Multipurpose Learning Factory

Traditional learning factories are recognized for their effectiveness in teaching manufacturing skills—such as lean management, resource efficiency, quality control, and logistics, often having limited scope and being hindered by high starting and running costs. The Multidisciplinary Learning Factory in the School of Engineering Practice and Technology (SEPT) at McMaster University overcomes these limitations by supporting a broader range of courses across various manufacturing disciplines, including Industry 4.0 and business management. The SEPT Learning Factory operates under an innovative model, producing marketable products that are sold on the open market or donated to community members in need. This approach not only addresses the typical challenge of low return on investment but also expands the scope of educational resources, moving beyond the examination of isolated aspects of industrial production. The Learning Factory extends its impact through nontraditional activities, including community outreach initiatives and collaborating with local high schools to inspire students to pursue STEM courses and contribute to developing a skilled future workforce. In addition, the learning factory supports international collaboration initiatives aimed at achieving the UN Sustainable Development Goals in developing countries by providing practical solutions and knowledge transfer in sustainable manufacturing practices. Finally, the SEPT Learning Factory plays a crucial role in university recruitment, showcasing the practical, hands-on learning opportunities available to prospective students.

Keywords: *Learning factory, community outreach, experiential learning, engineering education, international collaborations*

Introduction

In an increasingly complex and interconnected manufacturing environment commonly referred to as Industry 4.0 in literature, the demand for graduates equipped with practical competencies across engineering, technology, and business has never been greater (Ferrario et al, 2019). While traditional educational models such as laboratory work and lecturing are effective in imparting foundational knowledge, they often fall short in preparing students for the multifaceted challenges of modern industries (Bao et al, 2023). Learning factories are instrumental in providing hands-on experience in manufacturing skills such as lean management and quality control, through multidisciplinary project-based learning. However, their limited scope and high operational costs restrict their use and effectiveness (Lutters et al, 2022). The SEPT Learning Factory leverages a multidisciplinary framework to address these limitations, offering a broader range of courses that incorporate principles of Industry 4.0 and business management. In addition, the learning factory supports the university agenda of integrating community outreach and internation collaborations in teaching and learning. By adopting a multipurpose model, the Learning Factory maximizes the utility of its resources, enabling it to serve diverse educational needs while also contributing to community engagement and global development.

This paper highlights the unique characteristics of the SEPT Learning Factory, including its commitment to producing marketable products and its outreach initiatives aimed at inspiring the next generation of STEM professionals. Furthermore, it underscores the factory's alignment with the United Nations Sustainable Development Goals, demonstrating its role in promoting sustainable manufacturing practices in developing regions. Through this comprehensive approach, the Learning Factory not only enhances the educational experience but also reinforces the university's mission of fostering community involvement and social responsibility. By showcasing the transformative potential of integrated, practice-based education, this paper aims to position learning factories as essential components in the evolution of modern educational paradigms.

The SEPT Learning Factory enhances the learning model by relying primarily on students to manage most of its functions. This approach not only reduces operating costs—since full-time employees would be significantly more expensive—but also provides participating students with valuable opportunities to learn about business and technology management. The rest of this paper is arranged as follows: Section 2 covers the limitations of learning factories, while Section 3 deals with the multipurpose nature of SEPT Learning Factory. Conclusions are covered in Section 4.

Limitations of Learning Factories

Learning factories are skill development facilities that simulate manufacturing environments. While research shows that they are some of the most effective learning facilities for teaching complex multidisciplinary Industry 4.0 concepts and technologies, they face a key limitation of being resource intensive (Deshpande at al, 2022). Establishing such a learning factory requires significant financial investment and skilled personnel for various roles, including equipment maintenance, content development, and management of access to the factory and its resources. Additionally, implementing a learning factory necessitates ample space, including a suitable factory hall with appropriate energy sources.

Most learning factories focus on specific aspects of industrial production, often tailored to sectors or processes, which limits their overall educational scope. For instance, the Technical University (TU) Darmstadt has two advanced learning factories. The first, a greenfield factory, focuses on interdisciplinary methods to reduce energy use and CO2 emissions. While it is primarily used for research, it is used for teaching in a limited set of courses. The second factory at TU Munich focusses on energy productivity, incorporating various machining and handling processes for real industrial products, covering lean manufacturing concepts through several modules (Abele et al, 2017). The Bernard M. Gordon Learning Factory at Penn State College of Engineering serves multiple educational purposes, including capstone projects and research, and features modern facilities for design and manufacturing. It also fosters partnerships with industry, enabling students to work on real-world projects (Penn State Engineering, 2017). The Free University of Bozen-Bolzano in Italy has established a learning factory that simulates the production of pneumatic pistons, allowing students to engage in practical exercises, such as planning and optimizing flexible assembly systems during lectures (Matt et al, 2014).

Learning factories generally offer limited scalability compared to other learning environments. For instance, hundreds of students can attend a lecture, and tens can participate in a laboratory exercise without issues. In contrast, a learning factory typically accommodates only seven to ten students at a time. Even when multiple courses run concurrently, the facility's capacity often restricts its use, leading to the unfortunate reality that usually only one course operates at a time. While learning factories are designed to support high-quality competence development, these objectives are often not integrated into the facility's design. Moreover, the learning modules typically lack thorough reviews to assess whether these objectives are being met.

These limitations present significant obstacles to achieving the goals of learning factories; but most important, collectively they diminish the return on investment of learning factories. Despite their educational effectiveness, learning factories can be challenging to promote to university administrations because they offer training that can also be conducted through other methods, with less effectiveness though, while presenting major handles. Consequently, at SEPT Learning Factory we have adopted a university-wide agenda, supporting many university/faculty-wide incentives, resulting in a multipurpose learning factory.

Multipurpose Nature of SEPT Learning Factory

The W. Booth SEPT Learning Factory was originally established to support teaching and learning in smart manufacturing technologies by providing students with access to facilities for modern design, prototyping, and manufacturing processes that incorporate Internet of Things (IoT), Industrial Internet of Things (IIoT) and Industry 4.0. The learning factory was supposed to provide two main learning channels. The first channel was based on undergraduate students designing and testing PLC/robot programs on the assembly, inspection, and testing tables; while graduate students would design and optimize the whole process or design new parts/products and processes. The second channel was based on capstone projects, where the learning factory would support university-industry/community partnerships with students designing and implementing projects that enable industry/community-student-faculty collaborations, thus benefiting themselves, their environment, and the sponsors.

The first learning channel worked well during the initial phase of setting up the learning factory. In 2017, over thirty Automation Systems Engineering Technology students worked in the factory on projects ranging from PLC wiring and programming to Industrial systems integration and cloud computing. Since the implementation did not follow a specific model, many process features did not match the purpose features. Therefore, once the facility setup was completed, Industry 4.0 and smart manufacturing projects dried up. By 2020 less than ten undergraduate students were using the facility for capstone projects, some of which did not even focus on the original subject matter. Graduate projects on the other hand focused on additive manufacturing that led to the need to purchase more advanced manufacturing equipment. This increased the manufacturing component of the learning factory at the expense of the other product creation phases such as product design, materials procurement and management, and production monitoring that are crucial to Industry 4.0.

As already stated, establishing and maintaining a learning factory is an expensive venture. Therefore, we quickly noticed that the return on investment of the SEPT learning factory was very low. We decided to address this issue by increasing the functions of the learning factory beyond the following usual functions:

1. Supporting experiential learning.
2. Providing opportunities for research in industrial systems integration and optimization.
3. Providing demonstrations to give students insight into the full cycle of manufacturing information flow from product design to supply chain management.

To include functions that support the university strategic plan, including (1) supporting community outreach initiatives such as collaborating with local high schools to inspire students to pursue STEM courses and contribute to developing a skilled future workforce; (2) playing a crucial role in university recruitment, showcasing the practical, hands-on learning opportunities available to prospective students; (3) supporting international collaborations aimed at achieving of UN Sustainable Development Goals in developing countries by providing practical solutions and knowledge transfer in sustainable manufacturing practices.

Community Outreach Initiatives

The SEPT learning factory utilizes its resources and products, such as walking cane and RC car, to contribute to the university's community outreach efforts. Through these initiatives, it actively supports engagement and assistance programs.

Walking Cane

The Customizable Walking Cane represents one of the Learning Factory's flagship projects, exemplifying its capacity to integrate design, engineering, and manufacturing into a functional product with a significant social impact. The cane is fully customizable, allowing users to select from a variety of materials, including pine and walnut, different handle styles such as brass antique or solid brass, and various tip types tailored to individual preferences and needs. The canes are donated to deserving members of society or are sold at cost recovery prices.

All stages of the manufacturing and assembly process of the cane are conducted on-site, with recent enhancements informed by user feedback, including the use of stronger adhesives and the introduction of adjustable lengths. This iterative design process demonstrates the facility's ongoing commitment to refining product quality based on real-world performance. Looking ahead, the Learning Factory is advancing a Smart Cane prototype that will incorporate fall-detection sensors linked to cloud-based systems. These sensors will notify caregivers or family members in the event of a fall, offering a potentially life-saving innovation. This progression underscores the facility's ability to merge engineering expertise with healthcare applications, creating practical solutions that have meaningful, transformative potential.

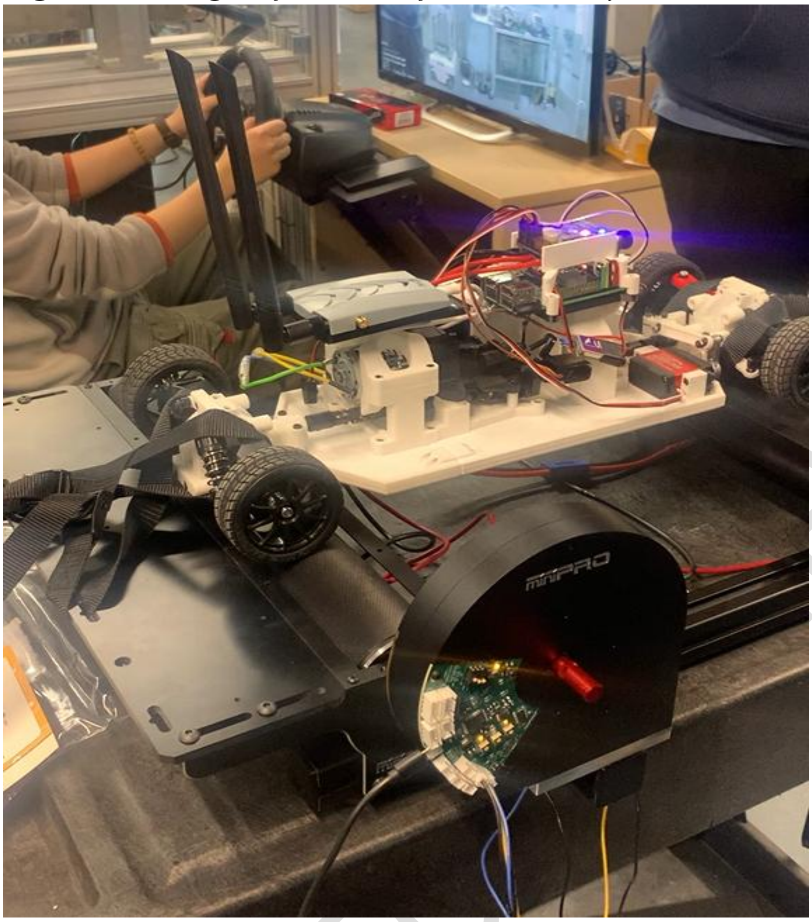
RC car

The SEPT Learning Factory has developed a community outreach program dedicated to providing hands-on, industry-relevant experiences that engage high school students in science, technology, engineering, and mathematics (STEM). One of our key initiatives is an RC car program, which serves as a scalable platform for student engagement, with potential applications in student clubs, after-school programs, competitions, or course material. The RC car and its associated test equipment such as the Dynamometer in Figure 1 and wind tunnel provide an opportunity to introduce students to fundamental concepts in design, manufacturing, and engineering through interactive, experiential learning. Beyond the RC car project, the Learning Factory is committed to collaborating with educators to develop new projects that align with students' interests and curriculum requirements, encompassing areas such as prototyping, robotics, automation, and other engineering challenges. Our broader mission is to serve as a valuable STEM resource for schools, particularly through outreach programs that engage local high schools, with a focus on supporting students in disadvantaged neighborhoods. These efforts aim to foster innovation, technical skills, and equitable access to STEM education.

Coop opportunities

Another key pillar of our community outreach program is the opportunity for high school students to participate in co-op placements at the SEPT Learning Factory at McMaster University. This program allows students to earn credits towards their high school graduation while gaining practical skills and real-world experience in an advanced engineering environment. The co-op program is designed to provide meaningful learning experiences through carefully selected, modular projects tailored to each student's level of education. These projects expose students to engineering concepts, hands-on problem-solving, and industry-relevant technologies, fostering their interest in STEM fields and better preparing them for future academic and career opportunities.

Figure 1. *Testing Performance of RC Car on Dyno at SEPT Learning Factory*



Promotion and Student Recruitment

The SEPT Learning Factory at McMaster University plays a vital role in the university's promotion and student recruitment efforts by showcasing its state-of-the-art facilities, hands-on learning opportunities, and industry-relevant projects. Through interactive demonstrations, outreach programs, and experiential learning initiatives, the Learning Factory highlights the unique strengths of McMaster's engineering technology programs to prospective students, parents, and educators. The McMaster University website is littered with images and videos from the SEPT Learning Factory promoting all sorts of experiential learning opportunities provided by the university's Faculty of Engineering.

High school engagement activities, such as STEM workshops, co-op placements, and the RC car project, provide students with firsthand exposure to the innovative, applied learning environment offered at McMaster. Additionally, the Learning Factory actively participates in university open houses, career fairs, and industry collaborations, reinforcing McMaster's reputation as a leader in engineering education. For example, Figure 2 shows a high school student building an oversized differential gear. By bridging the gap between academic learning and real-world applications, the Learning Factory serves as a powerful recruitment tool, attracting students who are eager to develop practical engineering skills and pursue careers in advanced technology fields.

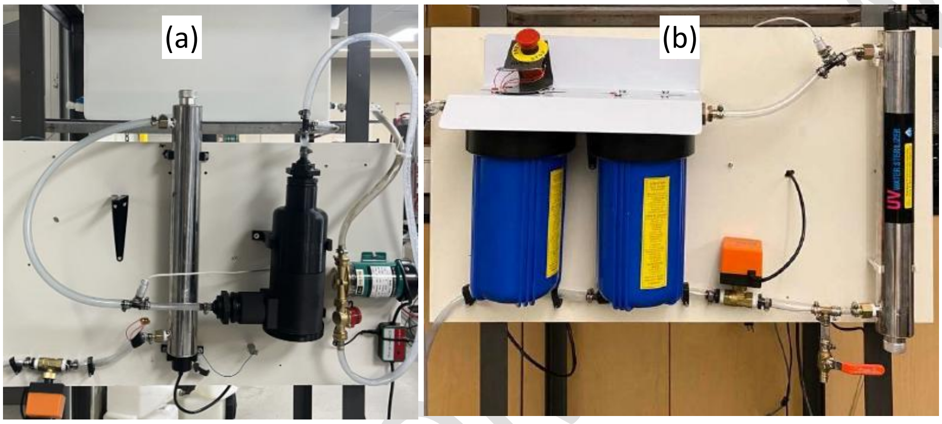
Figure 2. *Hands on Skills Development for High School STEM*

International Collaboration - Water Filtration Initiative

The water filtration initiative represents the Learning Factory's commitment to blending engineering expertise with social entrepreneurship. This early-stage project seeks to address clean water access challenges in developing countries, with an initial focus on Uganda. The system employs a three-stage filtration process: sediment filter to remove large particles, activated charcoal to remove chemicals and improves taste, UV light for final purification and disinfection to eliminate bacteria and other pathogens. The innovative aspect of the project lies in its self-reliance model. Rather than continually supplying filtration systems, the Learning Factory aims to provide communities with 3D printers and open-source designs, empowering them to manufacture and maintain their own filtration devices. This approach minimizes dependency on external resources while fostering local innovation and problem-solving.

This project aims to support Dr. Tom Wanyama's research that aims to improve maternal healthcare outcomes through improved Water Sanitation and Hygiene (WaSH) in healthcare facilities in Sub-Sahara Africa (Laux 2018). The research is being done in collaboration with Uganda Christian University and Save the Mothers – East Africa. The SEPT Learning factory is developing an integrated 3D printed filter, whose prototype is shown in Figure 3(a), to replace the segment and the charcoal filters in Figure 3(b). Though still in its infancy, the Water Filtration Initiative exemplifies the Learning Factory's ability to tackle global challenges through sustainable engineering solutions to support McMaster University desire to support achieving the UN Sustainable Development Goals in developing countries by providing practical solutions and knowledge transfer in sustainable manufacturing practices.

Figure 3. *Water Filtration System Developed by SEPT Learning Factory*



Conclusion

In conclusion, the Multidisciplinary Learning Factory at McMaster University exemplifies the potential of innovative, integrated learning environments in bridging engineering, technology, and business education. By expanding the scope of traditional manufacturing training and incorporating Industry 4.0 concepts and business management principles, the SEPT Learning Factory offers a cost-effective model that maximizes resource utilization while addressing educational, community, and global needs. Its unique approach not only enhances students' practical competencies but also fosters community engagement through initiatives such as outreach to local high schools and collaborations aimed at achieving sustainable development goals. Furthermore, by producing marketable products and supporting international partnerships, the Learning Factory demonstrates its role as a catalyst for social good, knowledge transfer, and workforce development. Ultimately, this model highlights the critical role of multidisciplinary learning factories in fostering hands-on, real-world education that supports the broader mission of academic institutions, prepares students for future challenges, and contributes to the sustainable development of global communities.

References

Abele E, Chryssolouris G, Sihn W, Metternich J, ElMaraghy H, Seliger G, Sivard, G., ElMaraghy W, Hummel V, Tisch M, Seifermann S (2017) Learning factories for future oriented research and education in manufacturing, CIRP Annals - *Manufacturing Technology*, Vol. 66, pp, 803–826, 2017.

Bao C C K, Tran Trung Thanh T T (2023) Development of a Digital Learning Factory toward multi objectives for Engineering Education: An educational concept adopts the application of Digital Twin, *SSRN Electronic Journal*, Available at SSRN: https://ssrn.com/abstract=4378748

Deshpande M, Khandelwal M, Singh K (2022) Multidisciplinary avenues on the integration of industry 4.0 in the degree of mechanical engineering, *Proceedings of the 3rd International Conference on Future of Engineering Systems and Technologies, IOP Conf. Series: Materials Science and Engineering*, Vol. 1228. 2022

Ferrario A, Confalonieri M, Barni A, Izzo G, Landolfi G, Pedrazzoli P (2019) A Multipurpose Small-Scale Smart Factory for Educational and Research Activities, *Proceedings of the 29th International Conference on Flexible Automation and Intelligent Manufacturing (FAIM2019)*, June 24-28, 2019, Limerick, Ireland.

Laux S (2018) Using the power of big data to improve maternal health in Africa, *Queen Elizabeth Scholars Advanced Scholars*, Available as of March 2025 at https://uwaterloo.ca/queen-elizabeth-scholars-advanced-scholars/news/using-power-big-data-improve-maternal-health-africa

Lutters E, Massa J, Damgrave R, Thiede S, Gommer L (2022) Integration of learning and research in a multi-perspective learning factory, *Proceedings of the 18th CDIO International Conference*, Iceland, Reykjavik, 2022.

Matt D T., Rauch E, Dallasega, P (2014) Mini-factory – a learning factory concept for students and small and medium sized enterprises, Variety Management in Manufacturing - *Proceedings of the 47th CIRP Conference on Manufacturing Systems*, ScienceDirect, pp. 178 – 183, 2014.

Penn State Engineering (2017) The Learning Factory, available as of November 2017 at http://www.lf.psu.edu.