

High-Impact Engineering Education: Using the LTI to Influence Knowledge and Skills for Sustainable Economy

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Structured Abstract

BACKGROUND

Australia needs more creative graduates. Over the past decade, the Australian economy has become increasingly dependent on the mining and goods/services sectors. Growth in these areas has largely been at the expense of the manufacturing sector, which was previously the largest sector in the economy. The country's education system has also progressed disproportionately towards the dominant service sector, mostly at the expense of a progressively-designed, innovative Engineering education system. Traditional Engineering curriculum has inappropriately progressed towards abstractness, rather than the necessary interactive, integrated experience based on practical learning. There is a need to re-evaluate the current educational infrastructure to ensure that emerging professionals are equipped to function and excel in both service and manufacturing capacities.

PURPOSE

This project specifically seeks to identify high-impact practices for working with secondary and tertiary students to implement the proposed "Learn-To-Invent" (LTI) methodology to stimulate the higher-order thinking needed to participate as creative inventors of the future.

DESIGN/METHOD

There is a need to re-evaluate the current educational infrastructure to ensure that emerging professionals are equipped to function and excel in both service and manufacturing capacities. This project of Learn-to-Invent (LTI) will investigate the factors contributing to quality educational experiences that lead to the development of the higher-order thinking skills needed in the field of creative engineering. Methodology used to analyse the current educational infrastructures and environments at the secondary and tertiary levels will include data collocation of basic engineering experiential examples in a document, literature review and interviews, with an emphasis on identifying learners' experiences with problem solving, learning curve progress from practice to theory by application of experiential and hands on-practice examples, learning by repetition of basic tertiary complex ideas and theories at different academic and research levels, and mentoring and promoting specifically identified talents and preferences.

RESULTS

LTI applications to two secondary school projects are discussed. USQ is in the process of implanting the method to some secondary schools in Queensland with the results to be published in a book. Although the proposed method of LTI is not conceptually new, it has been practiced in various forms and formats at the best and highly ranked schools across the globe. It has proved its success most specifically in traditional experiential and expeditionary schools learning self-inspiration, confidence, motivation, engagement, hard work and persistence leading to creation and invention.

CONCLUSIONS

By raising motivation, enthusiasm, passion, encouragement and proactive constructive-competition, LTI learners are directed to promote their imaginations and capabilities beyond the particular learnt experience. The model offers a generic, layered education system to inspire and train future potential and capable students to direct their creative ideas and learn to fulfil and achieve their inventions.

KEYWORDS

Higher-Order Thinking, Curriculum Alignment, Innovative Pedagogy, High-Impact Practices, From Practice to Theory, Problem-Solving, Experiential Learning

Introduction

At 68% of the GDP, the Australian economy is heavily influenced by its service sector depending substantially on the mining and agricultural products mainly shipped to East Asia. Nearly 20% of Australian GDP is contributed by mining and mining related sectors, of which 10% comes from mining and 9% from mining related industries (Colebatch, 2012; DFAT, 2011-14). Over the past decade, the Australian economy has become increasingly dependent on the mining and goods/service sectors. Growth in these areas has largely been at the expense of the manufacturing sector, which was previously the largest sector in the economy. For decades mining and mineral processing have significantly been contributing to the Australian economy. However, the mining investment boom seems to be over, as indicated by a significant drop (17.8%) in capital expenditure/investment in the mining industry, buildings and structures, equipment, plant and machinery and manufacturing in the past year (Jericho, 2014). The country's education system has also progressed disproportionately towards the dominant service sector, mostly at the expense of a progressively-designed, innovative engineering education system. Traditional Engineering curriculum has tended to progress towards abstractness, rather than the necessary interactive, integrated experience and practice required to stimulate creative thought. Even though service industries (from retailing to finance) are expected to grow by investing more than 10%, the proportion of employed young Australians has declined significantly in the past two decades where only 57.4% of young people have jobs (Uren, 2014). Many of Australia's car production factories are shutting down. The crisis started with Mitsubishi shutting down in 2008, followed by final closure decisions for Ford in 2016, and both Holden and Toyota in 2017. These car manufacturers together could hardly produce a minimum of 250,000 vehicles per year – the minimum threshold number normally required to be internationally and economically competitive and functional (Dowling, 2014).

One important factor contributing to the current technology and job crisis is the lack of innovative experiential education opportunities in secondary and tertiary schools. Teaching based on sparse, specific, abstract ideas without any intentional and integrated practical experience has no ground for producing inventive and creative engineers of the future (Dewey, 1938; Kolb, 1984). The result of these practices is an overwhelming interest from students and their supporting educational communities towards pursuing studies in business, commerce and other service sectors in preference to creative engineering and manufacturing industries. Therefore, there is a need to re-evaluate the current educational infrastructure to ensure that emerging professionals are equipped to function and excel in both service and manufacturing capacities. The decline of the manufacturing sector has had significant economic and quality impacts on the global competitiveness of our education system. Special infrastructure, education and training are required to implement the culture and notion of "adding values" to Australia's manufacturing, mining, and mineral sectors. Mines are the source of all the metals purchased for buildings, cars, airplanes, household products and other electronic/electro-mechanic equipment and devices. While Australia sells its precious raw mining and mineral material extracts to the world, normally at an inexpensive basic price, it has to re-purchase them at more expensive and much higher price (many folds) in the form of manufactured and processed goods and products.

The purpose of this paper is to discuss and highlight the strategic policies, infrastructures, facilities, curriculum, research and training programs and plans that are needed to reverse this unstable and unsustainable trend. Without a strong manufacturing sector, the country's economy becomes based on mere service dominated by abstract engineering education. Such focus is highly vulnerable and unsustainable due to inherent uncertainties and instabilities involved in service segments. The question is: how can the Australian economy be helped to recover to its expected internationally competitive level through the educational preparation of future engineers? Specifically, this project seeks to identify high-impact practices for working with secondary and tertiary students to stimulate the higher-order thinking processes that will allow them to thrive as creative inventors of the future.

Characteristics

Inventors are not created overnight. It takes a long time and process to develop the required characteristics and environment for a child to flourish. The most important factor is providing them with a stimulating environment that encourages self-thinking, self-esteem and self-experience, as well as giving them exposure to abundant opportunities as they grow up with their own dreams, interests and imaginations (Kolb, 1984; Challoner, 2010). However, the spectrum of learning pedagogy and education satisfaction is very wide and not equal for everybody. Some students may prefer the same abstract traditional model of education while many others do not. Learners are all different and therefore have different needs. There is no single model that fits all learners or all educational cultures and attitudes (Dewey, 1938; Kolb, 1984). Of course, not all learners will become inventors, nor do most of them have the desire to do so. The question is what will be the most appropriate, optimum, flexible curriculum that addresses the needs of all learners, including the frequently neglected future inventors (Challoner, 2010). It is this adaptive pedagogy and environment that we are focussing and ultimately seeking to incorporate into the education of our children (Dewey, 1938; Kolb, 1984; Proudman, 1995).

Majority of creative students seem to grow better in an unforced, unstressed, natural, rich, experiential, competitive, experimental, pedagogical and enjoyable environment. Curious minds seem to prefer freer, more stimulating environments outside their schools (compared with the dry formality inherent in the traditional schooling). Their self-thinking and self-derivation should be encouraged, with the teacher providing them with a path to explore, rather than dry, possibly inaccurate answers (Handbook of principles of learning and teaching, 2012; Challoner, 2010).

It is not surprising to see that a great number of well-known, gifted, eccentric researchers and inventors did not fit into their formal educational classes in their school. These are normally the common characteristics/traits amongst most inventors (Challoner, 2010):

- a) Highly practical – normally hands-on-practical people with lots of enthusiasm for experiential learning;
- b) Fearless of failure – failure is not an option or plan B for them;
- c) Confident, persuasive, energetic and tireless – never lose their focus and concentration;
- d) Persistent – never give-up and love to solve problems one after another;
- e) Curious and competitive - inquisitive mind and sceptical about all contemporary ideas, willing to challenge even the most authoritative mentors with their ideas and self-confidence;
- f) Incredibly knowledgeable in their field – explore all possibilities and are the first to know which ways and methods don't work!
- g) High achievers and highly ambitious – passionate and eager to climb the ladder to success;
- h) Visionary with big dreams - want to shake things up and explore and develop their own theories.

Examples of pioneer role models are abundant. The list is exhaustive: from Leonardo da Vinci - who demonstrated all of these characteristics at the highest possible levels, and was also a fine painter, sculptor, architect, musician, mathematician, engineer, scientist, anatomist, geologist, cartographer, botanist, and writer - to Yaya Lu, 16, a high-school student from Hobart, Australia, who set her mind on helping people with disabilities by inventing a fully voice-controlled new wheelchair technology. Australia, like other countries around the globe, needs more inventors. As masterminds of their time, such creative people change the world and contribute significantly to its history.

Experiential Learning Model (ELM)

The Learn to Invent (LTI) model discussed here is based on learning from learners' own self-experience, and building more complex layers on top of that via repetition, constructive-competition and further mental stimulation.

The philosopher Aristotle once said: "For the things we have to learn before we can do them, we learn by doing them" (Bynum and Porter, 2005, p.21.9). Kolb (1986) expanded this basic idea and contributed substantially to the understanding and implementation of the field of "*experiential education*" where learning occurs and materialises through an individual's own experience.

Kolb's model states that knowledge is gained continuously through personal and environmental experience, and for a learner, genuine and sustainable knowledge requires certain abilities and capabilities; particularly the learner should (Dewey, 1938; Proudman, 1995):

- be motivated or willing to be actively involved in the experience;
- be able or motivated to reflect on the experience;
- possess and use analytical skills to conceptualize the experience; and
- make logical decisions and develop problem solving skills.

A good example of a real-world application of Kolb's model is the experiential learning involved in learning how to ride a bike (Kraft, 1994). There are four distinct steps in the experiential learning model (ELM) of Kolb: The first stage is the "*concrete experience*" (CE) where the learner physically experiences the bike in its real time and place. The second stage is the "*reflective observation*" (RO) of what happened in stage one. In this stage the learner has the opportunity to consider what is working or failing (reflective observation). In the third stage the learner naturally thinks about ways to improve on the next riding attempt, i.e. "*abstract conceptualization*" (AC). "*Active experimentation*" (AE) is the result in the fourth stage, where every new attempt is informed by a cyclical pattern of previous experience, thought and reflection (See Figure 1).

<i>concrete experience</i> (CE)	the learner physically experiences the bike in its real time and place.
<i>reflective observation</i> (RO)	the learner has the opportunity to consider what is working or failing
<i>abstract conceptualization</i> (AC)	the learner naturally thinks about ways to improve on the next riding attempt
<i>Active experimentation</i> (AE)	every new attempt is informed by a cyclical pattern of previous experience, thought and reflection.

Figure 1 – Example application of Kolb's experiential learning model (Kraft, 1994)

LTI Model

Not every student in a class is predisposed to being an inventor; however, there are many adults whose creativity and talents have never been explored, discovered or nurtured during their secondary school studies, possibly resulting in a stagnation or death of those traits. As an essential component, the experiential learning (ELM) model explained above is the first step and foundation layer for nurturing our future creative students and inventors.

Past experience affects present experience influencing future experience, according to Dewey (1938) who proposed experiences based on continuity, interactions and intellectual purposes are high above traditional, abstract education. "The principle of continuity of experience means that every experience both takes up something from those which have gone before and modifies in some way the quality of those which come after" (Dewey, 1938, p.27). Most successful learners and inventors believe that their true learning and understanding of creative concepts and ideas would not have happened if they did not have a real physical or mental experience. However, experience alone does not necessarily lead to learning. To fulfil the learning cycle, an *experience* has to be carried out and deeply explored first, then *contemplated*, analysed and reviewed by reflection followed by *conceptualisation* and application where the learners will deepen and broaden their understanding of the concept or theory

by cementing their experience through *generalisation* (Enfield, 2001; Kolb, 1984; Pfeiffer & Jones, 1981; Carlson & Maxa, 1998).

Recurring cycle, or repetition, and constructive competition play major roles in the LTI model (Kolb, 1984). As a result of the cyclic reflection and application phases and levels, the seed concepts, hypotheses, theories and experiments are constantly improved, deepened and climbed up through the ladder and layers of complexity, rigour and diverse applications.

Implementing LTI (based on ELM) into school curriculum could be very expensive and very few schools may be able to afford the required cost for a sustained long term period. As an example, the "Dawson School in Boulder, Colorado in the US" (<http://www.dawsonschool.org/>), allocates only two weeks of each school year to experiential learning, during which students visit surrounding states to engage in community service, visit museums and scientific institutions, and engage in activities such as mountain biking, backpacking, and canoeing. On the other hand, the LTI proposes a cultural shift in the educational system as a whole by embedding its philosophy throughout the entire curriculum, thereby distributing the investment over the school year, rather than investing in an isolated project.

LTI has to be continual, sustainable, and enhanced further to be more generic and proactive to promote learners' imaginations and capabilities beyond the particular specific experiences learnt in the conventional EL methods. The curriculum objective in LTI model is not only to train and educate for the desired student learning outcomes in a specific content area, but also the best creators and inventors of the future. This model has not yet officially been implemented and requires revolutionised planning, design and articulations for its adaptation to current approaches and curricula. To train such ideal future inventors requires the invention of new experiential tracks in school systems that are focused on creative thinking. As some key features of the proposed LTI model, in addition to their formal academic curriculum content, the following ideas and features are worth considering for implementation into the current primary and secondary school curricula:

1. Engage in more physical activities and methods of solution, rather than sitting for long hours in a sedentary fashion, thus aggravating modern age undesirable and unhealthy habits.
2. Reapply and implement relevant historical successful engineering experiences.
3. Develop an interactive step-by-step problem solving approach with diverse applications.
4. Help students develop their own thoughtful creative innovative imaginations, mathematical-experimental modelling methodologies.
5. Provide plenty of practical examples and have learners generate other examples. (Having good, experienced professional teachers-coaches are essential and crucial here)
6. Raise motivation, enthusiasm, passion, and encouragement by doing what?

To successfully implement the above ideas, educators will certainly want to better understand their rationale and relevance to specific content areas. To this end, the following suggestions are made. Educators should:

1. Apply the model to teach formal school materials and solve formal course content problems.
2. Promote self-motivation, imagination and curiosity on materials outside the traditional school curriculum through a variety of methods.
3. Collect their own self-problems in documents for permanent record and future access— add improvements, new methods and levels of solutions, new ideas and ways thing might work better, i.e. engage in learners' self-reflection, outcomes, and areas of potential improvement of own practice.
4. Strive to develop their own problem-solving skills by creatively addressing day-to-day issues in unique ways.
5. Modifying or expanding previously solved problems and participating in professional dialogue with others desiring to develop these skills.
6. List and formulate unsolved ideas and problems with their potential methods, resources and ways on how to tackle, solve or possibly invent them and discuss these ideas with others in formal or informal brainstorming sessions.

Discussion

The LTI model has been applied to a few cases at the secondary school level in Australia, and two examples are briefly discussed below. One case addresses "*Beam theory*" in engineering mechanics for year 10 high school student, and the other involves "*Schrödinger's equation*" of quantum

mechanics for year 11 high school student. According to the proposed LTI model, both of these two problems can be introduced lightly in primary school and formally taught in high school, in an engaging way and with enhanced learning outcomes expected. Going through the same four steps of the EL model, students need to have a *concrete experience* (CE) first followed by *reflective observation* (RO), *abstract conceptualization* (AC) and finally *active experimentation* (AE) stages of the model, as part of their required course pedagogy for the assigned exercise. Each student was directed and encouraged to select one of these two topics as part of their research project assignments. The question was whether these two students were able to complete their tasks successfully, despite these challenging assignments.

The success index was defined by determining the degree that a student completed the task and gained the required knowledge and problem solving skill after completing the task. Furthermore, the exposure of hidden talents and learning preferences of each student was followed to determine if the approach influenced their emergence. While the sample size was very small, initial results indicate that the LTI model was an appropriate model for not only preparing average high school students for such challenging tasks, but also to shed light on their talents, likes, dislikes, preferences and capabilities. In addition, the approach informed teachers whether a student's natural orientation is primarily theoretical, practical, or a combination of both.

Beam theory: As part of an important prerequisite course in most engineering disciplines, engineering students are formally taught beam and elasticity theories in university second year, in their strength of materials course. The concrete experience (CE) part of the LTI model can begin to crystallise through physical introduction to a *deformable push bar*. The student was encouraged to both enjoy the exercise and also ponder the bar deformation that he could observe occurring due to his weight as an applied gravity force. The student was allowed to try different positions on the bar grip (change of bar length), different bar sizes (change of bar diameter), different bar materials (steel, timber, aluminium, plastic) and different weights resulting in different amount of bar deflection. After the fun part of the exercise, the student was encouraged to talk and explain if he could feel any difference in the bar deflection by changing such variables or parameters as weight, length and diameter during the experiment. Then he was asked to ponder any trends or relationships between them. He was then asked if he could design a method of measuring the variables or parameters of the experiment and graph them in different forms. Once the student drew all the possible graphs, he was asked if he could establish some basic functional relationships from these graphs. It was only after this stage that the mathematical approach for general bar deflection prediction was introduced. This skill is generally one where university students struggle due to the difficulties in comprehending the abstract math involved without any connection to the real world practice. Allowing students to experience this disequilibrium in their thinking is one of the most important pedagogical situations normally neglected in classrooms today. However, as expected, the student passed this stage quite comfortably and successfully due to the experimental background and the passion, motivation and satisfaction after observing the perfect match of the theory and practice. He could then successfully discuss the meaning of the full experiments, the parameters involved, and the theory and math behind the exercise. In addition, he could easily answer basic questions such as: Why does the bar deform? What is the cause of deformation? Is there a relationship between the force and deformation in the bar? How do all these relate to the material property of the bar? Can these variables be measured in a test or formulated in a mathematical equation? What are the effects of bar thickness, material, length and pulling force?

Schrödinger equation: The initial student's preference and interest in math was used to encourage her towards this project. The student's objective here was defined to enable her to completely understand the use of the equation, comprehend its mathematical parameters and variables and be able to derive it, produce graphs of its behaviour, and finally be able to apply it to problems in quantum mechanics in Physics. Unlike the beam theory exercise, the pedagogical process for this example problem was much more challenging, as there was no physical exercise planned or designed for the quantum mechanics parts. Instead, the practical exercise started with a classical mechanics problem exploring more familiar concepts of *momentum*, *kinetic* and *potential energies* at the high school level – where the student was familiar through her high school courses. The pedagogical path was a bridge between classical mechanics and quantum mechanics on these basic concepts and how to go from one side of the bridge (familiar classical mechanics) to the other (unknown quantum mechanics). Again, the results were highly successful and the student is now working on a more challenging research project in quantum mechanics

Conclusion

The need to stimulate creativity in emerging professionals is imperative for economic stability. The LTI model is being presented here as an approach that can be utilised to foster and encourage such creativity, with the goal of increasing innovative professional decisions throughout the engineering field. While currently in its early stages, this project seeks to eventually:

- identify strategic policies and infrastructures that will foster creativity and higher-order thinking skills in secondary and tertiary students in an effort to promote national economic growth and recovery in the areas of industrial manufacturing, engineering, science and technology; and
- develop and align novel, non-abstract pedagogical methods of learning and teaching across Australian schools and universities, emphasizing curriculum, research and training programs in all subjects, particularly Math, Science and Engineering.

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