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Effective Learning of Innovation by Engineering Students in a Multi-Disciplinary Context*

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The teaching of innovation to engineers is often fraught with challenges and misgivings, as the definition of innovation itself, often confused with invention and research and development, is still a subject of research in the fields of science, engineering and management. In this paper, we offer the results of a novel graduate-level engineering course that attempts to develop among its students the ability to identify, define and manage innovation within a project-based and multi-disciplinary context, and in a manner that is stakeholder-centric. We present in this paper for the first time a Universal Innovation Framework that offers a practical and distinctive approach to the teaching and management of innovation that foregrounds societal impact as opposite to technical prowess. Preliminary results show a significant impact of the course on student understanding and perception of innovation.

Keywords: engineering management; innovation; innovation education; management of innovation; multidisciplinary pedagogy; immersion; project-based learning; problem-based learning; engineering design education; entrepreneurship education; public policy education

1. Introduction

As strategically important and as commonly used as it is, the definition of innovation remains vague and muddy in most cases. Used loosely by practitioners, it is often assumed to imply worthwhile activities involving creativity, research and development, inventiveness and new ventures. It is important to all but has a different meaning to each. In scholarly circles however, there have been extensive attempts to provide a general definition for innovation. In the Schumpeterian view, it's often equated with entrepreneurship [1], while in established companies, it is usually equated with the introduction of new technical methods, products, sources of supply, processes and forms of industrial organization [2]. Innovation is usually measured by R&D intensity, number of patents granted, and number of knowledge workers involved. It is often regarded as the exclusive realm of scientists and engineers that are dedicated to changing the world with their creativity and inventiveness. This remains, by far, the most prevalent understanding of what constitutes innovation, and forms the basis of most definitions thereof. For fewer authors, innovation reflects a more "strategic intent" [3] and takes a more market-pull approach. Conceptually, it is tightly linked with the outcome, as opposite to the outputs or the process, which is the successful commercialization of inventions and other intellectual property to gain a strong competitive advantage. This business model-based, market-driven definition of innovation has been further expanded by Gary Hamel [4] and Henry Chesbrough [5]. The latter points out that a better business model, such as Wal-Mart in retailing, Dell in PC's or Southwest Airlines will often beat a better technology from a competitor. In sum, however, all these definitions of innovation revolve around a "multi-stage process whereby organizations transform ideas into new/improved products, service or processes, to advance, compete and differentiate themselves successfully in their marketplace" [6].

In other words, all the above definitions fall short from providing a unified definition of innovation, let alone one that allows its practical and effective teaching to students from different and multidisciplinary programs, using a practical framework and a common language. While there is an emerging pedagogical literature on the importance of teaching innovation in a multi-disciplinary and trans-disciplinary setting, the definition and hence understanding of innovation is almost always implicit and hence vague and up to the "eye of the beholder" [7], and even cases where innovation is still equated to invention [7].

Engineering education itself is an artifact of innovation. After the second world war, engineering education was refashioned in the image of reductionist research and scientific thinking. In keeping with Adam Smith's central thesis that division of labour and specialization leads to higher productivity, and hence greater wealth [8], universities fully embarked on supporting and serving an industrial economy where the key competitive advantage of a company was to make more of the same at lower cost and higher performance, and where innovation was mostly about how to improve those two key

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performance indicators: i.e., cost and performance of their existing product lines. Only in the last decade or two has that single idea come under fire. Engineering design has grown from an afterthought to a key pillar of innovation and is playing an increasingly important role in the education of the profession [9]. Recent research in engineering education has highlighted increasing challenges, particularly in globalization and innovation, which require better synthesis and system building skills by engineering students [10, 11]. Rapid change in business, the important role of technology, and large and inherently transdisciplinary challenges faced by society have led to a call, led primarily by industry, for engineers to be seen and educated as more than just specialists. Gereffi et al. have shown that graduates of engineering programs fulfill very different roles. They classified engineering work as *transactional* and *dynamic*. Transactional engineers work in specialized areas usually within an organization typically on engineering problems [13]. Whereas dynamic engineers are comfortable working on broadly interdisciplinary teams involving abstract thinking and complex problem solving and are mostly likely to lead innovation. Others have called for engineering education to prepare its graduates to be *change agents* [13]. In one of the few examples of a longitudinal study of design education, a key conclusion of the authors related to the need to train students in both hard and soft skills [14].

In this paper we present an interdisciplinary and problem-based course, called the "Innovation Studio", which in addition to training students on key soft skills, embeds also what we believe to be the first definition of innovation that offers a practical and effective framework that allows students from three separate programs, including entrepreneurship, engineering design and public policy, to identify, design, develop and manage innovation in a multidisciplinary context, and with the goal to generate multi-faceted value, such as economic, social, environmental or a combination thereof.

This paper is organized as follow. In the theoretical framework section, we first do a review of the current literature on innovation from a practitioners' and pedagogical perspectives. We then present our proposed definition of innovation and the Universal Innovation Framework, and then proceed to explain our methodology on how we implemented and tested this framework through embedding it into an experiential course on innovation, called Innovation Studio. In the third subsection of the theoretical framework, we present a brief description of the "Innovation Studio" course with its key learning outcomes, and providing a more detailed outline in Exhibit A. The results of a survey of more than 50 graduate-level engineering students from three (3) different programs, i.e., entrepreneurship, design and public policy, that took the Innovation Studio in the first term of their master's program. We then discuss the results of this study, and its limitations, and we finally conclude by summarizing key takeaways of our study.

2. Theoretical framework

2.1 What is innovation?

Innovation is a term that has become ubiquitous in our culture particularly with respect to business, technology, public service, academic research, health, education and the economy. This ubiquity underlines the very importance of the notion to a myriad of fields, disciplines and organizations. Yet to each practitioner it means something different. Researchers have identified common elements in some fields but its use and application in education and in the academy is typically highly disciplinary. In this section, we will briefly trace the meaning of the term from its roots in invention to the current usage. From this basis, we will introduce the Universal Innovation Framework (UIF), a unified model for understanding innovation in an interdisciplinary and inter-professional educational context.

Where the term innovation is not in everyday or common use, it is often synonymous with the notion of invention. This is the meaning of innovation that is most commonly used in engineering-centred and technology-centred organizations. Genrich Altshuller [15] systematized the notion of invention. His approach, TRIZ (which translates from Russian as "theory of the resolution of invention-related tasks") laid out a hierarchy of inventions. At level one are routine design problems solved by methods well known within the specialty. This requires no invention. At level five are found rare scientific discoveries or pioneering inventions. As an example, a level 1 invention could be the incremental increase in memory in a USB stick while keeping or reducing its physical size. A level 5 invention would be the invention of the first transistor. An invention does not need be used to be called such but must have the attributes of novelty and usefulness in the eyes of the members of the discipline or industry solving similar problems, as well as the attributes of non-obviousness for someone familiar with the art of the invention. Meeting those requirements will qualify the author of that invention to apply for patent protection and as such become an inventor. Altshuller's techniques for generated and classifying inventions have been extended by others into various technical and non-technical domains.

More recently, business has strongly argued that invention is distinct from innovation. That in fact, invention, by itself is not innovation at all. This view is most strongly represented by Schumpeter [16] who introduced the idea of "creative destruction" in which a new way doing something, in business, replaces the old. This type of change is classified into five categories of innovation: (i) the launch of new or improved existing products; (ii) new methods of production or sales of a product not already proven; (iii) a new market; (iv) new sources of raw material or semi-finished goods; and (v) new industry structure. Both Schumpeter's notion of innovation and that of invention are based on the introduction in the market place of a new or novel idea in some sense. The economic perspective includes a wider domain of ideas in relation to products, services, operations, process, and people [6]. They need not be technical improvements whereas inventions must be. Secondly, innovation is only deemed real if it has a measurable economic impact such as market share. Wong et al. [17] further added that "innovation can be defined as the effective application of processes and products new to the organization and designed to benefit it and its stakeholders". In this definition, usefulness only depends on the positive value of change as measured or assessed by those who have a stake in the change.

Some thinkers in the business are broadening even this definition of innovation to include systemic business change and the business model itself as part of the range of domains for change [4, 5]. This is a natural extension of the idea that innovation is change that results from new ideas that benefit an organization (existing or new) and its stakeholders. The business model is the vehicle by which an organization delivers its products or services to the market place in a manner that creates mutual benefit [19].

Social innovation until recently fell outside the scope of engineering and technology but with the advent and spread of social media the intersection has become clearer. Social innovation involves new combinations or use of existing elements which cross organizational and disciplinary boundaries and create new benefits for stakeholders resulting in compelling new social relationships [18]. Unlike prior definitions of invention and innovation, the elements of combination in social innovation are social relationships rather than knowledge. However, to be successful, this innovation must also have a business model which delivers economic value to a certain class of stakeholders, e.g., the advertisers in the case of social media, which value can then be shared by the innovative organization in the forms of revenues and profit. Another common attribute between social innovation and the other forms of innovations discussed earlier is that it must be able to endure against current and future competition. While the traditional product-driven innovation typically relies on patents and trade secrets to fend off its competition, social innovation also needs an element of durability to maintain its preferred status with its stakeholders.

2.2 The universal innovation framework

This leads us then to ask what the common components and attributes of innovation across all the fields are and disciplines and seek from there to attempt developing a unified innovation framework that can then be used to teach innovation across multiple disciplines, contexts and applications. From our broad survey of what is called innovation, we reduced it to the following three components and two attributes:

The three components:

1. The Problem—unmet needs, pain, etc.—a socially constructed idea of what is the "problem". While the problem statement is initially inherently subjective and context-dependent, it may be informed by research, observations, data and validated knowledge. Examples could range from millennials who insist on texting while driving, to a gas company that believes its underground infrastructure is being damaged during the construction of neighbouring buildings.
2. The Solution—the product or service or policy that meets the need and/or removes the pain—found in different domains. An idea or concept drives the creation of a system which may be technical or social (including business). This includes things like a hardware or software product, a service, a process, a building, or even a policy.
3. The Value Creation Model—the effective delivery vehicle of the solution from the organization to meet the needs of its target stakeholders in a way that creates *net positive value* to the stakeholders as well as to the organization. In commercial jargon, the Value Creation Model is none other than the business model.

The two common attributes:

1. Newness—To be an innovation, one or more of the three components must be new. While the traditional definition of innovation always assumed the newness in the solution; a new product, service or process, our definition assumes no such thing. The newness can also be in the identified market need or in the value creation model itself. Examples of these include

Facebook's targeting of college students' needs for online socializing and Dell's selling IBM compatible PC's through their build-to-order model. The alert reader will notice that this simple extension of were the newness attribute attaches, readily unifies product innovation with business model innovation as well as with market innovation within one single framework.

2. Durable Advantage—To sustain its ability to continue to create net positive value for its stakeholders and its organization, an innovation must also have a long-term barrier of entry against existing and potential competitors. Again, traditionally, this sustainable competitive advantage has been associated with the solution itself in the form of intellectual property, such as patents, trade secrets or source code. However, other competitive advantages associated with the market and the business model can often provide as strong, if not stronger, barriers of entry against competitors. Such is the customer lock-in and high switching costs that Facebook leverages against its competitors, the legacy channels that prevented IBM, HP, and other earlier and bigger PC manufacturers from effectively competing against Dell.

We can now graphically represent this framework as shown in Fig. 1.

The three components of the UIF are clearly strongly interconnected, where each component strongly affects the other two and is equally affected by them. Not only does the framework require the innovator to clearly articulate what each of those components are, but it also provides an iterative process of continuous refinement of each of those components both in qualitative and quantitative manner. As such, the UIF demands a multidisciplinary and systems thinking approach in order to define and analyse, taking for instance the example of a commercial start-up, the (i) customer needs, pains and desirable outcomes, as well as the addressable size, and the price sensitivity; the (ii) product definition, feature and functionality, cost of development and for hardware product, the supply chain and cost of manufacturing; and finally (iii) the business model which defines the product delivery vehicle, the sales and marketing channels and their associated cost.

Furthermore, the two attributes, novelty and sustainable competitive advantage, must also be clearly identified and articulated from the beginning. Within this system thinking approach, either one of them can be associated with the product, the market or the business model. They can also be the same or different. For example, Google's newness and sustainable competitive advantage was the higher speed and efficiency of their search engine technology, while for Facebook, the newness was in their college target market of college students, as opposite to My Space and Friendster, while their sustainable competitive advantage was in the customer lock-in and high switching cost they could achieve with their end users.

A key element of the use of the UIF is the definition and design of the innovation in such a way that it creates *Net Positive Value*, which is defined as the value created for the stakeholders less the value expended by the organization. In commercial parlance, the value created is upper bounded by the dollar value of the annual addressable market for the product, while the value expended is the cost of R&D, manufacturing, sales and marketing and other overhead. In financial jargon, this means that the proposed innovation must have an aggregate positive bottom line over its useful life, and the exercise of quantifying that bottom line will help assess the investors' internal

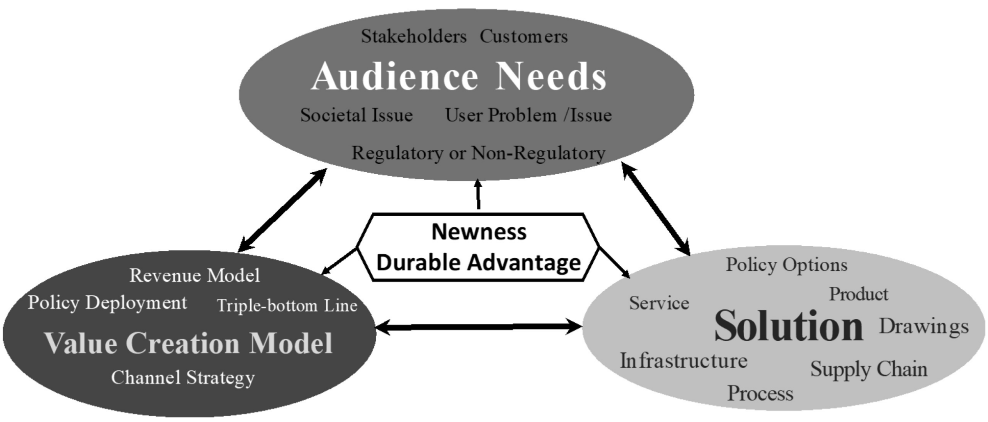


Fig. 1. Universal Innovation Framework showing different variations to the three components as applicable to entrepreneurial, commercial, public sector and policy innovation.

rate of return for their investment. We can see from here that the concept of Net Positive Value, when it's economic, requires the ability to develop credible financial projections to determine whether the total value created is positive or not. Finally, the attribute of sustainable competitive advantage allows the extension of the useful life of that innovation and delays its obsolescence, and hence value reduction, by the competition.

The UIF, as shown in its most general form in Fig. 1, can also be used for social, public sector and policy innovation. Whether its purpose is the creation of economic, social or environmental value, it is always a *social event that seeks to create net positive value with novel thinking*. Although, social and environmental values cannot be as reliably quantified as economic value, extensive research is now attempting to do so via the triple-bottom line framework [19]. Moreover, from the social exchange theory, innovation must realize net positive value for all the stakeholders involved in its value chain, as each stakeholder, be it the innovator, the customer, the investor, the employees, the supplier or the channel must realize a "profit" from their participation. Defined this way, innovation brings us back to the concept of shared value [20].

Indeed, for an invention to grow into an innovation it must be designed to create net positive value for all its stakeholders. That means it needs to address a market need or want that has a customer base that is large enough and for whom the product creates a value to them (be it objective or perceived) that is greater than the price they are asked to pay. Conversely, the product price must be greater than the total cost of making and delivering it to the market place. This last requirement involves both the product and business model key parameters. Finally, to maintain this shared value creation, and recoup their R&D investment, the innovator must have a sustainable competitive advantage, in some form, to be able to protect their invention from being easily undermined by competitors and hence negate the shared value creation.

Similarly, for a new policy to become an innovation, it must also identify an audience need among its citizenry and develop the policy (like a product in business) in a way that meets that stakeholder needs better than other existing policies. It must also design a value creation model to effectively deliver this policy in a way that creates net positive value not only for the intended audience, but also for all the other stakeholders that participate in the value chain, such as the tax payers that provide the financing, the government officials that design, implement and monitor the policy, the environment, the community, etc. A case in point would be the Feed-in-Tariff policy that was developed and endorsed by many countries worldwide to encourage and accelerate the adoption of renewable energies and reduce the environmental impact of fossil fuels. The solution consisted of offering feed-in-tariff for generation of electricity from renewable sources at a significantly higher price per kWh than the market price of electricity. The value creation model consisted of using government subsidies to finance the purchase of the higher cost electricity by the utility companies, and the net positive value generated was a combination of profitable sales by the solar panels manufacturers and their downstream channels, which spurred the rapid growth of that market and hence further reduction in cost of solar panels, the faster payback period for the buyers of those solar panels and the increased environmental benefits.

2.3 Application to teaching of innovation—course description

Students at the Walter G. School of Engineering Practice and Technology are enrolled in three distinct programs each with their own curriculum, teaching faculty, and requirements. These distinct disciplinary programs are entrepreneurship, engineering design, and public policy. All students are required to complete a complement of obligatory and elective courses and must complete a degree-required project. In some of these elective courses, students from the three programs may meet. One single course is mandatory to all the students, and that is SEP 772—Innovation Studio. At the end of their respective programs, entrepreneurship, engineering design and public policy students deliver and defend a start-up proof-of-concept with a business plan, a design or prototype, or a policy paper, respectively. Despite the differing nature of the three deliverables, they have on characteristic in common—they are driven by the desire to effect change, through innovation, not in their respective fields but in the community or industry which is the context of the students' work. Take the transportation as an example. Policy students may explore policy alternatives for encouraging autonomous vehicle technologies; design students may be testing new ideas in assistive driving technologies; and entrepreneurship students may be developing a new enterprise project around a new after-market assistive driving product.

The only place in their curriculum where they share a common learning experience is the *Innovation Studio*. Students in each of the programs either arrive with strong idea of what it means to be in policy, design, or entrepreneurship or quickly identify with these areas early in the program.

For the purpose of this course, we defined innovation as the *"creation of net positive value with novel* *thinking*", where value is defined in the triple-bottom line sense of economic, social and environmental value. Rooted in a multi-faceted concept of value creation, this definition of innovation enabled us to present the course to a very diverse student audience using a common and consistent language, as well as an inspiring approach where the focus is on the societal impact rather than the technical prowess. Based on the above conceptual definition of innovation and driven by the need to develop a pragmatic deployment thereof, we developed the Universal Innovation Framework (UIF) as presented in Section 1.1.

The course was taught to more than 70 master's students belonging to three separate programs from the Walter G. Booth School of Engineering Practice and Technology. The cohort comprised about 50 students from the Engineering Design program, 21 students from the Entrepreneurship program and about 10 students from the Public Policy program. The 12-week course was taught collectively by three faculty and assisted by two staff members of the School. The course was inherently project-based, and challenged the students to select specific themes, form a project team, and select an innovation project based on clearly identified audience need, which must be validated by direct stakeholder engagement. A detailed outline of the course is shown in Exhibit A.

This innovation framework was presented as the underlying backbone of our approach to guiding the students through their opportunity identification and development. It provided a shared language, a common process and evaluation criteria among all the students, despite the wide disparity between the projects and end-goals between entrepreneurship, design and public policy students.

3. Methodology and key findings

3.1 Methodology

To assess the effectiveness of the course in teaching innovation, we conducted an anonymized survey of all the students after the completion and marking of the course. The survey was distributed by a research assistant who was also in charge of collecting and delivering the data to the authors of this paper for analysis and discussion. The survey contained twenty questions, probing (i) the evaluation of the students of the importance and practicality of the various tools learned in identifying and managing innovation and (ii) a self-evaluation by the student of their acquired innovation skills from the course. The survey included both quantitative (i.e., Likert scale) and qualitative questions, the latter inviting the student to provide open-ended comments. The survey questions are displayed in Exhibit B.

There was a total of 49 respondents to the survey among the 70 students who enrolled into the course, representing a 70% response rate. For the analysis of text-based open-ended questions, we used the text analysis tools from Voyant Tools [23], which provides word cloud, type frequency charts, along with many other text-analysis visualisation tools.

3.2 Key findings

Some of the salient points of the results of the survey are as follows:

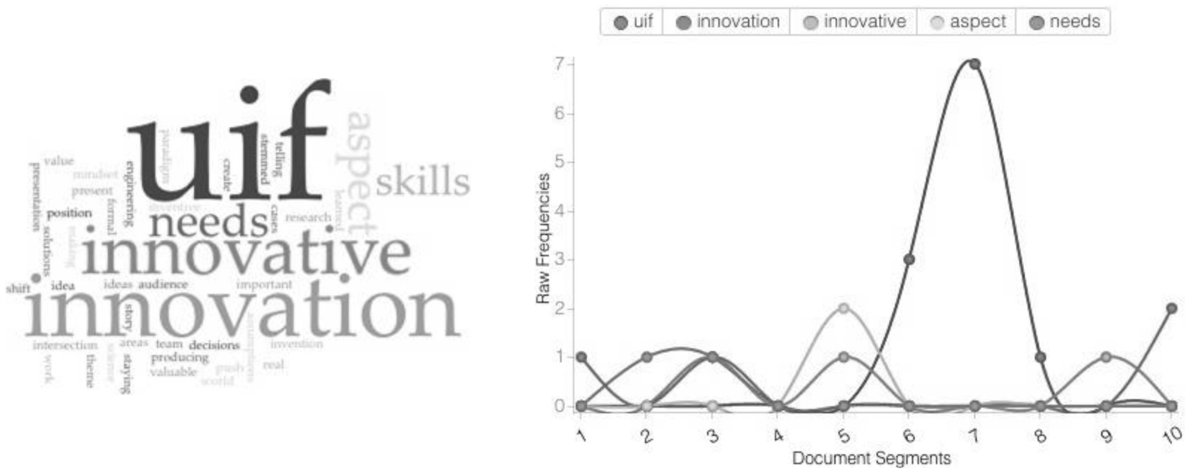
- To the question of whether the course changed the students' prior understanding of innovation, more than 76% answered affirmatively. When asked, in the qualitative section of the survey, *how* their prior understanding of innovation changed, students offered the following comments:
  - "Innovation is a social event and does not necessarily need technology";
  - "Innovation has to be tailored to customer needs in order to be successful";
  - "Innovation is very important even to a formal engineering position";
  - "Importance to identify the stakeholders and learn what is most important to them (from their perspective)"
  - "I did not know the difference between invention and innovation. With SEP 772, I can now differentiate."
  - "[The course] helped me look at the subject in terms of business ethics, societal value, and validation."
  - "I learned how innovation impacts our life"
  - "[The course] helped me think through the whole process, from problems digging to value creation"
  - "Now, I'm able to consider my projects or works more systematically, following an innovation logic or process"
  - "When I came to this program it was all about what I wanted to do, but after I've taken this course, it's all about what my community needs."

  The comment about learning the difference between invention and innovation occurred three times in different forms.
- To the question on how similar or different invention and innovation were perceived by the students after the course, about 73.5% responded that the two were different but closely related, while 24.5% responded they were totally different and only 2% (1 student) responded that they were pretty similar.
- While students say both innovation and invention are critical for our economic well-being, on a

Likert scale of 0–5 where higher is more critical, innovation scored a mean of 4.07 with a standard deviation of 1.14 while invention scored a mean of 3.37 and a standard deviation of 1.20, reflecting a 20% higher margin for innovation.

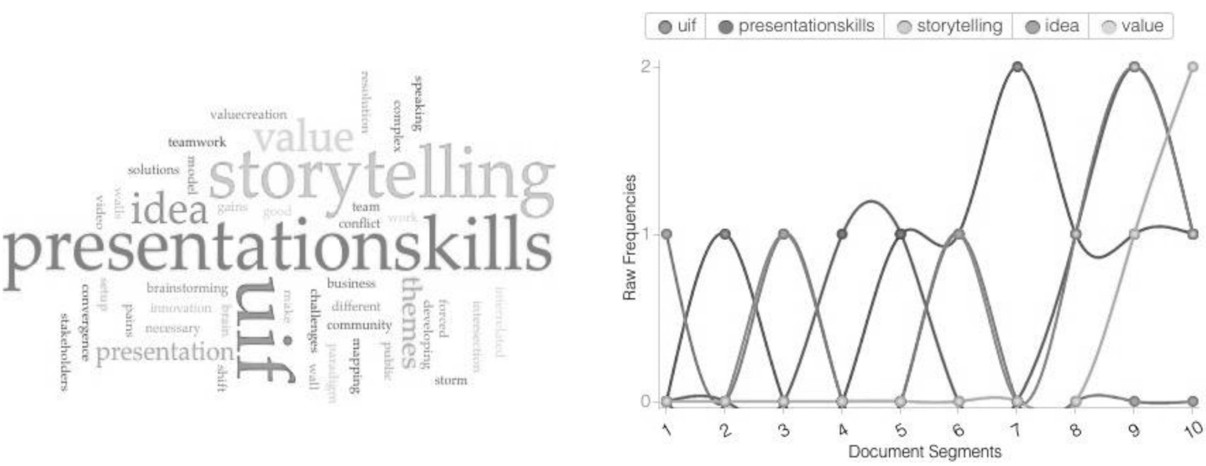
To the following open-ended questions (no multiple choices offered), we received the following responses:

- What is the most important concept you have learned in SEP 772?
  - There were 24 respondents or 40% of the total participants who answered this question. Of those, 46% cited the Universal Innovation Framework (UIF) as the most important concept learned in the course. The number 2 and 3 concepts revolved around the connection of innovation with value creation in society on the one hand, and the presentation skills/storytelling on the other with 20% and 12.5% respectively. The Voyant Tools were used to generate a word cloud visualization and a type frequency charts, illustrating the analysis of the open-ended answers, as shown in Fig. 2(a) and (b) respectively. When broken down by program, it was interesting to note that the UIF made 60% the choice of the Engineering Design students, 33% of the Engineering & Policy and only 14% of the Entrepreneurship & Innovation (E&I) students. This was unexpected considering the fact that the UIF concept was first taught to the E&I students in previous years, and this was the first time it was presented to all the three programs together.



(a) (b)

Fig. 2. (a) Word cloud visualization of the most recurring concepts and words describing the most important concept of the course. (b) Type frequency chart of the most recurring concepts and words describing the most important concept of the course.



(a) (b)

Fig. 3. (a) Word cloud visualization of the most recurring concepts and words describing the 3 most useful concepts of the course. (b) Type frequency chart of the most recurring concepts and words describing the 3 most useful concepts of the course.

- What are the three most useful concepts you have learned in SEP 772?
  - There were only 17 respondents to this question, with each answer containing up to 3 concepts. The three most popular concepts were (i) the UIF (8x); (ii) Presentation Skills (6x) and (iii) Storytelling (6x). Other recurring themes were the idea mapping and the value creation concepts. Fig. 3(a) and (b) show the word cloud and type frequency visualization charts, obtained with the Voyant Tools software, respectively.

4. Discussion of results

The results above indicate the course has shifted many students' perception of innovation away from the traditional Schumpeterian view of innovation being always technically driven through inventions and R&D. Instead, the concept of innovation as the creation of societal value using novel thinking seems to have taken hold. In that context, the students seem to overwhelmingly reject the idea that innovation and invention are similar with 24% believing they are totally different and 73.5% believing they're different but relater. Another outcome of the course is that innovation scored higher by about 20% than invention in its critical importance for the economic well-being, and this with an audience that is overwhelmingly composed of engineering students.

Perhaps, the most important validation of the course's approach to the effective teaching of innovation to a diverse audience of students across three very different programs (i.e., entrepreneurship, design and public policy) are the results of the open-ended non-leading questions. The text analysis, using Voyant Tools, revealed that the Universal Innovation Framework (UIF) was perceived by far as the most important concept introduced by the course, reflecting the choice of 46% of the respondents. Also, when asked about the three most useful concepts of the course, the UIF again garnered the top spot, closely followed by "presentation skills" and "storytelling". These results support the notion that from the students' perspective, the UIF is not only a conceptually important theoretical framework, but also a very useful and practical one to help guide the innovation process. This was indeed one of the key objectives of the course. The second and third most useful skills, namely "storytelling" and "presentation skills", further outline the importance of these two skills.

Let us now discuss some of the limitations of our study and hence the implications of our results. One of the key objectives and challenges of the course is to teach innovation using a generally applicable framework so it can be effectively conveyed to a very diverse audience of students, but also in a way that is practical and useful to all those students, regardless of their program or their particular project. The results of the study strongly suggest that the UIF was indeed the one unifying concept that stood above all others in its importance to the conceptual understanding and differentiation of innovation. The results also suggest that the usefulness of the UIF in the practice of innovation ranks higher than any other concept, followed by presentation skills and storytelling tied for second place. That said, these results are based on the response of about 50% (or 24 students) of all the students that took the survey, which themselves represent only 71% of all the students that took the course. In effect, we still lack the response of about 65% of all the students that took the course. While we expect that the decision to respond was random, we have no data to show that the respondents are a representative sample of the full population. Another limitation is that the results presented are the aggregate response from all the respondents across all three programs. We have not attempted to analyze the data at the program level, except for the unifying concept of the UIF. In that respect, we were surprised to find that the UIF garnered the lowest score as the "most useful concept" for the Entrepreneurship & Innovation students with a score of 14%, which was lower than even that of Engineering & Policy (33%) and much lower than the Engineering & Design with 60%. We speculate that this low score may be attributed to the fact that the UIF was not new to the Entrepreneurship students, as it is introduced separately in the first entrepreneurship module, and as such did not get their top score, because to them it's not the most useful concept *learned from the Innovation Studio course*.

5. Conclusion

In conclusion, we have presented a novel course that seeks to teach innovation to a multidisciplinary, graduate student audience belonging to three very different programs, using a novel format of teaching, involving multiple instructors and using an innovation framework that is both universal in concept and generally applicable in practice. The results of the study of the effectiveness of this course measured by our quantitative and qualitative survey of the students after the delivery of the course suggest a strong shift in the students' understanding of innovation, from the traditional technically-driven definition to one that is socially-driven. The student survey also reflects a strong and across-the-board support of the importance and usefulness of the Universal Innovation Framework. Further longitudinal research would be useful in both confirming these findings as well as in improving the course's effectiveness.

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Appendix A

SEP 772 Innovation Studio - Course Outline

Course Description and Goal

Innovation Studio brings together all the students at the beginning of their programs from the design, entrepreneurship, and public policy. Students will build teams, learn from one another, and identify an innovative direction for their degree-required projects, that is, design projects, new enterprises, and policy papers, respectively. The course will be presented in 13 three-hour sessions including a session during Welcome Week before other courses are underway.

Learning Objectives

By the end of the courses students will:

- be able to create and select paradigmatic alternatives based on their analysis and evaluation of the schemes by which additional value is created by change and through innovation;
- apply the key dimensions of strong sustainability in developing and advancing solutions to societal challenges;
- be able to lead (enlist the aid and support of) stakeholders to attain a common goal;
- be able to work effectively in teams composed of persons with different background knowledge and/or expertise;

- communicate effectively in public and professional environment through oral and written skills; and
- be able to demonstrate the personal integrity and maturity that enables them to build trust with others, value differences, and create synergistic relationships.

Students' Deliverables

By the end of the course, each project team will deliver:

- an electronic portfolio containing evidence of work throughout the term and evidence of an oral or written publication;
- a brief presentation sharing their Innovation Studio journey; and
- a brief presentation explaining their work and idea to be made at the end of term.

Assessment of Students' Deliverables

Each item of work will be assessed by two faculty members, representing different programs. The grade is pass/fail.

Assessment Criteria for Students' Deliverables

Creativity—Is there evidence that a concerted effort was made to explore a new idea in the theme area of interest? Would the idea be viewed as novel or non-obvious by practitioners in the theme area of interest?

Engagement of stakeholders—Is there evidence that two or more external stakeholders were engaged in meaningful conversation around the new idea?

Interdisciplinary teamwork—Was the creative exploration performed by an interdisciplinary team with members either inside or outside the School?

Public and professional communication—Was the new idea communicated in a public forum or to a broad audience at an acceptable level of professionalism?

Schedule of Classes

Prior to Welcome Week

- Survey sent to students asking them to respond with their themes of interest and experiences of innovative work.

Welcome Week

- The School and its mission are introduced.
- Individual faculty and staff introduce themselves.
- Students' questions are answered.

Week 1: Jingle & Mingle

- Course outline shared and discussed.
- Past student work is presented and discussed in the context of
  - What impact have your projects made to the community?
  - What impact have you had on the community?
  - Should you have an impact on the community?
- Icebreaking exercises.
- Students asked to share what projects you have done; why were these projects important; what is their current status?
- Students' responses to the survey are acknowledged.
- Lecture and discussion of portfolios.
- Students' assignment is to initiative portfolio with a reflection.

Week 2: Shatter your Paradigm

- Lecture and discussion of the definition of innovation and introduction of the Universal Innovation Framework.
- Initial portfolio assignment taken-up.

- Alumni invited to reflect: sharing their journey, role model reflection, interview style.
- Students' assignment is to add a presentation to their portfolio on their cultural knowledge around one of themes identify in the survey.

Week 3: Familiar Issues

- Students share their presentations.
- Lecture and discussion on themes.
- Using the survey data, the most popular themes are identified, and students groups themselves under a theme.
- Students' assignment, in a team, is to collect secondary research on the theme.

Week 4: Exploration

- Students share their secondary research. Followed by a facilitated discussion.
- Lecture on team formation.
- Preform a personal SWOT analysis; what complementary skill-sets will you need if you take on a challenge within your theme(s)?

Week 5: Share the Passion

- Students flock around common themes and build an idea wall.
- Lecture and discussion on expressing ideas, tools and mediums of expression, art of communication, and "What if" questions.
- Students refine idea wall.
- Students practice presentation to community partners
- Students form teams.

Week 6: Meet the Community

- Community partners attend; provide feedback on idea walls; share their challenges with the students.

Week 7: Stakeholder Engagement

- Students share experience with community partners.
- Students given opportunity to identify a challenge within their chosen theme that they would like to address (individual or team).

Week 8: Declare the Challenge

- Students share the challenge they wish to pursue and/or are pursuing and why they wish to and/or are pursuing the challenge.

Week 9: Strategy to Get your Word Out

- Students share their strategies and their plan to address your chosen challenge.
- Students asked to prepare a presentation for their portfolio on their journey from when they joined the School.

Week 10: Share your Journey

- Individual presentations; students share their journey.
- Prepare for community check-in.

Week 11: Express your Idea

- Students practice presentations to the community. Students present a direction they are explored based on a chosen theme and Innovation Challenge.
- Best presentations chosen.

Week 12: Community Check-In

- Offsite presentation to the community of best presentations from previous week.

Appendix B

Students Course Survey

Q1: *What is your Program Category? Note:*

- SEPT: W Booth School of Engineering Practice & Technology
- SEAS: School of Engineering & Applied Sciences
- SEPT/Graduate
- SEPT/Undergraduate
- SEAS/Graduate
- SEAS/Undergraduate

Q2 *What is your gender?*

- Male
- Female

Q3: *What is the SEPT program you're currently enrolled in:*

- Engineering & Public Policy
- Engineering Design
- Entrepreneurship & Innovation

Q4: *Have your taken SEP 772 (The Innovation Studio)?*

- Yes
- No

Q5: *Pick the most appropriate answer*

- Innovation and Invention are pretty similar
- Innovation and Invention are totally different
- Innovation and Invention are different but closely related

Q6: *How practical did you find the Universal Innovation Framework in defining what an innovation is?*

- Extremely practical
- Very practical
- Fairly practical
- Slightly Practical
- Not Practical at All

Q7: *Please place slider according to fit your response (higher is more agreeable) (-1 position is default and does not count)*

______ Innovation is critical for our economic well-being
______ Invention is critical to our economic well-being
______ I have a clear understanding of what innovation means
______ I know how to conceptualize an innovative project
______ I know how to manage an innovative project
______ I consider myself an innovator
______ I consider myself entrepreneurial
______ A knowledge of innovation is important to engineers
______ A practical knowledge of Innovation tools is important to engineers
______ I desire to work for a large company after my graduation
______ I desire to work for a startup after my graduation
______ I desire to work for the government after my graduation
______ I desire to start my own company after my graduation
______ I am comfortable working on inter-disciplinary teams
______ I am comfortable giving public presentations
______ I am comfortable working on projects that are outside my engineering discipline
______ I am eager to get criticism from others

______ I understand the importance of the stakeholders needs to the innovation process
______ I understand the importance of the customer needs to the innovation process
______ My classes properly prepare me to be successful in the real world
______ Most of my ideas are unfeasible or impractical or have already been thought of

Q8: *What did you like the most about SEP 772 (Innovation Studio)?*

Q9: *What did you like the least about SEP 772 (Innovation Studio)?*

Q10: *Did SEP 772 change your prior understanding of Innovation?*

- Yes
- No
- Not sure

Q11: *In what way did SEP 772 change your prior understanding of Innovation?*

Q12: *What is the most important concept you have learned in SEP 772?*

Q13: *What is the most useful concept you have learned in SEP 772?*

Q14: *List the 3 most useful tools/concepts you have learned in SEP 772 that you did not know from before*

Q15: *Comments: Write any additional comments below*

Lotfi Belkhir, PhD is a physicist, inventor, entrepreneur and currently the Endowed Chair in Eco-Entrepreneurship at the Walter G. Booth School of Engineering Practice and Technology at McMaster University. Dr. Belkhir's current research and teaching have for core mission the advancement of a sustainable society through innovation, entrepreneurship, design and policy. Dr. Belkhir is also a proven practitioner; he founded in 2001 Kirtas Technologies, the maker of the world's first and fastest automatic book scanner, which, under his leadership, ranked as one of Inc. 500 fastest growing companies in America two years in a row. Dr. Belkhir is a regularly featured speaker on the subjects of Entrepreneurship, Innovation, Sustainability and Corporate Social Responsibility at many venues. He holds a Ph.D. in physics and a Master's in Management of Technology. He is fluent in English, Arabic and French.

Robert Fleisig, PhD is a teaching-stream professor in the Walter G. Booth School of Engineering Practice and Technology (W Booth School) and the first-year engineering program with a passion for inspiring empathy, creativity and interdisciplinary thinking in his undergraduate and graduate students as well as in academic and local communities. He believes that for the university and our graduates to make impactful contributions to society it is no longer sufficient to only have disciplinary expertise. The 'T-shaped' graduate is one who is equally at home in the knowledge-centred work of his or her discipline (i.e., the stem of the 'T') and at work with individuals of diverse education, language, culture, beliefs, and values both within their organization and outside (i.e., the arms of the 'T'). Key to his teaching are empathy, experience and reflection. In his first-year engineering course, undergraduate and graduate students from three faculties work together to create a device to help members of the local community with a complex and unique problem. In his graduate teaching at the W Booth School, students work with university researchers, hospitals, and local business to identify important problems in health and sustainability to design, prototype, and implement innovative solutions that are meaningful to the community and have an economic impact. He has taught more than 10,000 undergraduate students and has impacted students across three faculties, local organizations, researchers, and a broad range of companies.

David K. Potter, PhD is an Associate Professor of entrepreneurship and innovation. He teaches leadership and technology entrepreneurship in the Walter G. Booth School of Engineering Practice and Technology at McMaster University. He helped design and start the master's level entrepreneurship program in which students create real businesses as part of their degree. Dr. Potter also introduced entrepreneurship to McMaster's undergraduate Engineering and Management program. Prior to McMaster, he spent 16 years in industry in roles that included research and development, product development, and new business development. He has also co-founded two start-up companies. He is very engaged in the innovation community, particularly through his activities with the Conference Board of Canada where he has served as Chair of the Innovation Council and as the Inaugural Chair of the Council for Innovation and Commercialization.