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Work-in-progress: Elevating Chemical Engineering Outreach Through Collaborative Efforts Showcasing Fluid Flow Experiments

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ABSTRACT

The Summer Enrichment Academy (SEA) is a summer program at the University of Maryland, Baltimore County (UMBC), which introduces pre-college students to science, engineering, arts, and humanities fields. Students participate in engaging, informative, and interactive week-long workshops to gain a preview of the college experience. One of the modules offered as a part of the summer program is "Introduction to Chemical Engineering," which aims to provide students with a preview of the exciting world of chemical engineering (ChE). The goal of the module is also to raise awareness of various career possibilities in chemical engineering. Students work on hands-on activities and tours of research laboratories. One of the hands-on activities is that of mini fluid flow experiments showcasing one of the most important topics in the realm of ChE: fluid flow phenomena.

Improving the experiential learning of college-level students has gained special attention. One example is the creation of a desk-scale kit on fluid flow, aiming to facilitate the understanding of frictional losses and other fluid mechanics topics. University of Florida (UF) has created these kits as a special component of their unit operations experiments to enhance the learning objectives of ChE laboratories, introducing junior and senior students to the concepts of pressure drop due to friction losses in pipes. Furthermore, the desk-scale kits are also available for use in lecture courses as well as experimental demonstrations for outreach purposes. The latter can be used as a strategy to showcase practical applications of ChE among pre-college students, aiming to tackle the current decline in undergraduate enrollment in ChE programs.

In efforts to combine innovative outreach initiatives with improved teaching strategies, both institutions have engaged in a novel partnership by using the mini fluid flow kit to showcase fluid flow concepts to high-school students via the summer program. The novelty of this effort lies in the ability to introduce high-school students to one of the most important topics in ChE via simple yet versatile fluid flow experiments in a safe and modern fashion. Experiments involve the measurement of pressure differentials when water flows through multiple flow pathways, highlighting the effect of pipe diameter, flow rate, and pipe geometry on frictional losses.

Preliminary feedback from the summer program rollout indicates a positive reception of the fluid flow module as a mechanism for understanding what chemical engineers do. With that in mind as the primary motivation, the long-term goal of this collaborative work is to develop a systematic assessment method to measure how the experimental module is perceived by high schools. In subsequent iterations of the summer program, a pre-and post-module survey will be

administered to gauge the understanding of important fluid mechanics concepts such as pressure drop, friction, flow rate, and others, as well as to assess the ability of the mini fluid flow module to have students considering ChE as one of their prospective majors in college.

1. JUSTIFICATION

Chemical engineering (ChE) is among the first five engineering disciplines with the highest number of awarded bachelor's degrees in the United States, with approximately 11,148 degrees as of 2019. This was the result of the approximately 40,000 undergraduate students enrolled in ChE that year[1]. Despite these numbers, ChE undergraduate enrollment has been described as cyclic. The projected forecast is a new decline in enrollment for the next couple of years as a consequence of factors including the dominant industry, job offer and demand, and a process control-related oscillatory response influenced by graduation times, complex curricula, and salary reward[2].

Additionally, ChE freshmen matriculation has declined due to students leaving their major to other perceived "less pollutant" engineering disciplines such as those of civil, biomedical, and environmental. This poses a challenge for student retention, and it may be the result of misconceptions that chemical engineers will end up working mostly in companies with unsustainable processes, such as those of the petrochemical and mineral industries[3]. It is clear that students, teachers, and the general public need better guidance towards the diverse applications of the discipline.

Among the available strategies, exposing students to hands-on activities that foster a good understanding of the ChE profession appears to be effective, especially when done at earlier stages before students reach college[4]. Multiple efforts have been made in several institutions with exemplary outreach initiatives, demonstrating how important the institution's commitment is to educating students and the community better. Noteworthy, these efforts must be collaborative in nature, thus requiring the participation of multiple sectors within a given institution, the locality, and beyond.

Experimental demonstrations involving the flow of fluids through pipe networks are a promising entry point to engage students interested in ChE for various reasons. First, fluid flow phenomena are common to essentially any kind of physical or chemical process regardless of the scale or specific application. Thus, it can be used to introduce pre-college students to the importance of designing safe, efficient, and sustainable flow processes. Second, fluid flow experimental demonstrations can be designed to be simple and safe yet versatile, as they typically require water at room temperature, which is readily available in most locations. Third, fluid mechanics is one of the first fundamental courses in the molecular transport sequence of ChE curricula; thus, pre-college students can have a glimpse of what they will learn in the classroom if they choose

ChE as their major in the future. Therefore, showcasing the breadth of Chemical Engineering to high-school students via fluid flow experiments is an excellent outreach platform, as reported elsewhere [5].

This work-in-progress features collaborative efforts between two partner institutions committed to increasing the enrollment and retention of ChE undergraduate students by bringing together a structured pre-college summer program and versatile lab kits. The overall goal is to inform students what chemical engineers do via hands-on activities showcasing the flow of fluids through a mini fluidic device bearing pipes of different diameters and configurations.

2. BACKGROUND

2.1 Engineering and STEM Outreach

As a consequence of the decreased undergraduate enrollment, the downward trend in ChE graduations has been forecasted to reach a very low point in the United States within the next four years[1]. This trend has also been observed outside the United States; Spain experienced an approximately 5% decrease in undergraduate ChE enrollment between 2018 and 2022 as a result of demographic factors and changes in economic conditions[6]. Since these trends are widespread, it is imperative that institutions strengthen outreach efforts to advertise the profession among K-12 students better while retaining college students who are already enrolled.

Outreach programs may include on-campus activities such as summer camps and hands-on workshops. Other strategies involve off-campus activities such as school demonstrations, engineering contests, and science fairs in public places such as malls, convention centers, and museums. Among the strategies to simultaneously accomplish recruitment and retention, involving undergraduate students and faculty in outreach programs has been successful, with up to a 9% increase in undergraduate enrollment within a three-year window[7]. Some universities have created structured chemical engineering outreach programs as a curricular requirement for capstone courses. In this case, undergraduate students are involved in the design and execution of hands-on workshops, survey analyses, and final presentations on the impact of outreach efforts with schools in the community. This type of platform has been highly effective because college students can offer more realistic models for K-12 students, increasing motivation for STEM college education and providing better guidance on career choice[8].

2.1 Collaborative Efforts in Engineering Outreach Initiatives

Aiming to elevate the impact on the K-12 community, outreach programs may involve multiple partners, including universities within the same district, universities in different states or countries, universities and professional organizations, universities and industry, and combinations of them[9]–[11]. The participation of these sectors plays a pivotal role in fostering innovation, diversity, and societal impact. By bridging the gap between academia and real-world challenges, these collaborative endeavors cultivate a dynamic environment where knowledge exchange, resource sharing, and interdisciplinary collaboration work together. Frequently, collaborative outreach efforts include experimental demonstrations, workshops, and other hands-on activities. In some cases, experimental kits and cell phone-based modules are used to improve the experience of K-12 students in different outreach activities, which has proven to be significantly more effective in engaging students[12]–[14].

The synergy generated by collaborative initiatives employing hands-on activities drives innovation, fosters lifelong learning, and strengthens the bonds between institutions, paving the way for a brighter future fueled by technological advancement and social progress. This collaboration between UMBC and UF aims to combine their resources by integrating the existing Summer program at the former with the experimental kits developed by the latter. By doing so, they aim to engage high-school students in one of the most significant chemical engineering topics: fluid flow.

3. METHODS

3.1 Summer Program Structure

The Summer program at UMBC takes place annually in late June for five weeks, serving as a platform for the campus to better reach out to the broader community, especially pre-college students. This program showcases talented faculty, modern facilities, and the student body. It offers unique, fun, yet challenging and mind-expanding workshops and courses for middle- and high-school students. Activities in the program are rigorous and engaging and are designed to spark students' deepest passions and interests. The courses are low-cost (typically $200-300) with available discounts or fee waivers to qualifying students. After the deduction of the course expenses, 50% of the course revenue goes to the instructor's salary. Expenses include buying supplies for the various hands-on activities of the program. For full-day courses, lunch is also included for the students. In total, 857 students have participated in the summer program during the last two years, with 655 of them being high school students.

While numerous STEM-based summer programs at UMBC are available for high-school students, offerings related to ChE are notably scarce. The majority of these programs tend to concentrate on computing topics such as Cybersecurity, Data Science, and Programming. In response to this gap, a chemical engineering-focused summer outreach program for high-school students was launched in 2022. The first offering was conducted in a hybrid format, accommodating 15 students on-site and 3 students virtually. By the next year, the program expanded to include 18 participants, all of whom attended in person as a mechanism to better guide students in the execution of experiments to increase their engagement in the program. The third iteration will also be offered fully in person. Still, the option of running the program in a hybrid format remains open for subsequent iterations, especially to better reach students in other geographic areas and as a mechanism for students requiring special accommodations. Online rollout of the program requires some advanced logistical planning, such as compiling and packaging the supplies to send to the students. We would also like to point out that in the hybrid version, the online students miss out on the in-class interactions. The learning objectives of teamwork and collaboration are not met in the online setting.

The topics covered in the ChE-focused summer program include fluid flow, separations, energy conversion, mixing, and reactions. This work-in-progress paper focuses on experimental demonstrations showcasing fluid flow phenomena via hands-on activities utilizing a desk-scale fluid flow module with two partner institutions collaborating to increase high-school students' interest in ChE programs. Figure 1 shows a picture of participants in the first offering of the ChE Summer program engaging in mini fluid flow experiments under the supervision and guidance of a faculty member.

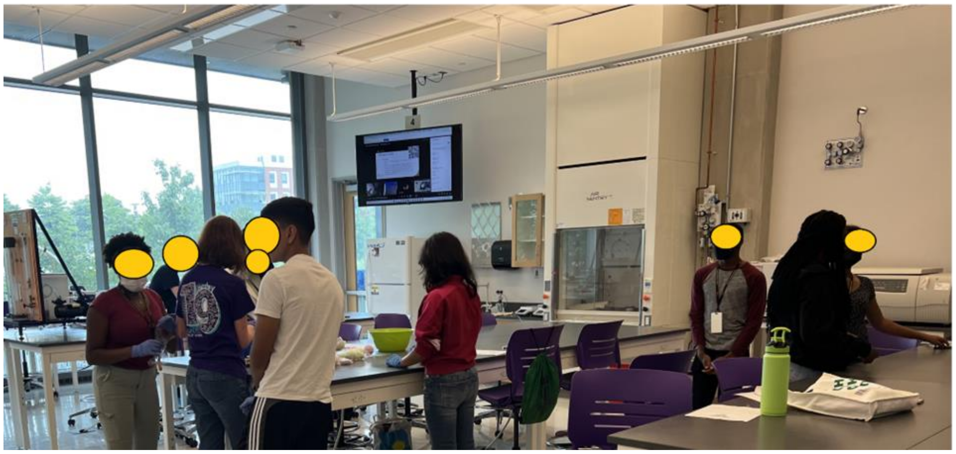


Figure 1 - High-school students engaged in hands-on activities at the ChE Summer program.

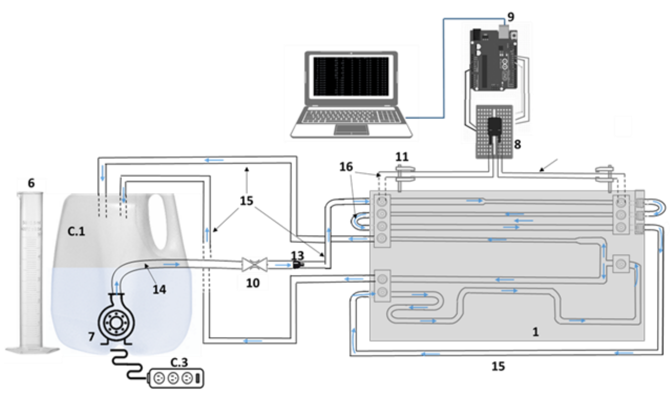
3.2 Hands-On Module for Mini Fluid Flow Experiments

The design and creation of a small fluid flow system was done by UF. The system consists of a 3D-printed mini-fluidic device bearing pipes of different diameters along with pipe contractions, bends, and pressure ports. Water is fed to the device through flexible tubing using an aquarium pump immersed in a feed tank. Water flows across the entire device and returns to the feed tank in a closed circuit. Pressure ports are connected to an Arduino-operated differential pressure sensor via flexible tubing. The sensor reads the signal and converts it into differential pressure readings displayed on the computer screen, which is connected to the Arduino microprocessor via a USB cable. Figure 2 shows a picture of the assembled system, including the feed tank, fluidic device, flow connectors and adapters, and electrical components. The laptop is not shown in the picture.

Figure 2 - Desk-scale fluid flow system designed by the University of Florida.

Initially, this and other three systems for experimentation on fluid mechanics and heat transfer were designed as take-home kits in response to the emergency remote teaching caused by the global COVID-19 pandemic. The pandemic was particularly challenging for laboratory courses because of the requirements of hands-on experience, teamwork, use of engineering equipment, and other important student learning outcomes [15]. To tackle this challenge, a team of faculty members at the University of Florida created low-cost, versatile, and shippable take-home laboratory kits for students to conduct experiments at home[16]. Noteworthy, the take-home kits were designed to cover the same fundamentals and topics in experiments typically conducted on a larger scale in engineering laboratories. Upon resumption of face-to-face laboratories, the mini fluid flow module became a desk-scale experiment, incorporated in regular experiments in combination with traditional fluid flow experiments conducted with existing laboratory equipment.

Since Fall 2021, UF has been using this and other modules aiming to create a teaching model based on multiple scales of experimentation. Schematics of the mini fluid flow system are shown in Figure 2, which depicts the direction of the flow and how data is monitored via Arduino IDE. Experimenters subsequently use data to analyze and explain the concept of friction losses due to different pipe diameters, pipe bends, and flow rates, using differential pressure as the main independent variable.



No.	Item description
1	3D printed mini fluidic device
6	Graduated cylinder
7	Submersible centrifugal pump
8	Differential pressure sensor assembly
9	Arduino microprocessor
10	Pinch valve
11	Plastic clamps
13	1/4 to 1/8 reducer
14	Tubing 1/4" ID
15	Tubing 3/32 "
16	Tubing 1/16 "
c.1	Plastic jug (feed tank)
c.3	Power strip with on/off switch

Figure 3 - Schematics of the experimental setup for mini fluid flow experiments, flow rate measurements, and data recording (not to scale). Numbers refer to materials listed in the appended table (not in correlative order, as they correspond to a more comprehensive list)

While desk-scale fluid flow systems have been developed by other groups [17], our system is especially advantageous for outreach initiatives because of various reasons. Overall small footprint, multiple flow path configuration which makes it versatile, and the ability to provide experimenters with real-time data monitoring and acquisition and the option to save all readings in a comma-separated values (CSV) file. In addition, materials are affordable, with most of them available from open-source e-commerce platforms; kit components are easy to assemble/disassemble, pressure readings do not require external or built-in manometers, and results have been proven to be reliable, accurate, and reproducible. If the reader wants more information on materials, CAD files, and software, please contact the authors of this work.

3.3 Designing a Mini Fluid Flow Module for the ChE Summer Program

The goal of the mini fluid flow module during the ChE summer program was to introduce high-school students to important topics critical for chemical engineers, using basic concepts of frictional losses during fluid flow in pipes and strategies to foster teamwork, data collection, inquiry-based learning, and science communication. A 3-hour session on one of the days of the summer program was dedicated to the execution of this module, starting with a lecture on introductory concepts followed by experimental work. The kit described in section 3.2 was utilized by high-school students in groups of 4 - 5 experimenters. The lectures included basic notions of fluid flow phenomena and relevant applications and an overview of experimental procedures. Students were also provided with printed instructions on the operation of the module. The instructor, along with the teaching assistant (an undergraduate student) guided the students to follow along. A video of the assembly and experimental procedure is shared for online students.

By combining efforts, the two participant institutions aim to expose high-school students to basic fluid flow concepts using a small-scale system that is easy and safe to operate. Primarily, we want to introduce basic concepts of frictional phenomena by illustrating the flow of fluids in pipes of different diameters and orientations by measuring the pressure drop across various flow pathways. In addition to fundamental topics of chemical engineering, students can gather technical and soft skills such as teamwork, effective communication, and data collection using Arduino-based sensors. For example, students were organized into teams (not more than 5 members), and they rotated different tasks such as assembling the setup, programming the Arduino, pump operation, flow rate measurements, and data recording and analysis. During experiments, students were required to discuss their observations with their teammates and to answer questions from the instructor to assess their understanding of the obtained results. Students collected data directly from the serial monitor or Arduino IDE. Even though they were not required to process data graphically or do subsequent analysis, they could compare the magnitudes of differential pressure across multiple flow pathways. They did it to explain the relationships between pressure drop and flow rate, pipe diameter, and pipe lengths.

To reiterate, the authors are open to contact if needed to provide more information on any aspects of the program.

4. PRELIMINARY OBSERVATIONS

The fluid flow experiment was well received by the participants, as reflected by the summer program course evaluations. Even in the online setting, which was used to accommodate students who were unable to make it in person during the first offering of the summer program due to various reasons, students were able to work through the detailed instructions and execute the experiment with real-time guidance and troubleshooting help from the instructor. An informal in-class poll was conducted to gauge the familiarity of fluid flow-based topics like flow rate, friction, pressure drop, and viscosity. Of these four topics, the most familiar topic was friction, while flow rate was the least familiar. However, the familiarity did not come from fluid flow context but from having heard the word "friction" from day-to-day life or science shows. One of the student's feedback comments is shown below, pointing to other potential target audiences: home-schooled kids.

> "*I really enjoyed all of the interactive experiments we did. I also really enjoyed the demonstrations and lab tours because I am homeschooled and did not get to do as many experiments with actual lab equipment.*"

This approach has the potential to cater to not only public and private high-school students but also students who do not have access to lab equipment because they are home-schooled or those who need to enroll in online education due to other reasons.
Because of the nature of the work-in-progress at this stage, we are only presenting preliminary observations. However, we aim to collect comprehensive qualitative and quantitative data from the upcoming 2024 summer session on the ability of our outreach initiative combined with the

execution of desk-scale experiments to accomplish the objective of this work-in-progress. Additionally, one of our long-term objectives includes an iteration of the mini fluid flow experiment conducted by ChE students in their second year. This will allow us to collect feedback and suggestions to improve the mini fluid flow module for the summer program, using the college students' perspective. We will use the strategies described in the proposed assessment section.

5. PROPOSED ASSESSMENT

5.1 High-School Students

For the upcoming summer 2024 session, we will perform a pre- and post-study for both demographics, i.e., high-school (HS) and college students, after receiving the IRB approval. The goal will be to measure if there is an increase in self-reported familiarity with the various fluid flow topics addressed in the module and to evaluate the effectiveness of the module in showcasing the exciting world of Chemical engineering among high-school students. We will roll out a pre-survey (shown in Appendix A) before the start of the summer program, followed by a post-survey once students have completed the experimental demonstrations of the summer program. We aim to collect quantitative and qualitative responses by combining Likert-scale questions along with open-ended feedback questions. An example of a quantitative evaluation that can be potentially used is shown in Table 1.

Table 1: Example of quantitative questions on a Likert scale where 5 is "strongly agree" and 1 is "strongly disagree".

The following topics are familiar to me:					
TOPICS	Strongly disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Strongly agree
Flow rate					
Friction					
Pressure drop					
Viscosity					
Heat Exchanger					
Scale up					

On the qualitative side, we first want to gauge how aware the students are of chemical engineering as a field. A potential pre-test survey question could be - “Have you heard of chemical engineering as a major? If Yes, please share your perception of what chemical engineering entails?” We also aim to investigate if the mini fluid flow experiments enhanced their understanding of chemical engineering, at least in one of the many topics of the profession: fluid mechanics. Specifically, we can ask the following questions in the post-surveys:

- Even though chemical engineering is much more than fluid flow in pipes, how likely would you be to choose Chemical Engineering as your college major based on your experience during the summer program?”
- Has your interest in Chemical engineering increased as a result of these experiments? If Yes, provide reasons why. If No, what recommendations would you suggest?
- In your opinion, how do you think chemical engineers contribute to solving global challenges?

Qualitative feedback will be used for thematic analysis to identify opportunities and limitations of the desk-scale experiments to showcase one of the many chemical engineering applications. Additionally, we plan to incorporate demographic data collection among survey respondents to analyze subgroup differences, thus strengthening the validity of findings in our outreach initiative.

5.2 University Students

As mentioned before, we will design a version of the mini fluid flow module with college students, specifically ChE students in the second or third year. This will serve as a source of feedback from the perspective of college students on how the module built in the summer program can be improved. The characteristic difference between assessments for college and high-school students is that college students will have received the relevant background to interact well with the modules. For college students, we want to gauge their thoughts on the following aspects:

- Would you like to have been introduced to these concepts before college?
- How would your understanding be if you had taken a high-school course on Introduction to Chemical Engineering?
- What changes would you recommend to the desk-scale fluid flow module for high-school students to absorb the material better?

6. FUTURE WORK AND BROADER IMPACT

We would like to study the long-term impact of the assimilation of ChE concepts using these desk-scale experimental modules. UMBC can track the yield of high school students who have taken the summer course and applied/enrolled in the chemical engineering program. Another space that we can tap into with the desk-scale modules is online education, specifically homeschooled students. Once we have a proper mechanism to ensure the delivery of sufficient kits, we can expand to other locations to tackle the challenge of decreased chemical engineering enrollment nationwide. We will also incorporate other topics like heat transfer and solid-liquid operations. UF has already developed these other modules; thus, their integration into the summer program can be planned in a smooth and organized manner, keeping in mind that they must be customized for high-school students.

The chemical engineering course in the summer program starts with an introductory presentation on chemical engineering and its various applications. It also emphasizes future career paths the students can choose from. During the execution of the fluid flow module, emphasis is placed on parallelism between the small-scale of fluid flow experiments and the complex nature of pipe networks of industrial-scale processes. Fluid flow in biomedical applications can also be highlighted with examples such as blood flow within the human body with the heart as a pump, dialysis machines to remove waste products and excess fluids from the body, or microfluidic devices for cell manipulation, diagnostics, and drug screening. In the upcoming version, we plan to introduce semiconductor industry applications such as water cleaning of wafers to remove surface residues or etching with flow control to achieve precise etch profiles and uniform etch rates.

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Appendix A: Example pre-survey

First name

Last Name

The following topics are familiar to me

	Strongly disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Strongly agree
Flow rate	○	○	○	○	○
Friction	○	○	○	○	○
Pressure drop	○	○	○	○	○
Viscosity	○	○	○	○	○
Heat Exchange	○	○	○	○	○

	Strongly disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Strongly agree
Scale Up	○	○	○	○	○

Please describe the context where you learnt these topics