ENGINEERING CLEAN WATER SOLUTIONS: A CHEMICAL ENGINEERING OUTREACH ACTIVITY FOR SECONDARY STUDENTS

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ABSTRACT

University outreach activities can inspire high school students to pursue STEM pathways. A new workshop, Engineering Clean Water Solutions, was developed at Monash to showcase chemical engineering principles through a practical design workshop, which situated students in realistic engineering roles (CDIO Standard 1) and engaged them in team-based development and testing of a water treatment process (Standard 5, Standard 8) that balanced efficiency, cost, and effectiveness. They also experienced analogous industrial practices at the Monash Membrane Pilot Plant. Student feedback highlighted the workshop's interactivity and industry relevance, demonstrating the value of aligning outreach activities with the CDIO framework. Importantly, this implementation of CDIO also illustrates how the Framework can be used as a pedagogical tool and also as part of the broader strategy of an institute to support goals such as student recruitment, offering an example of curriculum agility in action.

KEYWORDS

Chemical Engineering, STEM Outreach, Experiential Learning, Authenticity, Standards 1, 5, 8.

INTRODUCTION

University outreach activities are powerful pedagogical tools for fostering interest in STEM disciplines among high school students. Research has consistently shown that hands-on, immersive experiences significantly enhance students' motivation and understanding of STEM concepts, bridging the gap between abstract classroom learning and real-world applications (Maltese & Tai, 2011; Sadler et al., 2012). Outreach programs that align with frameworks such as the Conceive-Design-Implement-Operate (CDIO) framework (Crawley et al., 2014) provide students with authentic engineering experiences by situating them in real-world contexts (Standard 1: Context).

This is evident in Australia, where several programs have demonstrated significant impact. For example, the University of Newcastle Science and Engineering Challenge (SEC) engages high school students in STEM through collaborative, practical activities. It has demonstrated a measurable influence on tertiary STEM enrolments, with a decadal study showing that nearly one-third of participants pursuing STEM degrees as a result of this outreach experience (Reed et al., 2021). Similarly, a study of STEM outreach programs across Australian universities has highlighted their vital role in reversing declining STEM enrolments by aligning activities with the interests and aspirations of students, while also addressing workforce needs (Sadler et al., 2018). The effectiveness of such practical STEM outreach activities is also recognised by industry. For instance, the BAE Systems 'Beacon' program provides Year 4–6 students with access to modern technologies and real-world challenges, aiming to boost awareness and improve workforce development into the future (Pickham, 2022).

Building on the literature evidence of the success of such programs, Monash University has developed its own initiatives to inspire the next generation of engineers. One example is the annual John Monash Science School (JMSS) Immersion Day, which showcases Monash Engineering's facilities and provides an immersive, hands-on experience. The goal is to give students a real insight into what it's like to be a Monash Engineering student and allow them to interact with engineering academics and current students. This program supports CDIO Standard 5: Design-Implement Experiences by engaging students in collaborative, practical activities that emulate the work of engineers. The program spans a full day and includes two workshop sessions where students can choose activities that explore different engineering disciplines. This tailored approach enables students to align their interests with diverse opportunities in engineering.

In the past, Chemical Engineering outreach workshops at Monash have focused on chemistry-based projects, such as making bouncy balls, and physics-based experiments, like exploring fluidised beds. These activities effectively demonstrate foundational principles crucial for chemical engineering—such as polymerisation reactions, material properties, and fluid dynamics—which are essential for understanding the behaviour of materials and systems. However, such activities present only isolated phenomena and lack the integration and complexity inherent to chemical engineering. The essence of chemical engineering lies in applying these scientific principles to design and optimise processes that transform low-value feedstocks into high-value products, balancing efficiency, sustainability, and scalability. This broader, systems-oriented perspective, involving process design, scale-up, and economic considerations, distinguishes chemical engineering from its foundational sciences (University of British Colombia, 2025). In parallel, the increasing focus on curriculum agility in engineering education encourages the development of learning experiences—both within and beyond formal curricula—that can adapt to emerging needs and better engage future cohorts (Brink et al., 2020).

To better reflect the systems-oriented nature of chemical engineering, we developed a new activity for the 2024 John Monash Science School (JMSS) Immersion Day that engages students in process design and iterative problem-solving. This paper describes the activity, evaluates its impact, explores its alignment with the CDIO framework, and as proposes future improvements.

ENGINEERING CLEAN WATER SOLUTIONS – ACTIVITY DESCRIPTION

The Engineering Clean Water Solutions workshop is a 90-minute activity designed to engage secondary school students with the principles and practices of chemical engineering and inspire them to pursue their interests in STEM. The workshop highlights the critical role of chemical engineers in designing and optimising processes to convert low value feedstock to higher value products.

The workshop is predominantly practical: it begins with a short introduction explaining that industrial water treatment involves multiple steps to remove turbidity (cloudiness) – a key water quality parameter in industrial processes. Students then work in teams of 3–4 to design and optimise a water treatment process of their own by using a combination of physical and chemical treatment methods. Each team is given a sample of murky water and some simple benchtop equipment to enable them to treat their water by gravity settling, media filtration, membrane filtration, and chemical coagulation. They are asked to combine these treatment steps in any order and frequency to develop a treatment process that achieves the clearest water possible while balancing competing objectives such as efficiency and cost. Teams are encouraged to test the turbidity of their cleaned water as they go, enabling them and refine their processes and highlighting the iterative nature of engineering design.

Turbidity was chosen as the quality metric for this challenge because it is a key parameter in potable water standards and provides an accessible, visually satisfying measure of success. At the end of the session, the cohort comes back together and the lowest turbidity achieved by each Team is presented. The discussion focusses on the number and cost of the steps required to achieve the best results to highlight the multi-objective nature of industrial process design.

To contextualise their learning, the workshop also includes a guided visit to the Monash Student Pilot Plant, an industry-scale water treatment facility. Students are told more about industrial water treatment and observe the operation of the membrane filtration system. They are given an opportunity to collect and analyse the turbidity of water samples from the pilot plant, and compare their experimental results with the performance of the industrial system. This provides insights into scale-up challenges and the optimisation of design processes in professional engineering practice.

Through this workshop, students gain a practical understanding of chemical engineering principles, particularly the integration of physical and chemical methods to address real-world challenges. The activity fosters key skills such as teamwork, problem-solving, and iterative design, while explicitly connecting small-scale experiments with industrial applications. By providing a hands-on experience framed within a real-world context, the workshop offered students valuable insights into the profession of chemical engineering and its pivotal role in improving water quality and access on a global scale.

CDIO ALIGNMENT

The design challenge activity aligns closely with several CDIO standards, providing students with an authentic learning experience presented in the context of a real-world engineering challenge. It addresses:

- **Standard 1: Context** by situating students in the role of chemical engineers, designing water treatment systems that mirror industrial practices
- **Standard 5: Design-Implement Experiences** was exemplified as students progressed through the design and testing of their solutions, iterating to improve their results.
- **Standard 8: Active Learning** through its hands-on approach to exploring water treatment principles

By embedding these standards, the activity offers an authentic, engaging and practical introduction to chemical engineering to reinforce students interests and inspire them to pursue a STEM degree.

While the CDIO framework is often applied within formal curricular structures, this outreach activity demonstrates its utility in broader educational and institutional contexts. In particular, it aligns with the “Conceive” and “Design” stages not only through project-based learning, but as part of a strategic recruitment initiative. By offering prospective students a realistic and engaging engineering experience, the activity reflects curriculum agility and highlights how CDIO principles can support both student preparation and institutional responsiveness to future educational demands. In particular, our activity development reflects several of the relevant curriculum agility principles identified by (Brink et al., 2020). In particular, it reflects a proactive approach to curriculum development, is responsive to stakeholder needs, and aligns with institutional strategy by creating a forward-looking activity that engages and involves prospective students.

STUDENT FEEDBACK

Student feedback was collected by JMSS educators and comments were provided in deidentified form to Monash administrators of the Immersion Day. Students generally found the Engineering Clean Water Solutions activity engaging and informative, highlighting its hands-on nature and the opportunity to take initiative in solving the water treatment challenge.

Several students appreciated the interactivity of the workshop, noting that it offered a break from traditional lecture-style learning. One student remarked, *“It was interactive and engaging so we weren’t listening to a lecture the entire time and a lot of it was taking our own initiative to solve the problem.”* Others praised the clarity and simplicity of the explanations about chemical and process engineering, which made the concepts accessible and relatable. Students also enjoyed the challenge of creating the cleanest water and comparing their results, with one student commenting, *“It was fun, the little competition in trying to make the ‘cleanest’ water.”* Additionally, the hands-on experiment was commended for providing practical insights into water treatment methods and allowing students to compare the effectiveness of different approaches.

However, while most appreciated the activity's design, some suggested enhancements to the fairness and clarity of the task. For instance, one student suggested including a better explanation of the relative costs of the different treatment methods. Another proposed using a variety of samples, such as laundry water or river water, to simulate more realistic scenarios.

FUTURE IMPROVEMENTS

Based on feedback from the students and discussions with the demonstrators, the student engagement and experience will be enhanced in future iterations of the workshop by: including a wider variety and choice of water samples, improving the results submission process, and enhancing the workshop conclusions.

Providing students with a variety of sample to test, such as river water, laundry wastewater, and stormwater, will enhance authenticity and engagement. This adjustment will highlight the need for chemical and process engineers to tailor processes to specific feedstocks, even when the desired product, like clean water, remains the same. By encountering diverse scenarios, students will gain a deeper understanding of how unit operations are adapted to design efficient, sustainable, and scalable solutions. This improvement aligns with CDIO Standard 1: Context, as it situates the activity in realistic engineering challenges. It also gives students more autonomy and ownership over the workshop activities, enabling them to pursue their interests rather than being restricted to a particular scenario.

The workshop's conclusion will be restructured to provide stronger closure and reinforce key messages about water treatment and chemical engineering. By linking back to the introductory discussion on the iterative, multi-objective nature of chemical engineering process design, students will see how their hands-on activities reflect the work of chemical engineers in integrating physics and chemistry principles into practical designs. This will help clarify the broader role of chemical engineers in addressing global challenges while meeting quality, sustainability, and cost objectives, supporting CDIO Standard 7: Integrated Learning Experiences by tying practical activities to theoretical concepts.

In this first offering of the workshop, we relied on a QR code link to enable students to submit their results for the competition and workshop conclusion. However, most students did not have access to a device with which to do so as it is standard procedure for secondary students to leave devices in their bags during class. Therefore, to improve the flow of the activity, the results submission process will be updated. Future workshops will include shared devices at workstations for direct data entry into a central system and students will be supported by facilitators to upload results. These changes will reduce logistical barriers and maintain the competitive element of the workshop, aligning with CDIO Standard 8: Active Learning by ensuring students remain focused and engaged in iterative problem-solving.

POTENTIAL RESEARCH DIRECTIONS

Potential future research directions could explore ways to further evaluate and enhance the workshop's impact and effectiveness. Developing a standard survey for students to complete after participating in the workshop each year could provide valuable, ongoing insights into how they engage with iterative design and integrated problem-solving. Longitudinal studies might track participants' academic and career pathways to assess how experiential learning activities influence STEM choices. A longitudinal study could track participants' academic and career pathways to evaluate the workshop's influence on STEM choices. Expanding the workshop to include professional development for secondary teachers could empower educators to better integrate STEM concepts into their curricula and provide more informed guidance to their students. Additionally, research could examine the effectiveness of CDIO integration, such as how students grasp iterative design and teamwork. These directions could help to further refine the workshop while expanding its educational and societal contributions.

CONCLUSION

The Engineering Clean Water Solutions workshop shows how well-designed outreach activities aligned with the CDIO framework can inspire high school students. Students engaged in designing water treatment processes using physical and chemical methods, building practical skills such as teamwork and iterative design while connecting their lab work to real-world engineering solutions through their experience with running the Monash Membrane Pilot Plant visit. The workshop reflected several CDIO standards, including Standard 1: Context, by situating students in realistic engineering challenges, Standard 5: Design-Implement Experiences, through iterative process design, and Standard 8: Active Learning, by engaging students in hands-on, team-based problem-solving.

Student feedback praised the hands-on, interactive approach and the clear explanation of engineering concepts, though areas for improvement were identified. Suggestions include incorporating diverse water samples to enhance authenticity and refining the session's conclusion to reinforce key learning outcomes. Future iterations will implement the proposed improvements, enhancing the workshop's educational impact while continuing to inspire the next generation of chemical engineers to tackle real-world challenges with confidence and creativity. Potential research directions include developing a standardised survey to evaluate student experiences annually and exploring the workshop's impact on fostering systems thinking and long-term interest in STEM pathways, providing valuable insights for refining outreach strategies.

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GENERATIVE AI USE STATEMENT

In this manuscript, GenAI was used to refine and organise human inputs, descriptions and content, including summarising, language editing, and connecting concepts to literature and pedagogy.

BIOGRAPHICAL INFORMATION

Poh Xian Tay completed his bachelor's degree in Chemical Engineering at Monash University in 2021 and began his career as a production engineer in the fine chemicals industry. He collaborated with R&D chemists in scaling up lab-scale reactions to industrial production. During his role, he was involved in the design, modification, and optimisation of engineering equipment to meet various production goals. Currently, Poh is a Technical Officer and lab manager at the Faculty of Engineering at Monash University, focusing on supporting research students and teams with their projects, prototype and analytical testing, and equipment training, all while ensuring a safe working environment.

Dr Joanne Tanner completed her bachelor's degree in chemistry and chemical engineering at Monash University in 2008. She went on to gain industry experience in control systems design and configuration during her role at Honeywell, and subsequently managed and implemented client-driven chemical engineering research projects at laboratory, pilot, and industrial scale with HRL Technology. She returned to Monash and completed her PhD in reaction engineering. Joanne is currently a senior teaching fellow in the Faculty of Engineering at Monash University, with a focus on enhancing engineering laboratory experiences for undergraduate and postgraduate engineering students. She is the Director of the Monash Pilot Plant. Her teaching and research interests include sustainable processing, biorefinery, AI and digitalisation in chemical engineering, and the use of pilot scale equipment and processes to enhance engineering education.

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