught some of the relevant theory and demonstrated the experiments, a learning day where the students practiced the experiments under heavy guidance and supervision from the instructors, and a research day where the students used the knowledge they gained over the first two days to make decisions about the project and interpret the effects those decisions had on the outcomes. The students were asked to come up with a hypothesis after the first day of the project and asked to identify the independent and dependent variables after completing the second day.

Three types of membrane filtration techniques were explored: membrane chromatography, dead end filtration, and tangential flow filtration. The first project modeled tangential flow filtration using a cross flow membrane cassette (Vivaflow 50, Sartorius) to separate food dye from watercolor pigment [4]. A gel electrophoresis experiment (Flynn Scientific) was performed first to illustrate the size of dye molecules. The second project used membrane chromatography (Mustang Q Acrodisc, Pall) to separate the thiocyanate anion from a potassium cation [5]. The final experiment used yeast cells to compare membrane fouling in dead end (Nalgene Rapidflow) and tangential flow filtration (Vivaflow 50, Sartorius). The first and last experiment focused on calculating flux over time to quantify fouling and to observe the transport of each component through the process. The second experiment demonstrated the bind and elute process using a membrane adsorber and tasked the students with calculating the capacity of their membrane adsorber over multiple regenerations.

The students took two surveys in the final week, one to examine their cultural competencies and the impact the program had on their desire to pursue a career in STEM. Both surveys used self-evaluation and open response questions to collect quantitative and anecdotal evidence describing

potential improvements to the students' research skills and self-efficacy, mentoring relationships, and awareness and interest in careers in STEM.

Mentoring activities were held during the research experience and planned for the upcoming academic year as a part of the REM initiative. Emphasis was placed on sessions where the students could interact with the undergraduate and graduate student researchers in both formal and informal settings. The program supplied lunch weekly for the HS students and the instructors, giving them regular opportunities to talk informally to the graduate students. The HS students were immersed into the MAST center research community early on through a reception that was set up to welcome and connect the undergraduate summer researchers and the HS students. The parents of the HS students were also invited to this reception and a short presentation following it that gave them information on the program and its initiatives. Mentoring sessions during the academic year will continue to connect the students with mentors based on the area of STEM they hope to pursue, and work with them to prepare their results for a poster presentation at the Emerging Researchers Nationwide conference.

Results

The results for the first and second projects were mostly as expected. The gel electrophoresis component of the first project successfully separated large molecules from small molecules and confirmed the sizes of the dyes (350-750 g/mol). They found the membrane was able to separate the dye from the watercolor pigment, but not completely and only the permeate was a pure color. The flux was similar when pore size of the membrane was increased from 50 kDa to 100 kDa, with values of 1.23 mL/s to 1.26 mL/s. The second project was able to successfully demonstrate the function of the anion-exchange membrane adsorber by successfully isolating thiocyanate from a potassium counterion. The thiocyanate ion acts as an indicator by forming a deep red complex with iron when added to an iron chloride solution. Initially no color change occurred as the potassium thiocyanate solution was passed through the membrane adsorber, indicating it successfully bound the thiocyanate. The number of drops in the binding and eluting steps were used with the concentration of the thiocyanate solution to calculate the capacity of the membrane adsorber. The students initially calculated the capacity of the membrane to be 33.6 µg and 76.8 mg of thiocyanate for binding and eluting, respectively, using a stock solution of 0.16 mg/mL thiocyanate. The students commented that further standardization of this experiment (i.e., assigning recorder role, creating standards to compare to) would have likely produced more consistent results.

The students were asked to contribute to the design of their experiments to maintain the research element of their projects and were able to do so well. They applied knowledge gained from the first two days of experiments within each project to choose parameters such as the volume and time intervals over which to assess samples to ensure maximum accuracy, concentrations of solutions to make when appropriate, speed of the experiment (i.e., pump or syringe), and ideas to troubleshoot when results did not go as expected (particularly with the third experiment). The students did also enjoy choosing the colors to mix and using the dyes they had previously studied.

To evaluate the impacts on the students after the program, a survey was given to the students and informal interviews were conducted after the program ended. The results highlighted the strong impact the program had on the research self-efficacy and desire to pursue future STEM endeavors. On average, the students rated questions discussing self-efficacy very high, such as confidence in ability to contribute to science (4.67/5), confidence to do well in future science courses (4.20/5), engaging in real-world science research (4.83/5), and understanding what research is like everyday (4.50/5). Questions relating to the community and mentoring relationships also were highly rated, such as feeling a part of a scientific community (4.00/5), working relationships with other research group members (4.50/5), and interactions with my REU advisor(s) were both intellectually stimulating and interpersonally rewarding (5.33/6). The cultural competencies survey found that the cultural competencies of the students was low compared to university peers, suggesting that programs like this that expose the students to a diverse community are beneficial to them.

Observations and anecdotal results during and after the program support these quantitative results. The students asked the graduate student and undergraduate researchers engaging questions in both informal and formal settings. It was clearly impactful for them to be in the dedicated research lab and around a fast-paced research environment. The lunch sessions were specifically mentioned in the free response question as one of the most beneficial components of the program. Free response questions also noted the students feel more prepared and more conscious of working to find their career after graduation, the program improved their confidence in their ideas and socialization skills and helped make their seemingly "outrageous" goals were more achievable. Finally, one student toured the UARK engineering college after the program and now intends to pursue electrical engineering, and he attributed his interest to taking the tour directly to the program.

Summary

A research experiences and mentoring program was offered to rising high school seniors through a partnership with Upward Bound. The program sought to provide enriching introductory research experiences and connect the students to mentors within the MAST center network. The program consisted of three projects designed to demonstrate the process of STEM research to the students and start a discussion about ways similar technologies are used in different industries. The projects examined dead end filtration, tangential flow filtration, and membrane chromatography, and gave the students the chance to contribute to the optimization of parameters over the three-day project. The students were able to successfully calculate flux drop as a result of membrane fouling and visually observe separations based on size exclusion and molecule charge. Survey and interview results demonstrated the positive impact the program had on the students, particularly on their confidence as a STEM researcher and their ability to integrate into the MAST Center research community. The program will culminate with the students presenting their results at the Emerging Researchers Nationwide conference, which will continue to provide the students new experiences within STEM and STEM research they would not have experienced otherwise. Future iterations of this program will continue to refine the experiments while maintaining the creative aspect that allows the students to participate in their optimization. The impact this program had on the students that participates suggests research experiences are an effective experiential learning experience, even for HS students.

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Mr. McKean is currently pursuing a PhD in Materials Science and Engineering and plans to include engineering education as a major component of his dissertation. Mr. McKean received his MS in Microelectronics Photonics from the University of Arkansas in 2021 and his BS in Chemical Engineering from Syracuse University in 2017. Mr. McKean has served as the lead graduate student for MAST Center REU and REM programs since 2022, and has published and presented the results of the programs at numerous conferences. Mr. McKean plans to work to facilitate connections between academia and industry after receiving his doctoral degree.

Dr. Gary Bates

Gary Bates, Ph.D. is a full professor of Biology and the program coordinator for Agriculture and Biotechnology at Northwest Arkansas Community College in Bentonville, AR. Dr. G. Bates has worked with Upward Bound for many years providing high school students with an initial introduction to scientific research. Dr. G. Bates is on the advisory board for the Cell Biology Education Consortium and utilizes CUREs in his classes to allow students the opportunity to use tissue culture to produce phytochemicals. His laboratory research focus is oxidative stress on plants and human cells.

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