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Flow Forward: Early Experiences Empowering High-Schoolers in Chemical Engineering

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INTRODUCTION

Undergraduate Chemical Engineering (ChE) remains a top five engineering discipline; however, enrollment and degree production are notoriously cyclic. For example, from over 11,000 degrees awarded in 2019 [1], the number dropped to about 8,000 in 2023 [2]. While such downturns may reflect broader economic and industry cycles, they are often amplified by persistent misconceptions about what chemical engineering involves. These misconceptions can reduce the discipline to a narrow set of industries (e.g., petrochemicals) and, in turn, create the impression that ChE is misaligned with sustainability-oriented careers [3]. These perceptions matter because students' decisions to pursue and persist in an engineering major are shaped not only by academic readiness but also by whether they can clearly envision the professional work, societal relevance, and breadth of opportunities associated with the field. As a result, early-stage interventions that provide authentic, accessible exposure to engineering practice can play an important role in strengthening the pipeline and supporting long-term retention. In particular, hands-on outreach has proven effective in helping pre-college students develop more accurate mental models of engineering disciplines by connecting fundamental concepts to real applications through experimentation, data interpretation, and evidence-based communication [4]. For ChE, this kind of "definition work" is especially important because its impact is often embedded inside products and processes that are not immediately visible to prospective students. Thus, it is critical for educators to better communicate the diverse applications of the ChE discipline, and hands-on activities are an effective avenue for this communication.

Fluid mechanics offers an ideal platform for such engagement. As a foundational area in the ChE undergraduate curriculum, fluid flow is central to a wide range of physical and chemical processes, enabling high-school students to explore themes that resonate with modern engineering including safety, efficiency, reliability, and sustainability, without requiring advanced prerequisite knowledge. Moreover, fluid flow experiential learning activities using desk-scale kits are well-suited for summer bootcamp outreach contexts because they are portable, safe, repeatable, and fast enough to support multiple "what-if" trials within a limited time window. In this setting, students can directly connect design choices (e.g., tubing diameter, length, curvature, elevation, and fluid properties) to measurable outcomes such as flow rate and pressure drop for subsequent translation of those observations into explanations tied to real-world systems. This work extends the collaborative effort between two partner institutions to boost ChE enrollment and retention by implementing a hands-on fluid flow module in a pre-college summer program, and by studying changes in perceptions of high-school students towards chemical engineering before and after learning about fluid flow during the bootcamp experience.

BACKGROUND

Pre-College Engineering Outreach and the Role of Partnerships

Pre-college outreach efforts at colleges and universities are often developed and delivered independently, with programs differing in format (e.g., day programs versus residential experiences), duration, and instructional style. While this diversity can broaden access, it can also lead to fragmented messaging about what engineering is and what engineers do. National efforts to improve the public understanding of engineering have emphasized the value of consistent, audience-appropriate messages that highlight engineering's societal impact and the problem-solving nature of the profession [5]. In parallel, research on engineering summer camps suggests that well-designed outreach experiences can positively influence students' conceptions of engineering and technology, helping learners better understand engineering work and strengthening interest [4]. Because ChE can be less immediately recognizable to pre-college students than more visible fields (e.g., computing), partnerships between institutions can be particularly valuable for sharing outreach modules, reducing the duplication of effort, and sustaining programs over multiple years.

Across outreach contexts, hands-on, inquiry-driven learning is repeatedly identified as an effective approach for engaging learners. Evidence from higher-education research shows that active learning improves performance and reduces failure rates across STEM courses, and engineering education further supports active and collaborative learning as beneficial while also noting the importance of matching methods to goals and constraints [6]. Although these studies are not exclusively pre-college, they provide a strong pedagogical rationale for outreach designs that rely on experimentation, iteration, and real-time feedback rather than passive exposure.

Chemical Engineering Awareness and Common Misconceptions

A key motivation for chemical engineering outreach is that prospective students often hold incomplete or inaccurate views of the discipline [7]. Documents from professional societies and other studies explicitly document recurring misconceptions [8]. One of the classic misconceptions is that chemical engineering is primarily "doing chemistry," or that it is narrowly tied to a single industry sector. To tackle this misconception, the breadth of modern chemical engineering across manufacturing, pharmaceuticals, biotechnology, food processing, advanced materials, environmental health and safety, and related areas must be showcased. For outreach programs, these misconceptions shape how learning goals are framed: rather than only introducing terminology, activities should help students connect observable phenomena and measured data to the kinds of decisions chemical engineers make in practice (e.g., designing systems that are safe, efficient, and sustainable).

Summer Program Context: The Summer Enrichment Academy

Hosted by a professional program at the University of Maryland-Baltimore County (UMBC), the Summer Enrichment Academy offers middle- and high-school students the opportunity to engage in immersive, college-level experiences. Led by a mix of university faculty, industry experts, and/or graduate students, these sessions emphasize inquiry-driven, hands-on learning designed to spark intellectual curiosity. The program spans five weeks, featuring a variety of one-week workshops offered in both full- and half-day sessions. While ChE-focused courses were not initially part of the summer camp course portfolio at UMBC, a new ChE course was therefore started in 2022, exclusively for participants of the summer camp, and has been offered annually as five half-day sessions. Topics covered in the ChE-focused course in the program include electrochemistry, separations, energy conversion, mixing, and reactions. All of them as standalone "modules". Mini Fluid Flow was added as a module within the ChE course since its inception, which is the focus of this work. Noteworthy, no other engineering courses were offered to high-school students participating in the 2025 iteration of the summer bootcamp.

Desk-Scale Fluid Flow Kit

To introduce high-school students to fluid flow phenomena in ChE during the summer program, an existing desk-scale mini fluid flow (MFF) kit was used. This and other kits were designed to support experiential learning in unit operations and transport courses at the Chemical Engineering Department of the University of Florida (UF), enabling an educational model characterized by multi-scale experimentation and experiential learning modules in the take-home format [9]. The kit setup centers on a 3D-printed fluidic device with multiple internal flow-path configurations including different pipe sizes and turns, which enables students to test and visualize how design choices influence hydraulic behavior. The system operates as a straightforward closed loop: an aquarium, submersible pump circulates water from a feed tank through the device and back again to the tank. Pressure measurements are captured using an Arduino microcontroller connected to a differential pressure sensor, with flexible tubing linking the sensor to pressure-monitoring ports on the device. The measurements are streamed to a computer via USB and displayed in real time through a custom interface (see Figure 1).

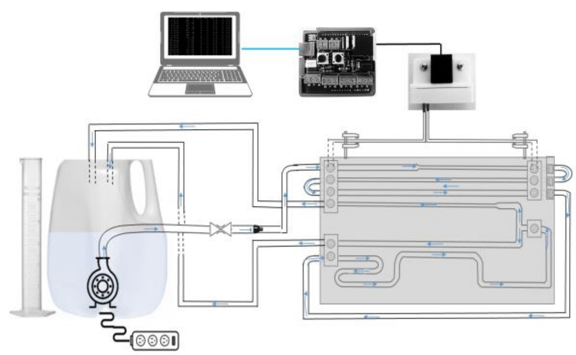

Figure 1 - Schematics of the MFF desk-scale lab kit (not to scale)

This type of desk-scale experimentation aligns with prior engineering education efforts, demonstrating that miniaturized fluid mechanics systems can produce measurable, predictable pressure responses suitable for instructional use [10]. In addition, recent work describes desk-scale fluid-flow demonstrations as an effective outreach mechanism because they allow learners to manipulate parameters and immediately observe consequences through sensor-based data.

Adopting an existing module developed and supplied by UF also supports practical outreach constraints such as portability, safety, repeatability, and short time-on-task. This enables the instructional design to focus on inquiry prompts, data interpretation, and connections to ChE-related applications. A three-hour session was dedicated to the fluid flow experiment within the summer program. More detailed descriptions of the desk-scale platform and related implementations are available in the literature [9].

Rationale for Using Fluid Flow Phenomena to Introduce Chemical Engineering

Fluid mechanics is a natural anchor for a chemical engineering outreach module because it sits within transport phenomena, one of the foundational “pillars” that unifies fluid mechanics with heat and mass transfer, and underpins how chemical engineers analyze, design, and troubleshoot real processes [11]. In most industrial sectors where chemical engineers work such as water and wastewater systems, food processing, pharmaceuticals, and energy, fluids must be moved, metered, mixed, heated/cooled, filtered, and transported safely and efficiently. Therefore, flow behavior is directly relevant to both performance and sustainability outcomes which is an attractive way to showcase a modern vision of the ChE profession. For high-school students specifically, fluid flow is also an unusually effective "window" into the discipline because it is visible, intuitive, and measurable: learners can formulate predicted responses, manipulate a design variable (e.g., diameter, length, bends, elevation, viscosity/temperature), and immediately see the consequences through experimentally measured data (e.g., pressure drop and flow rate). This tight feedback loop makes it easier to convey that ChE is not simply "doing chemistry," but rather engineering systems and processes using data and modeling to make decisions. This can be an important alternative to counter common misconceptions about the field.

A fluid flow desk-scale kit strengthens this rationale by making an authentic engineering experience feasible within outreach constraints: it is portable, safe, repeatable across teams, and fast enough to support multiple "what-if" trials in a single session while still generating real instrumentation data suitable for discussion and interpretation. If experiments are designed appropriately, students can directly connect frictional losses and design choices to real-world applications in a short, engaging format. In this study, the mini fluid flow experiments were selected not only as a convenient experiment, but as a discipline-representative intervention that helps students experience, in a concrete way, how chemical engineers use measurements and reasoning to improve safety, efficiency, and sustainability.

METHODS

Study Design and Context

The overarching goal of the summer program is to broaden high-school student awareness of chemical engineering (ChE) and, in the long term, contribute to increased enrollment by providing authentic exposure to ChE concepts. As mentioned earlier, topics covered in other courses of the ChE-focused program include electrochemistry, separations, energy conversion, mixing, reactions. The MFF module developed by UF has been implemented as a dedicated three-hour session. This study investigated changes in participating students' self-reported familiarity with core ChE topics and their perceptions of chemical engineering, with the following research questions (RQ) in mind:

RQ1. Does the student familiarity with ChE topics increase after participation in the MFF module during the summer program?

RQ2. Does the student perception of ChE improve after conducting the MFF module and other ChE modules of the program, including an increased likelihood of selecting ChE as a college major?

Intervention Overview: The MFF Module

The experimental MFF session began with a brief orientation and safety overview (20 minutes), including an introduction to the purpose of the activity, key terms (e.g., pressure drop, viscosity, friction), and an explanation of how instrumentation readings relate to physical changes in the flow path. Students were organized in teams of 4-5, starting with a guided setup and calibration step (20 minutes), during which they confirmed pump operation, checked for leaks, and verified that the pressure sensor and interface were functioning. After setup, teams conducted a series of short experimental trials depending on time availability, using a customized operating standard procedure. In each trial, students selected a configuration (e.g., baseline flow path, altered diameter, added turns) from the available module options. In each trial, students were told to qualitatively explain changes in differential pressure for different diameters, straight vs curved pipes, and low or high flow rate. Data collection consisted of recorded pressure readings and flow rate measurements using a stopwatch and a measuring cylinder (stopwatch and bucket method), while pressure readings were read from the software at designated pressure taps.

To promote inquiry-driven learning, each trial followed a prediction–test–explain cycle. Teams were prompted to (1) predict qualitatively how the selected change would affect pressure drop and/or flow rate, (2) run the trial and collect data, and (3) interpret results using age-appropriate explanations. The instructor facilitated discussion around common misconceptions (e.g., confusing pressure and flow rate, expecting linear scaling with turns or length) and emphasized how chemical engineers use experimental measurements to compare designs, diagnose performance, and make recommendations. While concepts of mechanical energy balances (e.g., Bernoulli and Darcy-Weisbach equations) were not formally introduced, discussions were facilitated based on the concepts introduced at the beginning of the session like the Hagen-Poiseuille Law, thus being more intuition-driven. The session concluded with a brief synthesis activity (15 minutes) in which teams shared key findings and connected them to real-world chemical engineering applications. Students were also reminded that similar reasoning and measurements are used in chemical engineering to improve safety, efficiency, and sustainability in industrial and societal systems.

Participants and Settings

The 2025 program enrolled 28 students. Because participants were minors, parental consent was required for inclusion in the study. Parental consent was obtained for 25 students; only responses from consented students were included in the analysis, even when students had personally assented. A pre-survey was administered in person prior to the MFF module on day 1 and yielded 25 responses (100% of students consented). The MFF module was conducted on day 3 of the program. Subsequently, a post-survey was administered asynchronously on the last day of the workshop (day 5) and remained available for up to one week after the program ended. From this, 18 responses were received (72% of consented students), of which 16 were complete (64% of consented students) after applying data-quality screening criteria as described. Even though other ChE topics were covered in the other courses on different days, the focus of the survey presented in this work was on the concepts specifically covered within the MFF module. The other modules covering other topics like reactions, separations, etc. were not evaluated in this survey for purposes of limiting the focus of the survey.

Demographic data collected included gender, ethnicity, and school seniority. The 2025 cohort was predominantly male compared to prior years. Figure 2 summarizes demographic distributions, including the fact that 40% of participants identified as White and 48% identified as Black/African American and Hispanic/Latinx combined.

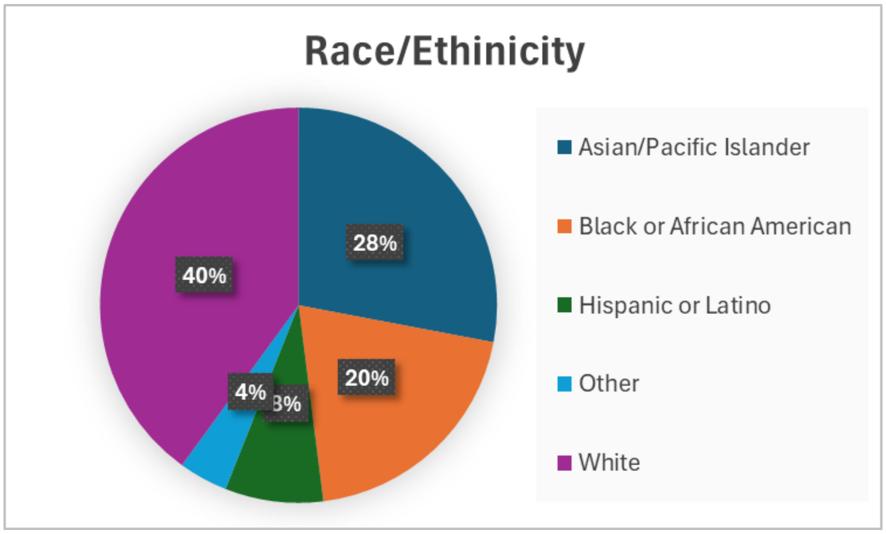

Figure 2 - Demographic data for ChE summer program surveyed participants from 2025

Surveys: Pre- and Post-Participation in the Program

A mixed-methods approach was implemented using a pre- and post-survey design to capture both quantitative trends and qualitative explanations [12]. The survey included:

1. Familiarity with ChE concepts (Likert-type items)- Participants rated their familiarity with five topics on a five-point scale: *never heard of it, somewhat familiar, neutral, familiar, very familiar*. The topics were: fluid friction, viscosity, pressure drop, flow rate, and process scale-up. The chosen topics were specific to the MFF module since that was the focus of the study. Other modules of the ChE course may have also included elements of process scale-up but not necessarily dealing with scalability of flow processes.
2. Perceptions and intent- Students responded to closed- and open-ended questions assessing their understanding of what chemical engineers do, perceptions of the field, and their likelihood of choosing ChE as a major (or interest in learning more).
3. Demographics. Gender, ethnicity, and school seniority were collected to characterize the sample and enable exploration of subgroup observations.

Pre- and post-survey responses were matched at the individual level to enable within-student comparisons over time. To protect participant privacy, matching was conducted anonymously using unique participant codes rather than student names or other personally identifying information. These codes were used solely to link pre- and post-survey records for analysis and were not used for any instructional or administrative purposes.

Surveys were refined between 2024 and 2025 based on preliminary findings. Although surveys were administered in both years, this paper focuses on the 2025 rollout to report results from the refined instrument and the most recent implementation.

Data Collection Procedures and Ethics

The study was approved by an Institutional Review Board (IRB), and parental consent was obtained prior to using data from minors. The pre-survey was completed at the start of the program (day 1), and the post-survey was completed once all program activities concluded starting from day 5 with a one-week completion window after the end of the program. To reduce pressure on students and encourage candid responses, students were assured that completing the survey would not affect their program participation.

Statistical Analysis Methodology

For student participants providing assent and parental consent, respective pre- and post-survey responses were converted to data to address research questions. Deidentified data was organized in Microsoft Excel such that each student's pre-survey data was aligned with their post-survey data. Next, Likert scale data was coded from the response descriptors to corresponding numerical values, to allow for quantitative analysis. For example, when queried for level of familiarity of content topics, the responses were coded as follows: Not Familiar = 1, Somewhat Familiar = 2, Neutral = 3, Familiar = 4, Very Familiar = 5. For ordinal categories of data, such as responses to demographic questions, descriptors were replaced with numerals so these variables could be treated as grouping factors in statistical tests. For example, underclassmen (students reporting their status as freshmen or sophomores in high school) were coded as "1," while upperclassmen (juniors and seniors) were coded as "2." After data was organized and numerically coded as applicable, it was imported into IBM SPSS Statistics version 31 for quantitative analyses.

Quantitative Analysis

After testing for normality, independent samples tests, paired tests, and correlation tests were applied to the data. Both Kolmogorov-Smirnov and Shapiro-Wilk tests of normality yielded p-values less than 0.05 for the majority of data buckets, indicating evidence of non-normality. Therefore, nonparametric statistical tests were applied to find meaningful, valid results to the research questions.

Independent-Samples Mann-Whitney U Tests were applied to ordinal categories of data responses (Gender, Ethnicity, School Year Status) to measure if they significantly impact other data variables. Related-Samples Wilcoxon Signed Ranks tests were applied for paired analyses to understand how individual students' responses change over time. Paired quantitative analyses examined changes from pre- to post-survey responses in familiarity ratings and selected perception/intent items.

Qualitative Analysis

Open-ended responses were analyzed using thematic analysis to identify patterns in how students described the chemical engineering field, their perceived relevance of ChE, and the aspects of the MFF module that shaped their interest.

RESULTS AND ANALYSIS

Baseline Awareness of Chemical Engineering and Prior Hands-on Exposure

In the pre-survey, participants were asked to rate their familiarity with chemical engineering on a scale ranging from *not familiar at all* to *extremely familiar*. Overall, most students reported low familiarity, with 28% indicating they were *not familiar at all*, and 56% reporting being *slightly familiar*. No students selected the *very familiar* or *extremely familiar* rating options. These results suggest that, for many high-school participants, chemical engineering is not a discipline they can readily describe prior to structured exposure. In addition, 64% of participants indicated prior experience with a small-scale lab kit or "do it yourself" (DIY) experiments, which supports the feasibility of using a desk-scale MFF device as an engaging instructional platform for this population.

Quantitative Results: Changes in Familiarity with Key ChE Topics

To evaluate changes in familiarity with foundational ChE topics, the surveys included Likert- scale type items with response options *never heard, somewhat familiar, neutral, familiar,* and *very familiar.* Students rated five broad topics: fluid friction, viscosity, pressure drop, flowrate, and process scale-up.

Because the number of usable responses was different from the pre- and post-surveys (pre: n = 25, post: n = 16), results are presented in two complementary ways:

1. Distributional comparisons (Figures 3–5) are reported as percent of responses per category, enabling an overall comparison of response profiles pre vs. post.
2. Paired descriptive and inferential statistics (Table 1) are computed using only matched pre- and post-responses (n = paired N, expected to be 16 if all usable post-survey responses are matched), which enables within-student comparison.

Topic-Level Shifts in Familiarity

Across topics, the response distributions shifted in a favorable direction upon participation in the program, with increases in the proportion of students selecting *familiar* or *very familiar* and corresponding decreases in *never heard*.

- **Fluid friction (Figure 3).** The most pronounced change was a shift away from *never heard* toward the upper categories (*familiar/very familiar*), indicating that ChE activities during the program, particularly the MFF hands-on session, supported students in recognizing and describing frictional effects in flow systems.
- **Process scale-up (Figure 4).** Process scale-up exhibited the largest overall gain in familiarity across the five topics. A plausible interpretation is that scale-up concepts are rarely emphasized in typical high-school science experiences, so students begin with limited exposure and show notable growth when the topic is introduced explicitly in an engineering context.
- **Viscosity (Figure 5).** Viscosity showed the least pronounced shift. This pattern is consistent with viscosity being a concept students may have encountered previously (e.g., in general science courses), resulting in a higher baseline and therefore less room for large pre/post changes.

Although the figures provide topic-by-topic detail, the overall pattern across Figures 3–5 is consistent: students exited the program reporting greater familiarity with the core ideas needed to interpret the MFF experiment by collecting pressure drop and flow rate data, and to contextualize those ideas within chemical engineering (e.g., process scale-up).

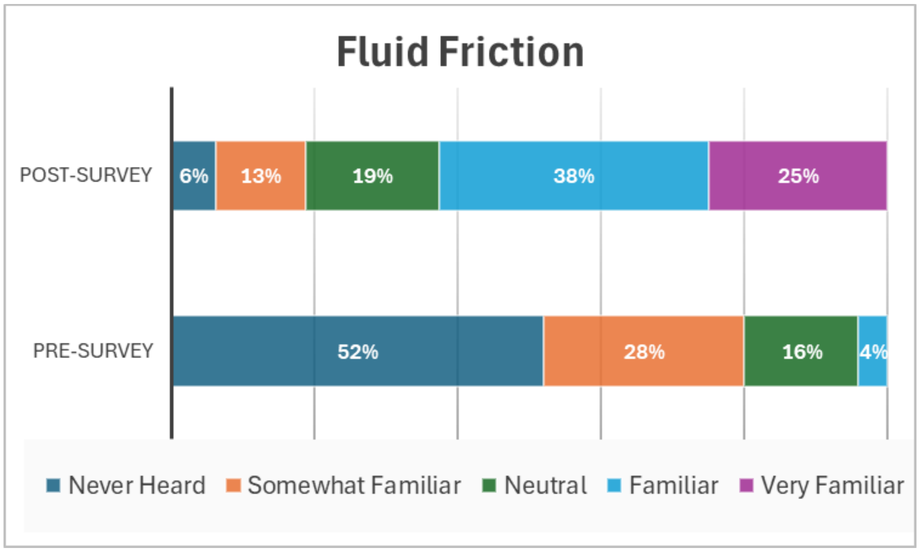

Figure 3 – Change in student perceptions of the topic *fluid friction* as a result of the summer program.

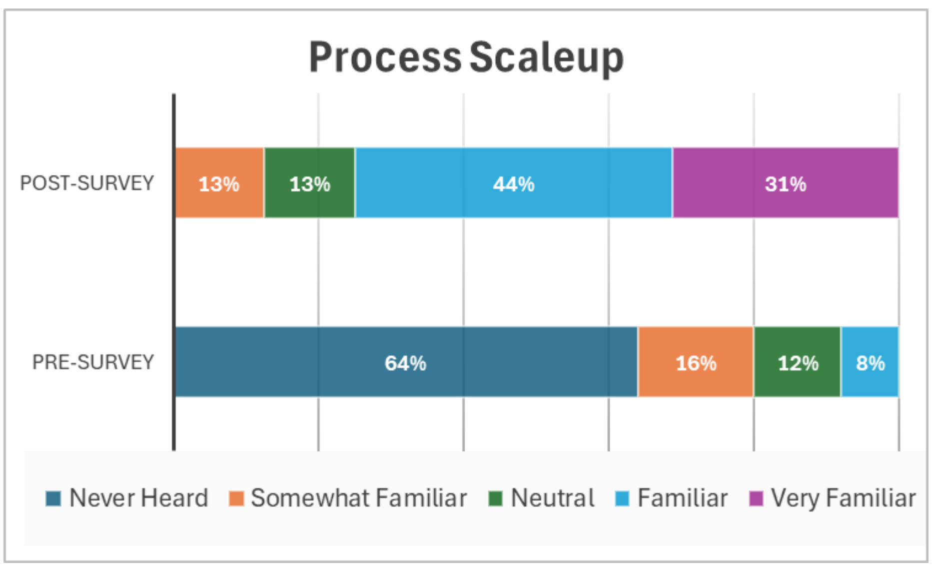

Figure 4 - Change in student perceptions of the topic *process scale-up* as a result of the summer program.

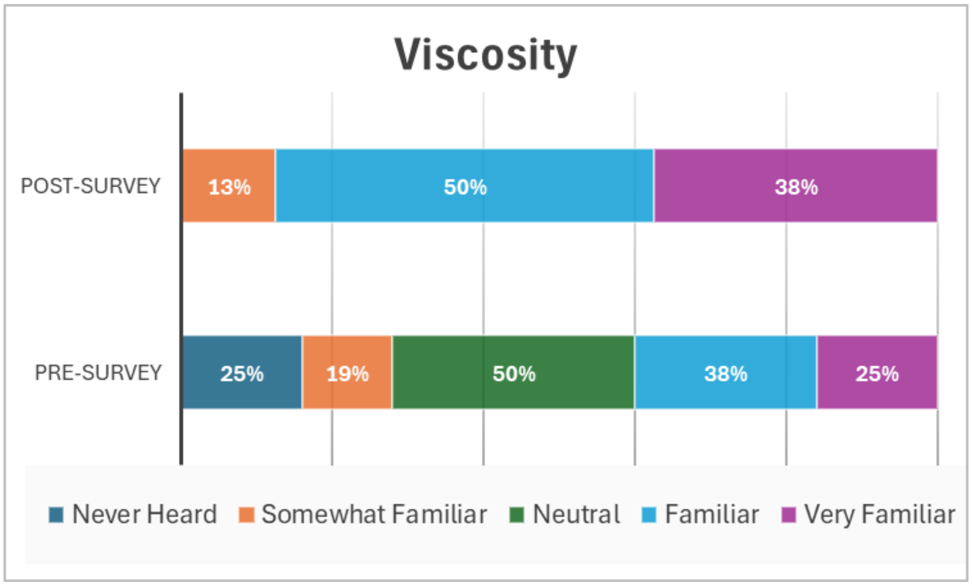

Figure 5 - Change in student perceptions of the topic *viscosity* as a result of the summer program.

Paired Descriptive Statistics

For descriptive statistical analysis, Likert responses were converted to a 5-point ordinal numeric scale: 1 = never heard, 2 = somewhat familiar, 3 = neutral, 4 = familiar, 5 = very familiar. Using the paired pre- and post-subset, Table 1 summarizes central tendency and spread (weighted mean, median, standard deviation) for each topic. Furthermore, *p*-values for the paired Related-Samples Wilcoxon Signed Rank testing are also shown.

Table 1 - Pre- and Post-Survey Descriptive Statistics for Various ChE Topics

Topic	**N**	**Mean±Std. Dev.**		**Median**		**%Gain**	**p-value**
		Pre	**Post**	**Pre**	**Post**		
Fluid Friction	16	**1.63±0.81**	**3.63±1.17**	1	4	123%	p<.001
Viscosity	16	**3.31±1.35**	**4.13±0.93**	3	4	25%	p=.015
Pressure Drop	16	**2.38±1.31**	**4.00±0.71**	2	4	68%	p=.002
Flowrate	16	**3.13±1.31**	**4.25±0.66**	3	4	36%	p=.007

Table 1 - Pre- and Post-Survey Descriptive Statistics for Various ChE Topics							
Process Scale-up	16	**1.56±0.89**	**3.94±0.97**	1	4	152%	p<.001

Table 1 also highlights the gain % for each topic. Although the gain is based on the pre-survey, it still provides valuable insights into the change between pre- and post-survey.

Several patterns emerge after checking the information in Table 1:

- **Fluid friction** showed one of the strongest gains in the distribution plots, yet it had the lowest post-survey mean among the topics in Table 1. This may indicate that, while MFF experiments in the program successfully introduced the concept, students still felt less confident with it relative to pressure drop or flow rate. This might suggest an area where additional scaffolding (e.g., more guided interpretation, additional trials, or clearer connection to everyday examples) may be beneficial in future iterations.
- **Viscosity** had a relatively high mean value in the pre-survey and remained high post-survey, consistent with students entering the program with prior exposure to the topic. Hence, this suggests that concepts of viscosity might already be understood to some extent. This is promising for future iterations of the program as experimental tests using viscous liquids can be incorporated in a safe manner (e.g., sugar solutions)
- **Pressure drop** had a mean and median of 4 with a tight clustering. There was a strong consensus around "familiar" indicating uniform conceptual understanding.
- **Flowrate** had the highest post-survey mean and the lowest standard deviation, indicating the strongest agreement across students. This may reflect that flow rate is probably the most intuitive and repeatedly referenced throughout the MFF setup and measurement process.
- **Process scale-up** achieved a post-survey mean close to 4, thus exhibiting the highest gain from the pre-survey. However, it also involved a higher variance than pressure drop or flow rate. This suggests that while many students increased their familiarity substantially, confidence remained uneven, which is consistent with the topic being newer and more abstract for some participants.

Statistical Analysis of the Quantitative Data

Effect of Gender

When data are coded by the students' reported gender, as either male (n=13) or not male (n=3) almost all survey response data do not vary significantly based on different genders. Two students reported gender identity as female, while one student reported their gender as Other. In an effort to conserve statistical power, we chose to combine results from all genders that were Not Male, to compare to the population that identifies as Male. Two categories where gender may have a significant impact were measured on the post-assessment. Male students (n=13, mean rank = 9.77) were significantly more likely than non-male students (n=3, mean rank = 4) to report that the laboratory experiment kits met their expectations, (Independent-Samples Mann-Whitney U Test, p=0.025). Similarly, Male students (n=13, mean rank = 9.77) were significantly more likely than non-male students (n=3, mean rank = 3) to report their likelihood of selecting Chemical Engineering as their future college major (Independent-Samples Mann-Whitney U Test, p=0.025). These gender-informed results are likely influenced by the majority of students reporting male gender, and only three students identifying as not-male. Therefore, the population may not allow a valid assessment of gender variance. With more data collected in the future, an assessment of gender variance may be implemented

Effect of Ethnicity

These datasets also do not vary significantly between groups of students who identify as different ethnicities. The following ethnicities were reported by the population: Asian (p =6), Black (p = 3), Hispanic (p = 2), White (p = 6), Mixed (Asian and White, p = 1). Since the population size is small, and this test considers five categories, there is likely not the statistical power to detect a significant difference based on race. Since prior research in STEM Education suggests that White and Asian students sometimes outperform historically underrepresented groups (e.g., Black and Hispanic students) on STEM assessments, a follow-up test asked whether there was a difference in responses between two groups: Asian and White students, compared to, Black and Hispanic students. One survey response area yielded a significant difference in reporting between
these ethnicity based groups: Black and Hispanic students (n=5, mean rank = 13.60) reported (on the post-assessment) significantly more familiarity with Chemical Engineering concepts, than Asian and White students (n=13, mean rank = 7.92), after having completed the one-week summer experience (Independent-Samples Mann-Whitney U Test, n=18, p=0.046). This result may suggest that the summer experience has a greater learning impact, in ChE, for historically underrepresented students.

Effect of School Year Status

When classified into four categories of "year in high school": freshman (p = 6), sophomore (p = 6), junior (p = 1), senior (p = 4); data do not differ significantly between these categories. However, similar to ethnicity above, the small sample size and large number of categories may yield nonsignificant results. Therefore, we elected to increase statistical power with the follow-up question and test of whether underclassmen (combined freshmen and sophomores) are different from upperclassmen (combined juniors and seniors) in their survey responses. Underclassmen (n=13, mean rank = 7.88) reported significantly lower than Upperclassmen (n=5, mean rank = 13.70) on how they ranked their familiarity of *Flowrate* on the pre-assessment (Independent-Samples Mann-Whitney U Test, n=18, p=0.035). Similarly, Underclassmen (n=12, mean rank = 7.00) reported significantly lower than Upperclassmen (n=4, mean rank = 13.00) on how they ranked their familiarity of *Pressure Drop* on the post-assessment (Independent-Samples Mann-Whitney U Test, n=16, p=0.030). This result may suggest that more seasoned students have a higher readiness level to integrate the new knowledge on *Flowrate* presented during the program.

Impact of the MFF Module Using Desk-Scale Kits on Students' Growth

When running paired Related-Samples Wilcoxon Signed Ranks tests on students completing the same five items on both a pre- and post-survey of ChE topics (indicators of concept familiarity), students ranked their comfort with the five topics significantly higher on the post-survey (after the summer experience) than on the pre-survey (prior to the summer experience). Therefore, by enrolling and participating in the program, students are likely to gain significantly higher familiarity in ChE key concepts, Fluid Friction (n=16, $p<.001$), Viscosity (n=16, p=.015), Pressure Drop (n=16, p=.002), Flow Rate (n=16, p=.007), Process Scale Up (n=16, $p<.001$). This may translate into their ability to understand the content, be interested in the content, and feel confident with the content in the future (i.e., selecting ChE as a college major). In addition, students' reported familiarity with ChE overall increased significantly between the pre- and post-assessment (Related-Samples Wilcoxon Signed Ranks, n=18, $p<.001$). Students were also asked to report their confidence in *Fluid Flow*, for which they also indicated a significant increase by the end of the summer experience (n=16, p=.009).

Correlative Relationships

Nonparametric Spearman's Correlation tests, to compare scaled variables, suggest numerous significant correlations among data categories. As "year in school" increases, familiarity with *flowrate* on the pre-survey increases significantly (n=18, ρ=.502, p=.028). As "motivation to learn ChE topic increases," as reported on the pre-survey, significant positive correlations are evident in *pre-viscosity* familiarity (n=18, ρ=.660, p=.003), *pre-process scale up* familiarity (n=18, ρ=.502, p=.034), *post-fluid friction* familiarity (n=16, ρ=.507, p=.045), and *post-pressure drop* familiarity (n=16, ρ=.506, p=.045). Notably, familiarity with ChE concepts as reported on the pre-survey, did not significantly correlate with high familiarity (n=18, ρ=.143, p=.570) or confident measures (n=16, ρ=.263, p=.326) on the post-survey; these may suggest that the summer experience had the potential to spark students' learning in ChE, regardless of their baseline knowledge. In addition, there was a significant positive correlation between students' overall reported familiarity in ChE on the post-survey, and their increased likelihood to consider a future college major in ChE (n=16, ρ=.535, p=.033). Similarly, students reported increased agreement that their lab/experiment expectations were met, and their increased likelihood to consider a future college major in ChE (n=16, ρ=.521, p=.039).

Measure of change in perception towards ChE

The ultimate goal of the MFF module utilized during the summer program is to improve the perception of chemical engineering and increase the likelihood of them choosing ChE as a profession. In line with **RQ2**, we asked the students if their interest in ChE has increased as a result of the summer program experiments. A high percentage of post-survey respondents (~70%) answered positively to the question and 25% reported unchanged interest. Only a small fraction of students responded in the negative.

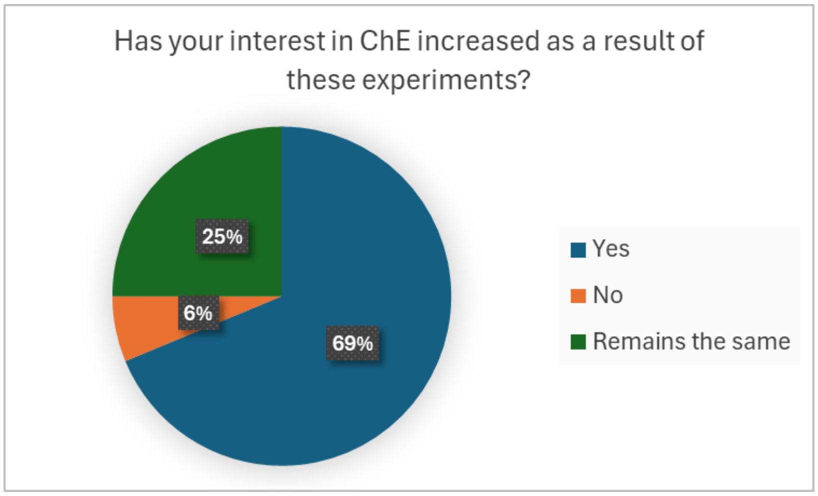

Figure 6 - Change in student interest towards chemical engineering as a result of the summer program experience.

Qualitative Survey Results: Main Themes from Student Perceptions Towards ChE

To complement the quantitative pre- and post-familiarity ratings, the surveys included open-ended questions aimed at capturing how students described chemical engineering, what they believed chemical engineers do, and whether (and why) their interest in chemical engineering changed after the workshop. Consistent with the mixed-methods design described in the Methods section, responses were analyzed using thematic analysis to identify recurring patterns in students' perceptions and the aspects of the program, particularly the MFF session that shaped those perceptions. These themes (shown in Table 2) are discussed below, organized to directly support RQ2 by illustrating how students' descriptions of ChE evolved from vague or narrow definitions toward broader, application-oriented views, and what experiences students attributed those shifts to.

Table 2 - Themes Across Pre-Survey Related to Student Perceptions of ChE

Theme (short label)	Summary	Representative Quotes
Work Environments	Chemical engineers work primarily in labs, testing chemicals, running experiments, etc.	*"Chemical engineering in my opinion is working in lab and testing out chemicals"*
Core Technical Activities	Chemical engineers work directly with chemicals, mixing or modifying them, studying reactions	*"Chemical engineering is the study of chemical compounds and their reactions. Chemical engineers work in labs and experiment with chemicals to test hypotheses on how chemicals interact with each other."*

Industries & Sectors	Frequently mentioned industries were pharmaceuticals/medicine, oil refining/energy. Nuclear and military/weapons were mentioned occasionally	*"Chemical engineers can work at treatment facilities and hospitals."* *"Chemical engineers can work in many fields such as pharmaceuticals, labs, and energy."*
Skills & Knowledge Base	Perceived skills required are chemistry, physics, mathematics, data analysis	*"Chemical engineers learn skills in physics and chemistry to solve problems and improve on products."* *"Chem E majors mainly have mathematical/chem skills such as data analysis and being good with Algebra/Geometry/Calculus"*

- **Theme 1: Work Environments –** The field is strongly perceived as experimental and bench-oriented, with limited awareness of design, modeling, or operations roles.
- **Theme 2: Core Technical Activities -** Students framed chemical engineering activities as *chemistry-like*, not distinctly *engineering-like*. Engineering is often implicit, not explicit
- **Theme 3: Industries & Sectors -** Chemical engineering is seen as industrially relevant, but primarily in traditional, tangible sectors.
- **Theme 4: Skills & Knowledge Base -** Participants recognize intellectual rigor and interdisciplinarity, even when unsure of specific applications.

Post-survey thematic analysis was also performed with explicit alignment with the pre-survey themes reported in Table 2 to identify if there are any shifts or if any new/emergent themes arise.

- **Theme 1:Work Environments -** The lab-centered view was still present, but they are now seen as part of the design-test-improve cycle. The scale up idea also appeared in the post-survey themes
- **Theme 2: Core Technical Activities -** There was an observed shift towards how chemical interaction was framed in terms of functionality, performance, safety etc.
- **Theme 3: Industries & Sectors -** This was expanded and diversified and industries like food, consumer products, cleaning supplies etc. were added. Students seemed to perceive chemical engineering as embedded in everyday life

Some new themes also emerged in the post-survey. Notable one was "Professional Rigor and Career Identity" - Students noted the difficulty and rigor of the discipline but still wanted to be a chemical engineer. We would like to share a portion of the post-survey quote that highlights this aspect: "*it definitely has shown me that this path won't be easy especially with all the Chemistry and Calculus I'll be doing in University. But this isn't holding me back from wanting to continue, as a matter of fact it makes me want to work harder to make sure I become a Chem E major.*"

CONCLUSION

This work examined the feasibility of a chemical engineering summer program, anchored by a desk-scale Mini Fluid Flow (MFF) session, to increase the familiarity of high-school students with core ChE concepts (**RQ1**) and improve their perceptions of ChE and interest in the major (**RQ2**). From quantitative analysis results, it was demonstrated that matched pre- and post-surveys yielded significant gains across all five targeted concepts: Fluid Friction ($p<0.001$), Viscosity ($p=0.15$), Pressure Drop (p=0.002), Flow Rate (p=0.007), and Process Scale-Up (p<0.001), all with n = 16. Additionally, a significant increase in overall ChE familiarity was reported (p<0.001, n=18) and fluid flow confidence (p=0.009, n=16).

Approximately 70% of post-survey respondents reported increased interest in chemical engineering as a profession, and a higher post-survey familiarity was positively associated with greater likelihood of considering ChE as a future major in college. Students whose lab kit expectations were met were also more likely to consider ChE, underscoring the importance of a well-scaffolded, hands-on experience to attract high-school students to ChE undergraduate programs.

Qualitative analysis of the main themes indicates that pre-survey responses often framed ChE as lab-based “chemistry”, while post-survey responses broadened toward design, testing, emphasizing performance, safety, and scale-up, with expanded awareness of everyday industries. An emergent theme, professional rigor and career identity, suggested that recognizing challenges did not discourage interest.

Overall, students described the summer program, particularly the MFF module functionality, as an instrument that made ChE topics feel more concrete through hands-on experimentation and real-time data, while also broadening their understanding of ChE as a discipline focused on designing and improving processes with societal relevance. We believe that the MFF module functioned as a discipline-representative outreach intervention that increased both conceptual familiarity and the clarity of what chemical engineers do.

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