
AC 2011-882: USING MATERIALS SCIENCE FOR COMMUNITY OUT-REACH, ENGINEERING EDUCATION, AND INNOVATION

Amy Hsiao, Memorial University of Newfoundland

Dr. Amy Hsiao is associate professor in the Faculty of Engineering and Applied Science and chair of the Master of Engineering Management program at Memorial University of Newfoundland. With also a cross-appointment in the Faculty of Business Administration, she teaches Entrepreneurship, Production and Operations Management, and Materials Science at the undergraduate level and Organizational Behaviour and Engineering Management Topics at the graduate level. Her research interests are in materials characterization and magnetic materials processing (on the Engineering side) and strategic management of technology and technology entrepreneurship (on the Business side).

Using Materials Science for Community Outreach, Engineering Education, and Innovation

Abstract - Innovation has its fundamental roots in engineering and entrepreneurship. This paper presents primary research gathered from high school science teachers from selected K-12 schools across Newfoundland and Labrador, Canada, addressing specifically the gaps that they have identified as being most challenging in defining what engineering is in the realm of 9-12th grade science curriculum. The research results are incorporated into the development of a hands-on learning tool, a “portable materials science lab kit” that considers the input from these community educators and uses various types of materials, i.e. composites, nanomaterials, magnetic alloys, to demonstrate what engineering is and how engineering and innovation are relevantly applied to the important sectors of the province (the energy, oil and gas, oceans, and wildlife sectors). The “portable lab kits” are designed for high school classrooms, in which small groups of students work through hands-on laboratory modules focused on a specific material in a specific application. The process of innovation is thus shown from the perspective of using materials science to illustrate “scientific concept”, to “design” (invention), to “entrepreneurship” (commercialization), to “technological application”.

Introduction

Engineering and entrepreneurship are topics that are not well-developed in the high school curriculum. While advanced courses in physics, chemistry, and biology may be offered, students in grades 9-12 rarely know what “engineering” really is and what technology-based “entrepreneurship” really means. This paper centers on the idea that these two “themes” can be better introduced before university, such that motivated young students can see the continuum between their education, how science is applied in engineering design, and how their innovative ideas can impact their communities.

Developing engineers with entrepreneurial skills is becoming a valued objective for engineering faculties across the country. Entrepreneurship courses are being added to engineering curriculum and graduate programs are being developed in Engineering Management, for example. This paper will also address this trend and present an assessment of the role of the province’s main university, Memorial University of Newfoundland (MUN), as an “entrepreneurial university”, by which academic entrepreneurs emerge and invention is converted to technology. That is, the university is a “locus of innovation”, by which individual characteristics developed at the pre-university level can be continually developed in university and recycled and regenerated back into the community.

Research Approach

This research rests on theories of hands-on learning, integrated learning, and continuation learning. It hypothesizes that when an idea or concept is revisited in different contexts and environments, i.e. through kinesic, multidisciplinary, or repeated experiences, the learner will have better understanding of the concept and its applications. Materials science is inherently an interdisciplinary field in which knowledge of chemistry, physics, mathematical modeling, and

engineering are often combined in use. In fact, practitioners in the materials science world often refer to a paradigm known as the “processing, performance, properties, and microstructure tetrahedron” to steer their technological advancements. Similarly, entrepreneurship requires in-depth technical expertise as well as various management skills. The proposed research activities will not only support hands-on, integrated, and continuation learning, but also analyze and evaluate the effectiveness of this type of approach.

Primary research was gathered in the form of qualitative data from science high school teachers across the province of Newfoundland and Labrador (NL). Questionnaires and follow-up interviews with randomly selected high school science teachers were conducted. A questionnaire was mailed to the principals of all K-12 and high schools in NL, constituting a total of ~100 schools. A cover letter also asked each principal to identify and provide a copy of the survey to all teachers who taught science curriculum at the grades 9-12 level. Thus, these science teachers were the respondents to the questionnaire. The questionnaire was designed to harvest valuable information about pedagogical issues and engineering education topics, such as the extent to which science teachers were knowledgeable about engineering, what opinions these teachers had about engineering, what teachers thought about the hands-on laboratory kit concept, how “ready” teachers were to lead demonstrations about engineering materials, and if they had any suggestions or ideas for the laboratory kit. Thus, it was designed to assess the extent of knowledge, readiness, and comfort level of science teachers in teaching engineering and technology innovation.

An extensive literature search was also conducted on pre-existing science experiment or laboratory kits produced by other universities and published as peer-reviewed research, as well as websites that sell products for science teachers in high school.

Results

The response rate was 40% out of the total questionnaires distributed, with 90% of the responses received online. In addition, 90% of the respondents were from schools outside of St. John’s, the capital city of NL. Sixty-two (62%) percent of the respondents were male; 38% were female. Of all respondents, 71% indicated that they were aware of at least one student who had plans to become an engineer in the future. The key demographics of the respondents are shown in Table 1.

Average Age	38.3
Average Years Teaching	13.4
Average Number of Students in Your School	212.3

Table 1: Key demographics of the respondents

The respondents taught a range of science courses from several levels of General Science, Mathematics, Chemistry, Biology, Physics, Environmental Science, Health, Physical Education, Earth Systems to Technology and Robotics. In response to the question asking respondents to describe in general what engineers do, or to define what “Engineering” is, the results revealed key words such as *design, plan, develop, solve, build, apply, practical solutions, and everyday problems*. When asked to name a field of engineering, respondents listed first Electrical, Civil,

Mechanical, and Chemical Engineering, in that order, as shown in Table 2. It is only upon thinking about other fields of engineering for their second, third, or fourth responses that engineering disciplines such as Aerospace, Biochemical, Nuclear, and Computer Engineering were named. Additionally, there were some fields listed that are not considered actual engineering disciplines, such as marine, technology, and military engineering.

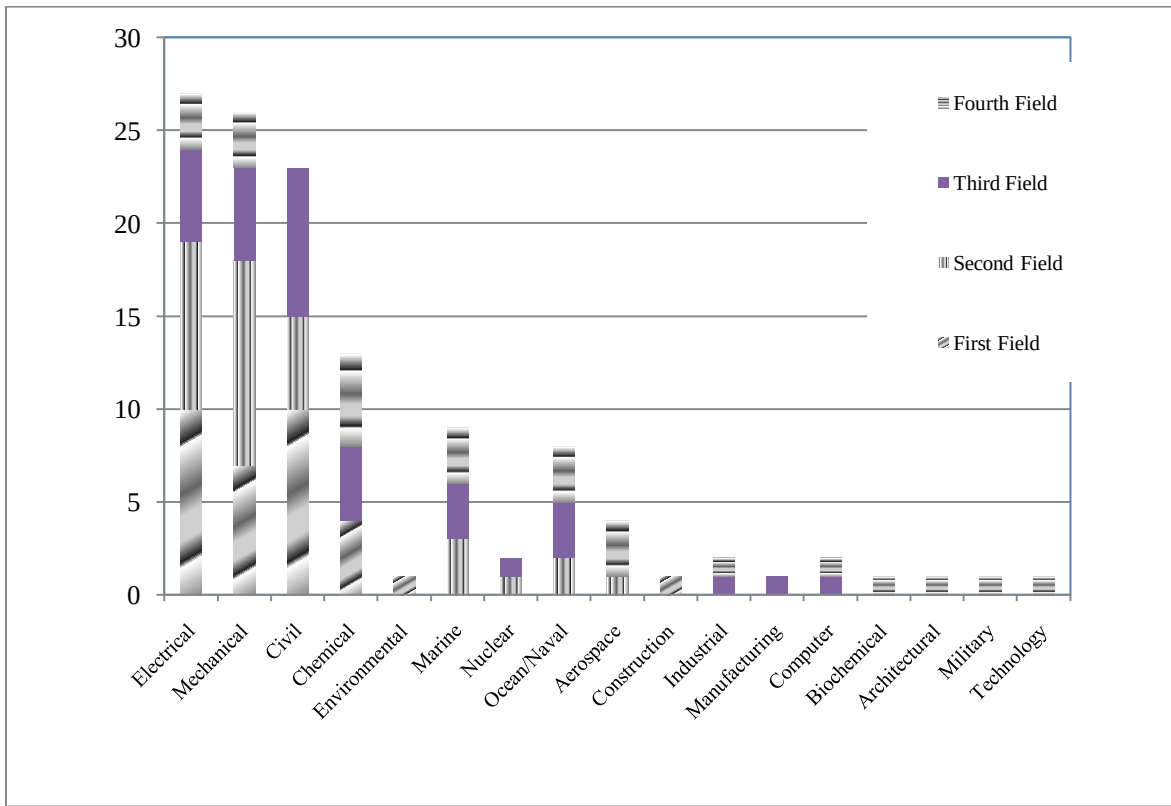


Table 2: Fields of Engineering Named by Respondents

When the teachers were asked to list five characteristics, besides science and mathematical aptitude, that students interested in engineering would possess, they listed initially: *curiosity to know, work ethic, problem solver, innovative, ability to manipulate mental models*. Second responses included *intuition, imagination, being technologically savvy, and having the ability to work in teams*. Third responses included *flexibility, ability to accept criticism, and strength of character*. The questionnaire results also indicated that the respondents regard engineers as making relevant contributions to society, in terms of economic success, practical applications, and environmental, business, and ethical impact.

The questionnaire also addressed the science teachers’ perception of Engineering as a profession, as shown in Table 3. It was clear that the respondents regard engineers as making relevant contributions to society, in terms of economic success, practical applications, and environmental, business, and ethical impact.

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Engineers are highly respected.	0	5.71	17.14	42.86	34.29
Engineering could be an enjoyable career.	0	0	8.57	40	51.43
Most of the skills learned in engineering are useful in everyday life.	0	0	14.29	60	25.71
A career in engineering would be financially rewarding.	0	0	2.86	54.29	42.86
Engineers are important to future economic success.	0	0	8.57	25.71	65.71
Engineers deal primarily with theory.	11.43	45.71	34.29	8.57	0
Engineers seldom get involved with business decisions.	20	65.71	14.29	0	0
Engineers have to deal with environmental issues.	2.86	0	2.86	45.71	48.57
Engineers need to know about economics.	2.86	0	5.71	57.14	34.29
Engineers deal with ethical questions about morality.	2.86	17.14	22.86	42.86	14.29

Table 3: Perception of Societal Impact of Engineers and Engineering (by % percentage)

An assessment of the science teachers' ability to make the link between what their students are learning in the 9-12 science curriculum to what Engineering is, is represented by the questions posed in Table 4. In this case, it is the respondents' own knowledge and understanding of what Engineering is that will facilitate an effective "bridge" between science and engineering, high school and university, education to innovation. "The bridge" would include the definitions of Engineering and the characteristics of engineers listed by the respondents previously. However, as seen from the results, the teachers do not frequently "make that bridge" nor feel comfortable enough to lead class discussions on what the link is between high school science curriculum and engineering applications. Lastly, these results also indicate that the respondents either do not have access to resources to inform themselves about Engineering or they do not know how or where to access the necessary information.

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
You frequently use the words “Engineer” or “Engineering” during your classes.	8.57	48.57	25.71	11.43	5.71
You are well informed enough to lead discussions about engineering and help guide aspiring engineers.	17.14	34.29	20	22.86	5.71
You know where to find the necessary information to help those students who want to become engineers.	5.71	11.43	11.43	51.43	20
You have the time and resources to improve your knowledge about engineering.	25.71	48.57	20	5.71	0

Table 4: Respondents’ Ability to communicate what engineering is (by % percentage)

An assessment of the science teachers’ ability to make the link between what their students are learning in the 9-12 science curriculum to what engineering is revealed that teachers do not frequently “make that bridge” nor feel comfortable enough to lead class discussions on what the link is between high school science curriculum and engineering applications. The results also indicated that the respondents either do not have access to resources to inform themselves about engineering or they do not know how or where to access the necessary information. Following these results: (1) 77% agreement: *The lab kit described would be an effective learning tool to inspire and encourage students to consider engineer as a career choice*; (2) 82% agreement: *Your students would be interested in seeing demonstrations involving engineered materials*, (3) 80% agreement: *Students who participate in science fairs could really benefit from having this kit available as a resource*; it was clear that a hands-on experience for students and a participative experience for science teachers would improve education of what engineering is at the pre-university level and increase interest.

Analysis and Application

It is interesting to note that words such as *manage*, *integrate*, *safety*, and *professionalism* are secondary themes that arose from the questionnaire responses. In addition, the misconception that “marine, technology, and military engineering” are Engineering disciplines reflects the common misuse of the word “engineering”. Technologists’ education in marine, factory, and defense instrumentation is a common form of vocational training in NL, such that teachers may know of technologists as “engineers” and thus define their knowledge of what Engineering is via interaction with these members of their community.

The primary research gathered focused the development of the hands-on laboratory kit using materials science to demonstrate engineering applications relevant to the province of NL. As such, the goals of the materials science laboratory kit were clearly defined from the results of the

questionnaire, i.e. (1) to emphasize the primary roles of engineers as being to *design, plan, develop, solve, build, and apply practical solutions to everyday problems*, (2) to focus the experimental modules in the laboratory kit on *Electrical, Mechanical, and Civil Engineering* examples, as most commonly recognized by the NL community through the respondents, (3) to use the laboratory kit to emphasize five characteristics required of engineers: *curiosity, passion, leadership, articulation, and critical thinking*, and finally (4) to highlight that engineering makes significant *economic, business, ethical, and environmental contributions* to society.

The research also indicated that the laboratory kit required the development of both a teaching note for instructors and an interactive information manual to guide users of the laboratory kit through each experimental module. This information is organized as such in the laboratory kit:

- Major Themes
 - The Importance of Nanomaterials
 - An Introduction to Materials Science
 - All About Innovation
- Properties of Engineered Materials
 - Metals
 - Ceramics
 - Polymers
 - Composites
- Using the Lab Kit
 - Spray-Coated Nanoparticles for Corrosion Protection in Harsh, Marine Environments
 - Oil Spill Absorbing Polymer
 - Shape Memory Alloy Sensors and Stents
 - Hockey (samples of composite stick, hockey arena glass, uniform padding, biocomposites)

The first module is designed to allow students to create a suspension of ceramic-metallic nanoparticles and participate in the action of spray-coating a potentially corrosive surface. The interactive information manual will provide images of corrosion occurring on the oil drilling platforms off the shores of Newfoundland. The second module is designed to illustrate how everyday actions of wiping a counter with a sponge can be applied to environmental issues using engineered materials to preserve the environment and the natural habitat of wildlife. The third module is designed to illustrate the idea of materials being “smart”, i.e. that they can sense, monitor, change, or store (energy) as a result of changes to its surrounding environment or external conditions. Finally, the fourth module is designed to show that the most beloved pastime of Canada is actually rife with applications of advanced materials, from the modern-day hockey stick, to the polymer that is used as hockey rink glass, to the lightweight yet protective padding used in hockey gear, to using the instruction manual to look at biocomposites, and in particular, to how it applies to “hockey great” Bobby Orr’s knee replacements.

Discussion

The examples selected for use in the materials science laboratory kit convey a strong message of innovation and entrepreneurship. That is, the materials used were based on basic research and development (R&D) conducted in industry or in academia and was an *invention* that was

commercialized into a *product*. The laboratory kit itself is designed to improve the high school environment for developing innovative-thinking students who may be future engineers.

At the university level, however, there is limited knowledge about the development of entrepreneurial skills, innovation in engineering education, the identification of new venture opportunities in academia, and the development of technology-based small business enterprises. Beyond fragmented approaches, there is little theoretical basis for understanding and characterizing the people who become entrepreneurs, the organizations that cooperate, and the favorable conditions for engineering innovation. The existing research on individual and environmental determinants of entrepreneurship focuses on social and economic reasons, some of which can be compared with, or applied to, education, engineering and entrepreneurship throughout the province and at MUN. These reasons include employment opportunities, overcoming a sense of being marginalized by the majority of society, industry characteristics, and geographic setting¹. Figure 1 shows the interaction of key factors for entrepreneurial activity that this research supports. That is, “what are the individual characteristics that can be developed at the pre-university level, such as education, experience, interest in impacting society and a passion for life-long learning, which can be continued in university and cycled back into the community?”, for example.

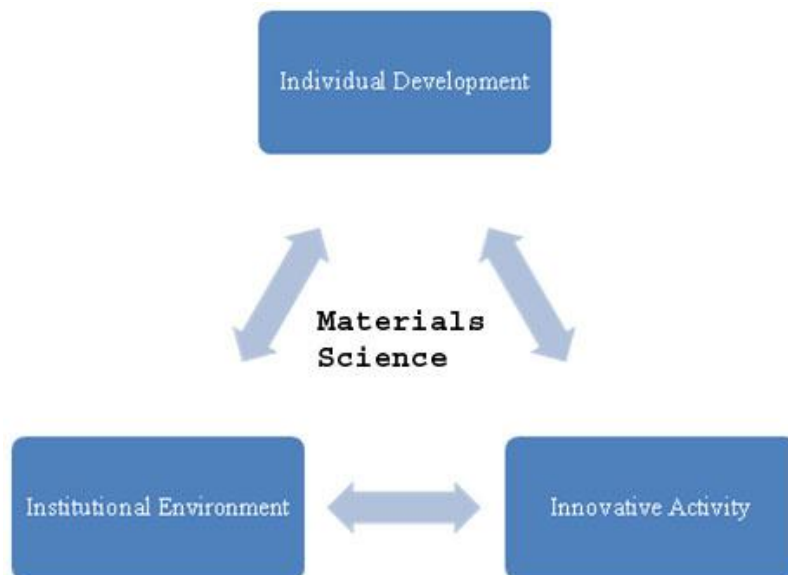


Figure 1: Integration of Community Outreach, Engineering Education, and Innovation using Materials Science

The emergence of the university technology transfer phenomenon, the evolution of the role of the university in provincial and national innovation systems, and the role of the university in economic development has caused a growth in research on the purpose, nature, and effects of university participation in community outreach, engineering education, and innovation. A literature survey identifies three categories for university-level entrepreneurship: *entrepreneurial university*, *academic entrepreneurship*, and *university technology transfer*, all of which position the university as a “locus of innovation”². The term “entrepreneurial university” was first coined

by Etzkowitz in 1998 to describe the case of MIT as the reference example and other universities that have proven critical to regional economic development.

While there is limited knowledge about the development of entrepreneurial skills, there is extensive research literature on the characteristics, information processing habits, and learning styles of engineers. Using Kolb's cycle of learning, the primary information processing styles of engineers are *abstract conceptualization* and *active experimentation*. That is, engineers tend to be what Kolb categorizes as "convergers", who like to consider practical application of ideas, enjoy solving puzzles and answering specific questions, believe in a "single right answer", are action- and design-oriented, and are prone to evaluate situations and thus ready to offer decisions and opinions³. While engineers may focus on these two primary learning styles, Kolb suggests that all four components are used for the most enhanced information processing experience; thus, *concrete experience* and *reflective observation* should also be included. The objectives of the laboratory kit developed as a result of this research attempted to incorporate all four learning styles such that science teachers and students can experience a concrete classroom activity that is experimental in nature, reflect upon the activity individually and collectively, and develop an understanding of how scientific concepts make the link with engineering applications.

Conclusion

This research focused on using the insights, perspectives, and abilities of science teachers in grades 9-12 in Newfoundland and Labrador to develop practical improvements to how Engineering is communicated to high school students through their science curriculum. A product of this research is the "portable lab kit", which uses materials science to introduce users to the various engineered materials used in applications in areas of interest to not only the province, but to students in general. This research illustrates the process of innovation and its key components: individual development and positive institutional environments leading to innovative or entrepreneurial activity.

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