Entrepreneurially Minded Learning & Fluid Intelligence Building in Community College Pre- engineering Calculus Physics Pedagogy

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Abstract
The importance of including Entrepreneurially Minded Learning in an engineering curriculum cannot be overemphasized, according to The Kern Family Foundation. Currently most public engineering schools lack the funding to include Entrepreneurially Minded Learning, according to the results of our web search using the Goggle Search Engine. The contrast of entrepreneurially versus tradition engineering has been highlighted in a Kern Entrepreneurial Engineering Network (KEEN) video, which emphasizes the understanding of the customer need, market dynamics, societal trends, and technical feasibility. A vital element of technical feasibility could be built with fluid intelligence physics problem solving ability early on during pre-engineering years in a community college; and the client-contractor simulation could be used to enhance Entrepreneurially Minded Learning. The pedagogy includes fluid intelligence building exercises supported by neuroscience data, together with traditional multitasking physics computer simulation and ranking exercises. The retrieval-induced forgetting frequency discovered in neuroscience has been observed to be reduced with reward such as snack allowance before class and instructor guided flip classroom exercise, consistent with neuroscience data. Relational learning in the theory of cognition has been found to be effective to increase fluid intelligence as reflected in technical feasibility test performance. When a potential client-professor explains a needed job/project to a contractor-student, the using of pictures and graphs with fewer verbal wordings for less memory loading has been found to be valuable. The student performance on the client- contractor simulation has been assessed as good for those students showing interest. Student feedback includes observed non-participation, indifference, and enthusiastic attitude variations, which bear similarity to grade histogram. Examples of student entrepreneurial physics based projects in space weather forecast, mobile-Health, solar energy in terms of enhancing Entrepreneurially Minded Learning are discussed.

I. Introduction

The Kern Family Foundation has initiated a university network called Kern Entrepreneurial Engineering Network (KEEN) to promote the idea of entrepreneurship learning. Multiple grants have been awarded to curriculums across the country to teach the engineering students about Entrepreneurially Minded Learning and assess the learning outcomes. The contrast of entrepreneurially versus tradition engineering has been highlighted in a Kern Entrepreneurial Engineering Network (KEEN) video. The video emphasizes the understanding of the customer need, market dynamics, societal trends, and technical feasibility. Currently most public engineering schools do not include Entrepreneurially Minded Learning, according to the results of our web search using the Goggle and Yahoo Search Engines. This non-availability may be due to a lack of funding. In order to offer some level of entrepreneurship training in a public college environment, we have incorporated the teaching of technical feasibility in terms of fluid intelligence in the science of learning. Fluid intelligence has been accepted as the ability to think logically and solve problems without the need of task-specific knowledge or experience learned in the past [1]. The role of physics department in a community college can be interpreted as a universal donor to all engineering departments in terms of student transfer. The learning of physics problem solving in terms of fluid intelligence is an effective tool to strengthen the foundation for technical flexibility to solve problems not learned before. And without fluid intelligence, a student would not even be interested in new horizons such as Entrepreneurially Minded Learning.

It is important to understand the role of memory in learning when implementing a new pedagogy. Memory and learning are intricately related as revealed by psychology and neuroscience. The striatum and hippocampus are considered to be complementary learning and memory systems, with the hippocampus specialized for fact-based episodic memory and the striatum for procedural learning and memory [2]. Recent advances have shed light on the student attitude response in terms of classroom learning. It has been known for quite some time that separable neural circuits are responsible for declarative memory (long term memory) versus habitual or procedural learning (unconscious memories such as skills (e.g. learning to ride a bicycle) [3]. Basically, the declarative memory relies on a medial temporal lobe system with the hippocampus, whereas habit learning relies on the striatum. In 2006, a report showed that the medial temporal lobe system is active in single-task learning, but the striatum would be activated with dual-task learning [4]. A NEA Higher Education Journal article in 2008 by Charles J. Abaté (professor of electrical and computer engineering technology at Onondaga Community College New York) summarized the learning situation as follows [5].

"When I use the term "multitasking," I refer to an attempt by individuals to engage in several tasks in rapid linear succession (rather than simultaneously) where at least one of the tasks is a conceptual learning activity……Thus, when a person is distracted, habitual learning actually takes over from declarative learning. In this sense, the two types of learning appear to compete with each other. And because procedural learning is more limited in applicability than declarative learning, it is "inferior" learning, to the extent that it is less capable of being manipulated, organized, and applied to new and unfamiliar situations than declarative learning. In short, multitasking actually changes the manner in which people learn and retain information. Given the results of this experiment, one can conclude that learning stored in different areas of the brain may well foretell serious limitations on the overall usefulness and future applicability of the stored information. Is it any wonder that professors increasingly bemoan students' inability to analyze and synthesize information, despite the wealth of information available to them?"

The traditional multitasking physics computer simulation approach has been used at least for 15 years and the PhET simulations from University of Colorado can serve as a good source nowadays [6, 7]. The ranking task exercises are also being taught as well. Book materials such as "Ranking Task Exercises in Physics" published in 2000 can serve as a solid platform for tasking training [8]. Using psychology cognitive process theory to model the student learning of physics was also published by Redish in 2003 [9].

The hippocampus-based "declarative" and striatum-based "procedural" memory systems have been further investigated in terms of stress. In 2012, researchers showed that "Stress impaired the hippocampus-dependent system and allowed the striatum to control behavior [10]. The shift toward "procedural" learning after stress appears to rescue task performance, whereas attempts to engage the "declarative" system disrupt performance." The finding points to another scenario that under stress, the procedural learning process would be preferred over the declarative system, and sadly the fluid intelligence problem solving techniques taught by a professor would be learned by students as a procedural learning in multitasking.

II. Technical Feasibility Pedagogy

The technical feasibility pedagogy focuses on fluid intelligence building exercises. Numerous neuro- scientific tools have been used to test the level of fluid intelligence. Yuan et al (2006) reported that correlational studies supported a close relationship between working memory and measures of fluid intelligence, and they recommend a decrease of cognitive load as a teaching method to improve fluid intelligence and science achievement [11]. Riding on the cognitive load theory, Stocia et al (2011) reported that the use of an interactive whiteboard would be excellent in teaching the use of physics concepts to guide problem solving beyond memorizing and calculating activities [12]. These earlier results on the science of learning were based on psychology tests. She et al (2012) collected electroencephalographic EEG data when students were solving optics problem, and they reported increased power in all the studied frequency bands when the task demands and task performance increased [13]. The EEG data collected by Lai et al (2012) also supports the advantage of encoding physics concepts with pictures as compared to words [14]. In any event, it is recommended that a physics instructor should select low cognitive load lexical-semantic sentences to facilitate conceptual gain with the enhancement of fluid intelligence.

The effect of high verse average fluid intelligence ability on the usage of brain oxygen as revealed by fMRI was reported [15]. Grade-11 students having fluid intelligence IQ RAMP score > 115 (N = 22) was compared to those having scores between 85 and 115 (N = 19) in a geometric analogies task at different difficult levels. The levels consist of having the identity condition as the easiest, followed by vertical mirroring, horizontal mirroring, mirroring on the diagonal tilted left, and mirroring on the diagonal tilted right as the hardest. Participants received extensive training on the task 4 weeks prior to the experimental session. The experimental session finished with an anatomical scan of the brain using fMRI. The data showed a negative brain activation–intelligence relationship in frontal brain regions in the high fluid intelligence group, in contrary to the average fluid intelligence IQ group. The study concluded that better behavioral performance in the geometric analogies task would reflect a lower demand for executive monitoring in the high fluid intelligence IQ individuals. The study also concluded that flexibly modulating the extent of regional cerebral activity, as revealed in detailed anatomical fMRI data, is characteristic for the presence of fluid intelligence. The study design was based on the accepted fact that analogical reasoning is necessary for organizing new knowledge and generating insights. The report also cited other studies that linked high analogical reasoning ability to fluid intelligence.

Analogical reasoning of metaphorical relations has been investigated actively ever since the structure-mapping theory was initialized by Gentner [16, 17]. The attributive metaphor and relational metaphor relationship investigation, using 600 double-character Chinese noun words, showed that relational metaphor relationship exercise would involve more integration processing as evidenced from EEG data. Attributive metaphor examples include "A cloud is like a marshmallow", "A football is like an egg", etc. One the other hand, relational metaphor examples include "A cloud is like a sponge", "A ladder is like a hill", etc. Relational metaphor is important in physics learning. Corral et al 2014 proposed that coherency would be an extra requirement in the theory relational learning especially for second-order and higher-order relational learning[18]. The physics statement, "A planet revolves around the Sun", would be a first order relation with a notation of revolve (planet, sun). The phrase "Gravity causes the planet to revolve around the Sun" would be a second-order relation with a notation of cause (gravity, revolve (planet, sun)). The causality is backed up with the coherency within the Newton's laws of motion.

Given the neuroscience findings, we had implemented the following modifications in our lesson delivery. Vector addition concept is a coherent tool in many physics topics. Examples such as "Boat crossing river was off-course because of current pushing" as in cause (current pushing, crossing off course (boat, river)), "Gravity causes object to slide down rough ramp" as in cause (gravity, slides (object, rough ramp)) have been difficult for student learning when vector addition exercises are multitasking instead of fluid intelligence focused.

Third-order relational learning with 7 concepts in notation G (F, E (D, C, (B, A))) is a common feature when it involves the difference of the outcomes of two second-order relational processes. A bat and prey example in Doppler shift learning would be represented as beat frequency (original frequency of bat, shifted frequency received by bat (echo-reflection, shifted frequency received by prey (original frequency of moving bat, moving prey))). An engineering thermodynamics example in the understanding of Steam Tables would be represented as average internal energy increase (higher pressure, average internal energy (temperature, phase description (pressure, mixture quality))). On the other hand, a collision example represented as stop distance (surface friction, wreckage speed (momentum conservation, wreckage (car-A, car-B))) would involve another principle other than just taking the difference of two second-order relational processes.

The psychology paper by Corral et al 2014 used the word revolve but physics acceleration at college level will infer a high degree of coherency among all acceleration phenomena. In fact, the explanation could use a third-order relational process. The concepts could be expressed as cause (planet high speed, universal attraction law (gravity, acceleration (planet, sun))), and it describes the centripetal acceleration requirement of high speed that would be needed to balance out the gravity pulling arising from Newton's universal attraction law. Without the high speed condition, a planet would simply fall into the massive Sun. The Corral et al 2014 second-order relational process example of an electron going around a nucleus could be expressed as a fourth-order relational process to capture the essence of quantum mechanics in introductory modern physics. The 9 concepts in the Bohr atom model could be expressed as cause (momentum quantization, radius (electron high speed, coulomb attraction (opposite polarity, acceleration (electron, nucleus)))). Explicitly asking a student to express his/her reasoning in an ordered relational process has been found to promote learning. Relational learning including higher-order examples in the theory of cognition have been found to be effective to increase fluid intelligence as reflected in technical feasibility test performance.

Last but not the least, a stress reduction technique in STEM class has been used with the following rationale. The assertion that striatum based multitasking switching in a developing mind would simulate parts of the brain associated with pleasure is consistent with the MIT Department of Brain and Cognitive Sciences finding that effects of dopamine depletion in striatum as recorded in local field potential oscillations are learning-dependent in a mouse model [19]. We are not suggesting L-DOPA therapy for students although Lemaire et al found evidence that the standard Parkinson's Disease therapy of L-DOPA had normalized the oscillations. Parallel to Dr Deak's suggestion in her forthcoming book, Neuroscience Literacy and Practice for Teachers [20], our pedagogy includes asking for student output after a 20-min teaching, as a strategy to release lesson stress. The retrieval-induced forgetting frequency has been observed to be reduced with reward such as snack allowance before class and instructor guided flip classroom exercise, consistent with neuroscience data. The explanation of retrieval-induced forgetting psychology has been found to be important to encourage students to do homework assignments.

Test questions have been designed with a technical feasibility as focus. For example a standard question of a ramp with a sliding mass, a massive pulley and a vertically hanging mass can be asked in the following manner. A parent would need to go away for a few days to hunt for food and a ramp was built for children to get water from a well without the danger of falling over the edge. The design called for a calculation such that a child would only need to control the number of blocks as the sliding mass, and be far away from the well edge. Such technical feasibility focused test questions have been found to be useful to direct the students to the entrepreneurship mindset in terms of a contractor building that ramp, and humanitarian aspect of engineering in terms of helping children.

III. Entrepreneurship Training Pedagogy

When a potential client-professor explains a needed job/project to a contractor-student, the using of pictures and graphs with fewer verbal wordings for less memory loading has been found to be valuable. Student physics based projects in space weather forecast, mobile-Health, and solar energy have been used as client- contractor examples. These client- contractor projects are based on the student understanding of the corresponding research projects. The student performance on the client- contractor simulation has been assessed as good (> 85%) for those students showing interest. The client- contractor simulation rubric is displayed in Figure 1.

Participant Deliverable	Highly Competent	Competent	Needs Improvement
Customer needs (15%)	Summarizes the needs of the client clearly and concisely with graphs and pictures	Summarizes the needs of the client with clear explanation without graphs and pictures	Summarizes the needs of the client approximately and adds what would be a convenient task for the company
Market dynamics (5%)	Illustrates the market dynamics with two examples	Illustrates the market dynamics with one example	Mentions the market dynamics without any example
Societal trends (5%)	Discusses societal trends with the client and cites two reference sources	Discusses societal trends with the client and cites one reference source	Discusses societal trends with the client and cites no reference source
Technical feasibility explanation (65%)	Summarizes the technical feasibility in meeting the needs of the client clearly and concisely with graphs and pictures, and increases the confidence level of the client	Summarizes the technical feasibility in meeting the needs of the client clearly and over-indulges in graphical explanation	Summarizes the technical feasibility in meeting the needs of the client with textbook equations only without numerical values.
Timeline & Billing explanation (10%)	Summaries the timeline clearly and provides explanation for each billing item	Summaries the timeline clearly and provides explanation for only a subset of the billing items	Summaries the timeline clearly without any billing explanation

Figure 1: The client- contractor simulation assessment rubric with the participant being the student. Scoring could be performed when assigning Highly Competent = 1, Competent = 0.8 and Needs Improvement = 0.6.

The student space weather research project would include the studies on the coronal mass ejection kinetics and the solar magnetic reconnection driven eruption mechanism. The details were published in the 2014 ASEE Conference Proceedings [21]. The client- contractor aspect has been designed with a client representing an electrical power plant having the need to know a solar eruption in advance and a student as a contractor to provide the space weather forecasting service. A student- contractor would need to persuade the power plant owner- client on the technical feasibility of each of the available forecasting tools.

The student mobile-Health research project has two components. They are the photon diffusion measurement using a LED light source and cell phone camera, and the iris response upon sudden change of illumination. The details were published in the 2014 ASEE Conference Proceedings [22]. The client- contractor aspect has been designed with a client representing a mobile medical unit having the need to measure tissue/nerve responses and a student as a contractor to provide a mobile-Health measuring platform. A student contractor would need to present the technology at a general level and also be mindful about the manufacturing cost.

The student solar energy research project focuses on solar power fluctuation driven by fast cloud transits and battery storage research as an extension of a collaboration effort between our faculty and Brookhaven National Lab scientists [23]. The client- contractor aspect has been designed with a client representing a homeowner having the need to store solar energy during cloud transits and a student as a contractor to design a protective storage system. A student as a contractor or consultant would need to understand the effect of power fluctuation and determine the criticality of each of the affected devices as defined by the client in order to come up with the optimum protective storage system, consistent with the available budget.

IV. Discussion

A rote learning exercise is a procedural learning process and with sufficient unused working memory, a spontaneous mind-wander would start to kick in [24, 25]. A conscious modification of information already acquired during the procedural learning in a rational manner would constitute the beginning of fluid intelligence building. Repeated experience would boost the confidence level. The crystallized facts/information and fluid intelligence confidence would lead to crystallized intelligence [26]. This learning model has been tested by us. First the meaning of procedural learning was explained to the class with a very simple example. Then we showed the students the implementation in physics learning.

We reminded the students with procedural learning of fact in terms of 5 + 7 = 12 in kindergarten learning with unit in apples, unit in oranges, and two units in fingers/toes. Such exercises would get easier with practice and clear fact would emerge with the mind having unused working memory. When a mind has unused working memory, spontaneous cognition and mind-wander would start. Subsequent rational modification of facts such as 4 + 7 = 11 and 5 + 8 = 13 would follow without actually doing the calculation using fingers and toes since 4 is less than 5 and 8 is more than 7. This is the process of fluid intelligence building with confidence. Then during a first grade picnic trip the fact that 5 cups of water + 7 cups of tea = 1 jar would happen. The high confidence level first grade student would think deeper and would conclude that 1 jar must have 12 cups of liquid or diluted tea. Such conclusion would be classified as a form of crystallized intelligence. We have found that the above primary school example offers a simple explanation to back up the rationale of the physics lesson delivery design aiming for learning technical feasibility with the building of fluid intelligence.

We have implemented algebra-based technology physics pedagogy that the entire semester of physics is taught within 7 weeks in terms of procedural learning, followed by fluid intelligence problem solving in the remaining 7 weeks. Our limited data set N = 25 showed that students performed better in the second physics course as if they had acquired better crystallized intelligence on the first physics course covering mechanics and thermodynamics. Whether this algebra based technology physics pedagogy with emphasis on procedure learning in the first half of a semester would apply to calculus based engineering physics is an interesting future project. A recent publication also supports the use of language skill in procedural learning. A study on inserting the human FoxP2 gene into mice found that the modified mice shown accelerated learning. The mice learned to master a procedural learning task of maze negotiation in 8 days instead of the usual 12 days [27]. The FOXP2 gene has been accepted as related to human language development. Relational learning as a language development process would trigger the FOXP2 pathway and reinforce general procedural learning ability. We plan to extend our 9-concept fourth-order relational learning, as discussed above, to topics other than the Bohr atom model.

The student performance on the client- contractor simulation had been assessed as satisfactory (> 75%) for the participated students. The rubric displayed in Figure 1 was followed. Student feedback includes observed non-participation, indifference, and enthusiastic attitude variations, which bear similarity to the grade histogram. The non-participation attitude could be attributed to a narrow mindset such as those focusing on taking the professional engineering exam as a first step in their Professional Engineer career pursuit. The indifference attitude could be attributed to shyness as well as the traditional rote learning academic experience. A recent 2014 study on academic performance of Grade-9 students showed that it is the fluid intelligence and the Grade-7 academic experience that are responsible for the Grade-9 performance, and that crystallized intelligence not only includes developed abilities and knowledge, but is also a reflection of fluid intelligence [26]. Although, as far as we know, there is no similar research reported for Grade-13/14 students, the contribution of fluid intelligence to crystallized intelligence in college learning should not be underestimated.

Even though the project complexity at a community college level would be inferior as compared to those available at the upper division of a senior college, the early exposure of technical feasibility issue and fluid intelligence training is still a reasonable endeavor to promote entrepreneurially minded learning. The learning of customer need, market dynamics, and societal trends perhaps can be emphasized in the general education courses within a pre-engineering curriculum. Encouraging students to join Student Cultural Club activity can help them to learn to communicate to non-technical individuals. A typical physics class setting can provide some guidance on web search when explaining a new physics discovery using web resources. Writing assignments such as “If Coulomb Law was discovered 50 years later than 1785, what would the society be like today?” can help pre- engineering students to think about societal trends.

Market dynamics awareness can be trained with some basic notions on web search and which databases are reliable. For example, MailOnLine has a news report March 5 2015 saying that “Scientists say toilet can be used to supply electricity in disaster zone” [28]. Sentences like “'Work by the Bristol BioEnergy Centre hit the headlines in 2013 when the team demonstrated that electricity generated by microbial fuel cell stacks could power a mobile phone.”, and “Prof

Ieropoulos (Bristol Robotics Laboratory at UWE Bristol) ,added: 'One microbial fuel cell costs about £1 ($1.5) to make, and we think that a small unit like the demo we have mocked up for this experiment could cost as little as £600 ($900) to set up, which is a significant bonus as this technology is in theory everlasting." are helpful to teach students about market dynamics along with the science.

V. Conclusions

The combination of technical feasibility focused lesson delivery and entrepreneurship training simulation has been found as an effective pedagogy to promote Entrepreneurially Minded Learning in a community college setting. The indifference attitude student group could be motivated with diverse physics based projects in addition to the current projects in space weather, mobile-Health and solar energy. The Entrepreneurially Minded Learning for the enthusiastic attitude student group could be enhanced in helping them to enter student contests such as the student competition offered by The American Association of Mechanical Engineers [29]. Future projects include the articulation with 4-yr engineering programs focusing on Entrepreneurially Minded Learning and the collection of physiology data such as EEG data to elucidate the building of fluid intelligence.

VI. Acknowledgements

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