Transforming Undergraduate Education: Project-based Learning in Engineering Design Course

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Great(er) Expectations

Thirty years ago, an industry-ready engineering graduate was well-served by a fundamentals-focused undergraduate program that later led to training in specific applications, and ultimately assuming a delineated professional role. Today, that graduate is expected to not only make sense of complex integrated systems from the outset but also possess hands-on experience in multiple applications and various domains. Other desirable traits include being an excellent communicator, a high-functioning team member, creative, socially aware, and ethically driven. Naturally, the demands on engineering programs have substantially shifted from their focus on fundamentals to providing hands-on experience that is academically rigorous and engages students in real-world applications. For both students and their engineering faculties, this is both a substantial change in program requirements and a meaningful augmentation of expected outcomes. As such, many engineering institutions are actively responding by planning and implementing major overhauls of their programs.

Transforming Undergraduate Education - The Pivot in McMaster Engineering

In 2019, Dr. Ishwar Puri, Dean of the Faculty of Engineering at McMaster, announced a ground-breaking initiative called the “The Pivot,” which sets a goal of a fundamental transformation of engineering education to respond to today’s technological and societal challenges. The Pivot is a $15 million initiative to transform undergraduate engineering education “to prepare students to be flexible in a rapidly-changing world and to meet challenges not yet imagined.” The Pivot vision is to “combine complex problem solving, critical thinking, adaptability, and creativity to prepare students for a world of disruption, collision, and creative forces.” The goal that every student graduating from the McMaster Engineering program is “a resilient, calculated risk-taker who is intellectually curious and unfazed by failure.”

The depth and breadth of knowledge and experience is a key objective for all undergraduates, with design thinking, an innovation mindset, and entrepreneurship embedded in all programming within The Pivot initiative. Foundational courses still exist, but traditional lecture approaches are replaced by self-directed and group learning activities and experiences in solving real-world problems via integrated systems. Through this combination of foundational coursework and relevant projects, students build core technical skills and durable competencies they can take into the future.

In The Pivot initiative, first-year engineering students are exposed to four cornerstone design projects. Working in teams, they develop solutions to real-life problems and “are challenged to innovate, with the guiding principle of finding a solution that makes life better.” Projects progress from small, industrially relevant problems with prescribed solutions to larger problems without prescribed or obvious solutions. Emphasis is placed on the development of social consciousness, design thinking, and client-focused skills, including empathy, defining, ideating, prototyping, and testing, while all in a team environment.

The Pivot’s Five Key Competencies

Through The Pivot program, students will be exposed to the following experiences:

- **Discover + Create (DC):** Mentored research or project experiences to enhance technical competence and creativity
- **Integrate + Solve (IS):** Understanding and bridging multiple and diverse ways of defining problems and posing solutions
- **Business + Innovate (BI):** Understanding gained through experience that viable business models are necessary for the successful implementation of engineering solutions
- **Global + Diversity (GD):** Understanding gained through experiences where serious consideration of cultural issues is mandatory to successfully implement engineering solutions
- **Citizen + Community (CC):** Deepen social consciousness to address societal problems

![Image source: www.eng.mcmaster.ca/about/pivot#New-First-Year](www.eng.mcmaster.ca/about/pivot#New-First-Year)
The McMaster-Quanser Partnership

The genesis of the Quanser collaboration with McMaster was driven by The Pivot’s objective to provide authentic project experiences that embody emerging engineering challenges in autonomous systems, IoT, AI, and cyber-physical systems. McMaster Engineering recognized Quanser’s global reputation for advanced academic technology platforms specifically designed for teaching and research in these modern fields. Additionally, the expertise at Quanser included years of collaboration with leading educational institutions in a broad range of ambitious academic applications.

Together, the teams from Quanser and McMaster Engineering combined their respective expertise in curricular design and experiential education. The result is the world’s most advanced and flexible technology and pedagogy platform: one that harmonizes modern-era smart applications with effective learning and modern design skills within an academically appropriate framework.

The Quanser Design in Support of The Pivot and Curriculum Framework

Quanser’s design for The Pivot was highly informed by its prior work with the University of New Mexico (UNM), where advanced robotics was used as a platform to highlight topics commonly encountered in first-year Electrical and Computer Engineering courses. Topics include analog/digital interfaces, servo control, battery technology, communication systems, etc. Building upon this, and with The Pivot’s four-stage project progression in mind, the McMaster-Quanser team conceived of several innovative projects based on the general smart systems application theme and centered on a full and rigorous treatment: a smart, robotic recycle sorting system.

From the start, students are exposed to the entire working system - a rigorous treatment of a technological solution to a real-world industrial problem. But the system is presented in a way that is accessible and appropriate to even younger students. The sequence of The Pivot projects leads logically toward a complete understanding of and experience with the full system. Students begin by working conceptually at first, then on portions of that system. As their learning continues, it progressively illuminates the components, architecture, and overall functionality of the complete platform.

Guided by this collaboration, Quanser set out to deliver an academically-optimized platform consisting of devices that offer the following:

- **Completeness**: A solution that includes the necessary core technology, learning resources, and academic support services specifically tailored for McMaster’s The Pilot Initiative. Additional services include comprehensive on-site commissioning and stakeholder onboarding.
- **Academic Robustness**: A pedagogical foundation derived from global best-practices. This includes a clear articulation of the learning objectives and outcomes that are aligned fully with the guidance provided by McMaster Engineering to a highly qualified team at Quanser.
- **Academic Appropriateness**: A hardware platform optimized for an academic environment. It consists of equipment that offers transparent instrumentation and access to raw measurement of signals. The physical dynamics of the platform are supportive of conventional engineering theory as presented in courses.
- **Agility**: A platform that can be repurposed for a broad range of courses, including control, mechatronics, mobile robotics, smart systems, cyber-physical systems, AI, and machine learning. Potential use-cases would range from outreach and first-year design projects all the way to graduate-level courses.
- **Scalability**: An extensive selection of platform features that offer potential application scalability in the future. This could include high fidelity virtual and augmented reality tools, a mobile-first learning platform, and a heterogeneous software platform that supports a broad range of languages in a way that is undergraduate-friendly.
This smart recycle sorting system consists of core Quanser hardware, including QBot 2e ground robots, QArm robotic manipulators, Rotary Servo systems, and custom Quanser application software. Together, these operate as a functioning smart recycle sorting system that is able to identify various objects based on their material, and using a manipulator arm places the objects on specific ground robot carriers to transport them to the appropriate recycling station.

The design of the supporting curriculum was guided by the following principles:

- Contiguous progression of themes and techniques
- Flexibility to refine and grow into future applications, technology, and methods
- Clear articulation and activity mapping of core engineering techniques of design: requirements, models, design variables, prototyping, testing, optimization, etc.
- Consistency in methodology and workflows framed by rigorous and robust engineering methodologies
- Explicit treatment of engineering literacy and critical thinking
- Exemplary embodiment of the vision of The Pivot

Over 30 robotic stations will be deployed in a learning studio setting, allowing students to work in teams as they progress through the Eng 1 Pivot at McMaster. In addition to the obvious benefit of the application theme, this innovative approach also embodies several key benefits that will help McMaster work more efficiently and effectively with the platform. It’ll also facilitate the management of the system’s future efficacy and scalability.

The Challenges Ahead

The complexity of today’s integrated systems continues to grow, and with that also increases the need for engineering graduates to have both breadth of experience and knowledge, and the ability to continue to learn quickly. In addition, both hardware and software capabilities advance and offer an ever-growing number of opportunities to create intelligent, automated solutions that solve critical problems. Transforming engineering education to seize these opportunities presents new challenges, including:

- Providing meaningful, engaging yet rigorous, hands-on learning experiences much earlier in the curriculum
- Introducing contemporary, complex, and rigorous curricula that allow students to explore their macro - system design thinking, while building micro - component-level discipline, informed and validated by core scientific principles
- Introducing teamwork and sprint-based projects that emphasize communication skills expected by recruiters
- Infusing awareness of ethics and socially responsible behaviour to guide future engineers in their implementation of an autonomous world that increasingly makes critical decisions

For institutions, defining, designing, and successfully implementing a new curriculum requires significant time, effort, and investment. We have seen that there is a considerable benefit when such planning includes considerations of both the options and the advantages of:

- Designing around a single, large scale integrated system that can be presented at the start, with a curriculum that unpacks and explores each element successively
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- Carefully choosing between making versus buying lab solutions with the understanding that both hardware and software must be reliable, will require support and, ultimately, must be designed for reliability and flexibility of operation

- Choosing suppliers who can act as partners rather than mere vendors by being fully conversant both with academic requirements and leading-edge industry applications and who are able to provide ongoing support

The McMaster Engineering-Quanser collaboration is ground-breaking in many ways. In addition to the advancement of methods and pedagogy in response to modern academic challenges, it strikes a modern dynamic relationship between an institution and industry. The dimensions of our collaboration are many-fold, and through this highly integrated collaboration model, McMaster Engineering and Quanser have set a new standard for education innovation for the modern age.

In 2019, Quanser, a Canadian based engineering education company, celebrated its 30th anniversary. With roots in control systems lab solutions, Quanser’s broad range of engineering technology has expanded into areas including mechatronics, robotics, aerospace, earthquake engineering. Found in over 2,500 institutions worldwide, Quanser labs provide complete roadmaps for engineering curricular transformation across many emerging subject areas, including artificial intelligence, Internet-of-Things, and Industry 4.0.

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Ranked among the world's top engineering schools, the Faculty of Engineering plays a significant role in helping McMaster University in Hamilton, Canada, to earn its reputation as one of Canada’s most innovative universities. The Faculty is known for innovative educational programming and its research and engagement with industry and community. Established in 1958, its institutes, centers, and laboratories have collaborated on numerous research projects with the public and private sectors. It has the distinction of being the first engineering program to have included problem-based learning into its teaching, importing it from the McMaster University Medical School, where it was first developed.

www.eng.mcmaster.ca/about/pivot

About The Author

Dr. Thomas Lee has been an active contributor in the global engineering and control systems community for over twenty years. As Chief Education Officer at Quanser, a leader in real-time control and mechatronics solutions for education, research, and industry, Dr. Lee develops and implements the company’s strategy for enriching and increasing the educational effectiveness of technology in the modern engineering education context. Prior to his appointment at Quanser, Dr. Lee was Vice President of Applications Engineering at Maplesoft, creators of the renowned Maple mathematical software system. In that capacity, he helped the company transform the mathematical technology to a complete engineering modeling and simulation solution.

He also serves as an Adjunct Professor of Systems Design Engineering at the University of Waterloo, noted for its leadership in engineering, computer science, and mathematics. Dr. Lee earned his Ph.D. in Mechanical Engineering at the University of Waterloo, and his M.A.Sc. and B.A.Sc. in Systems Design Engineering at the University of Waterloo. He has published numerous papers and is a frequent invited speaker in the areas of engineering education, engineering modeling and simulation, and engineering computation. In 2019 Dr. Lee was elected Fellow of the Canadian Academy of Engineering.