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PAPER

An Active Learning Approach for Applying STEAMeD-Based Education in Engineering Programs

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ABSTRACT

Applying STEM-based education in engineering programs using various active learning approaches has been shown to improve the quality of the learning process. This paper investigates further enhancements to the existing techniques via adding more emphasis on the learning components that are specific to art, entrepreneurship, and design. Different opportunities to apply the STEAMeD-based education in various engineering programs, which are delivered by liberal arts institutions, will be explored. The integration of the new emphases is demonstrated to resonate very well with satisfying the seven students' outcomes that are dictated by ABET accreditation. The specific role of the augmented art component in promoting creativity, aesthetic appreciation, and better reasoning skills is illustrated via different examples of simulation-based experiments and virtual modeling techniques. The entrepreneurship component of the engineering curricula is shown to better prepare the students for the challenging future via empowering them with better analytical skills, practical ingenuity, business-oriented communications, and adaptability to technological innovation, in an efficient way. It also overlaps with the requirements of the graduation design project that all students consider as the capstone of their engineering curricula. Adopting a project-based learning approach in many courses, at different levels in the curricula, proved to be very efficient, as verified by the many case studies illustrated in this paper. Tying the attributes of the STEAMeD-based education to the courses' contents, with clear description of the learning outcomes, will be demonstrated. Also, addressing novel pedagogical approaches to better equip the students for their careers is considered. Finally, a comprehensive discussion and a conclusion are given to highlight possible extensions to the proposed techniques.

KEYWORDS

STEM/STEAM/STEAMD/STEAMeD-based education, active learning approach, engineering education, ABET accreditation, and liberal arts in engineering

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1 INTRODUCTION

Active learning (AL) is currently being adopted and promoted by many educational institutions. The fact that AL is a student-centered approach allows more engagement in the learning process/environment at both the individual and the collective levels. AL adopts strategies that allow the students to think critically and to generalize their knowledge via relying on project-based and research-based learning activities. AL is proved to prepare competitive students who are more capable of addressing real-world problems and can easily integrate themselves in both the society and the future labor market. In engineering education (EE), specifically, technology can be used to promote the interactive learning process via incorporating hands-on activities that are directly related to the learning outcomes. This increases the retention and understanding of disseminated knowledge, since instructors mainly perform as mentors, evaluating the progress of the students who are exerting most of the effort [1].

AL has been used as the main teaching method in EE to cope with the present developments in higher education. According to Lima et al. [2], more than 40% of the modern research in EE is related to applying AL, via utilization of different techniques. In addition, a wide range of AL practices was recommended by many professional engineering associations, such as the Accreditation Board of Engineering and Technology (ABET), where the student outcome (SO)#7 (#i in the previous a-k SOs) is perfectly mapped and assessed. Another study that was presented in [3] illustrated that the performance of the students who followed an AL technique was better than those who followed traditional lecturing. This comprehensive metanalysis study included 255 data sets that were collected from different US undergraduate programs, following the STEM-based education. Many workshops were conducted by several keynote speakers to assist engineering educators in applying the new ideas and techniques of AL [4]. These workshops provide deeper insight into the philosophical and pedagogical aspects of AL and motivate educators to apply engaging mechanisms in their classes, labs, and exhibits to improve the learning process. In addition, they open the doors for more research in the field of AL and blending EE with liberal arts that include social sciences and humanities.

Students' resistance to AL can result in creating pedagogical barriers, along with other negative effects, that can lessen the engagement nature of the learning process. A comprehensive study was carried out in [5], in two different institutions, using four different engineering courses that involve both fresh and sophomore students, to observe and assess the effectiveness of the used AL approaches. The outcome of this study can be used as a robust validation method of AL. Another study addressing the different strategies that can be applied by engineering instructors to improve the students' response to AL was presented in [6]. This study included interview data from 17 different professors in the US who are teaching STEM-based engineering courses. The study found that by mainly relying on explaining the purpose of AL and facilitating it to the students, in addition to careful course planning, less resistance was faced by the instructors. Another supportive study, which collected and analyzed the responses of 1051students, regarding instructional practices in 18 different introductory engineering courses, was conducted in [7]. The effect of the social and physical characteristics of the classroom was investigated as a factor in determining the level of students' resistance to AL in [8]. Despite having different seating arrangements and adopting different AL strategies, no concrete conclusion was found regarding what is the best technique to promote AL; this highlighted the significance of triangulating the importance and the effectiveness of AL, using more observations and reporting methods.

More studies regarding applying AL in different engineering programs can be found in [9], [10], and [11]. These studies highlighted the advantages of AL and how it allows students to generalize and expand their knowledge via improving their communications skills. In addition, they introduced some of the most important techniques to apply AL, which are mainly related to project-based and research-based methods and how this is highly influenced by class and preparation times, administration effort, and availability of resources. They also recommended that more training be required for most faculty members in order to effectively apply AL, which should be fostered by a community of practitioners and education experts.

Project-based learning (PBL) is one of the most efficient techniques of AL, which is considered to be the best alternative to traditional instruction/teaching. When combined with research-based learning (RBL), much evidence for much better academic achievements were noticed, both at the school level [12] and the university level [13]. A comprehensive study was conducted in [13] to investigate the effect of using PBL, where students are the center of the educational system. It illustrated 46 different comparisons from data published in 30 recent journal articles, covering 12,585 students from nine different countries. The study concluded that PBL is an effective technique to improve the academic achievement of students, regardless of the educational stage and the group size. However, it also indicated that PBL is strongly dependent on other factors, such as the subject area and available IT resources. Although it is agreed that PBL is a learner-centered method of instruction, it is argued that many definitions do exist that add other dimensions to the nature and the merits of PBL. Self-efficacy and achievement among groups of students and teachers were investigated in order to arrive at the best planning for PBL activities in [14].

Recently, promoting PBL for many areas of EE was adopted [15, 16, 17]. In [15], an experimental computational lab, which is based on the popular MATLAB/Simulink software tool, was integrated into the curriculum of a course in vibration and control that is essential to students majoring in mechanical engineering. Due to the multidisciplinary nature of the course, students are expected to gain conceptual, analytical, and hands-on design experience, where 30% of the assessment was devoted to group projects. It was verified that applying PBL resulted in a better academic performance, in addition to allowing the students to build and improve different skills. The need for the industry to be an active constituent in PBL was investigated in [16], with emphasis on materials engineering. The learning process was divided into two phases, the first is for understanding a real-world problem, while the second is for proposing a feasible solution for it. It was found that the direct interaction between the academic institution and industrial sector resulted in helping the students to develop more confidence, while opening opportunities for further collaborations in terms of research projects and internships. Involving industry was extended to software engineering, which is usually a challenging subject to teach. In [17], redesigning the course was explored, with the aim of not only proving the necessary theoretical knowledge, but also stressing the industry-oriented PBL to increase the chances of the student getting employed and integrated in the job market. Verified signs of students' satisfaction and improved academic performance were noticed, while successful strategies for embedding PBL and RBL in EE were developed.

Having introduced the importance of AL and adopting PBL as one of the best practices for AL, we divide the rest of this paper as follows. Section 2 highlights the motivation of this research, which is improving traditional STEM-based EE, via providing additional emphasis on three more dimensions that include art, entrepreneurship, and design, resulting in the more advanced STEAMeD-based approach. Section 3 explores different case studies to exemplify the suggested techniques. Finally, Section 4 presents a summary of the proposed research, via highlighting best practices and future trends that can support and improve EE.

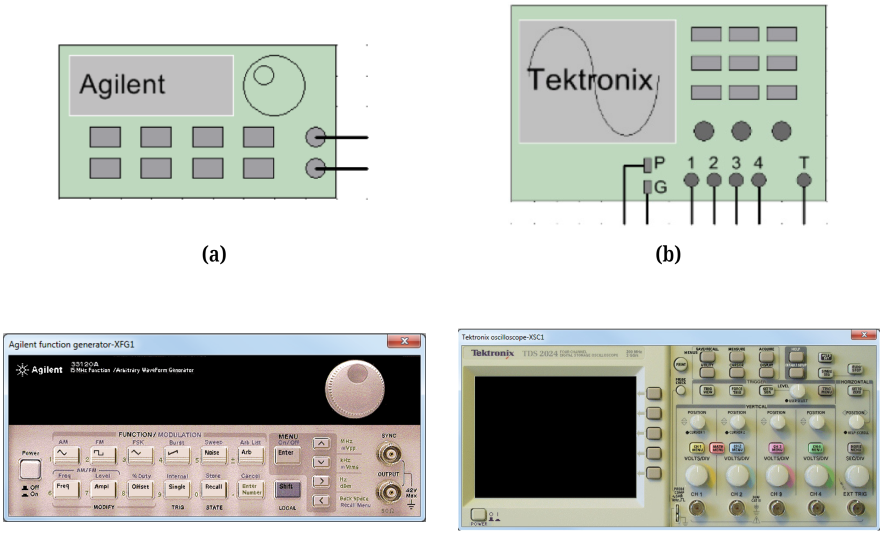
2 MOTIVATION AND LITERATURE SURVEY

The acronym STEM, which was initiated earlier as "SMET", was first introduced by the national science foundation (NSF) in the 1990s. It was short for science, technology, engineering, and mathematics. STEM was made up of separate disciplines, each of which could be taught separately in its own context [18]. NSF introduced STEM to emphasize the importance of these four disciplines in education, community, and society in general. Over the years, educators used the acronym to describe the interconnectedness between the four disciplines and design curricula and pedagogy that integrate them to achieve the ultimate goal: teaching in a real-world perspective, thus enhancing the individuals' overall abilities and STEM skills. These highly essential skills underline nations' economic growth [19]. Many nations around the world exhibited apprehension for improving STEM education as economies' sustainability and scalability demand for STEM proficiencies progressively became intense [20]. Due to the recent integration of liberal arts with Ees , it habecome possible to cross the boundaries between art and science in many engineering programs. In addition, the need for incorporating PBL and RBL into EE has promoted the need for more design components in many engineering courses, especially the capstone design project (CDP). Moreover, the currently challenging job market and the industry necessitated introducing entrepreneurship in the engineering curricula. This has had the effect of revolutionizing STEM, which as evolved into STEAM (to include art), followed by STEAMD (to include design), and finally STEAMeD (to include entrepreneurship). The characteristics and attributes of each phase are summarized in the following sections.

2.1 Adding the <u>a</u>rt component to STEM: (STE<u>A</u>M)

Many EE systems are now integrating art into the existing STEM-based systems to generate a synergistic relationship between them [21]. The new STEAM-based EE is believed to improve the skills of the engineering students, especially critical thinking and creativity, via inspiring them to benefit from many different positive aspects of art education, at the pedagogical, cultural, and economic levels. Including courses in the fields of art, music, social sciences, humanities, and linguistics, which are typically found in studies of liberal arts, into the engineering curricula is being adopted now by many universities worldwide [22]. The design, as a process, has many analogous features between engineering and art. Designing a program/application requires a flowchart when applying software engineering rules; this is analogous to drafting an initial sketch when applying art principles to design a painting. Both experimental and empirical techniques are adopted when designing a functional hardware engineering prototype; this is equivalent to a professional photographer adjusting the camera settings to take the best picture. Nowadays, design of concept cars requires adding an ergonomic touch, which is quite similar to an artist adding the final touches to a sculpture. Despite having different names, engineering and art use similar objects, e.g., laboratory vs. studio, and virtual simulation using Computer-Aided Design (CAD) software vs. rendering using graphics-specialized software. This promotes the synergy and correlation between engineering and art [23]. Now, many industrial projects require having a multidisciplinary team that contains both engineers and artists. The automotive industry is one of the leading examples in this field, where engineers and technicians build the engine and the controls, while artists decide on color, shape, and the interior design. It is expected that engineering students will perform better in their final year CDP when they get exposure to art-related courses during their study [24].

The academic performance of many engineering students was improved when liberal arts education was integrated into their curricula. Many students are testifying that they managed to sharpen their critical-thinking skills via studying courses that belong to the social sciences group, such as literature, history, and philosophy. In addition, they greatly improved their sensory awareness and creativity via studying courses that belong to the humanities group, such as music and art. The quality of the engineering capstone design projects in STEAM-based EE is found to be superior to those generated by STEM-based EE, because of mixing technical and scientific studies with artistic-based activities [25]. Another study for introducing STEAM-based EE, involving an ABET-accredited program, was introduced in [26]. Dependence on virtual engineering and simulation-based CAD software packages was explored to help students to retain knowledge and content, and to be more innovative when solving real-world problems. In addition, engineering students adopting a STEAM-based EE perform better in multidisciplinary teams involved in extracurricular competitions and hackathons, testifying to the importance of integrating art into traditional STEM-based EE.



(a) (b)

(c) (d)

Fig. 1. Regular schematics vs. their VR-based instruments

Promoting AL and student engagement may require having access to labs with limited facilities, at both the equipment and the space levels. To solve this problem, virtual reality (VR) simulators can be used, where students can get the exact feeling of being in the lab. These special VR-based simulators provide libraries for the individual components that have two types of graphical user interfaces (GUIs), where students can conduct the experiments using simple standard electrical symbols or an almost-identical 3D high-resolution graphical entity that represents the actual equipment. Figure 1 illustrates an example from Multisim, showing the actual schematic of a signal generator and an oscilloscope, with their corresponding virtual instruments in (a), (b), (c), and (d), respectively. This added artistic feature allows the students to get the required hands-on experience while not physically being in the lab.

2.2 Adding the design component to STEAM: (STEAMD)

Students learn more by doing. This is fundamental to PBL and was demonstrated and verified for schools and universities [27] via examining instructional and motivational issues that need to be incorporated when implementing it. The individual roles of the students, instructors, and technology were investigated to arrive at the best appropriate techniques to analyze data, design projects, and devise teaching and assessment methodologies. Involving the industry and addressing the real-world problems of the community is a key factor in the success of PBL, as explored in [28]. Novel collaborative efforts and pedagogical approaches were presented to show how PBL can benefit the students to gain more interest and knowledge about the subject at hand, in addition to helping them in securing more career development opportunities in the long run. Introducing the design science to develop a method for modeling the learning process was introduced in [29]. A technique called "learning of a complex concept (LCC)" was proposed to monitor the behavior of the students in electrical engineering labs, where they try to acquire knowledge via conducting experiments. It was argued that better designs for the engineering curricula could be obtained by applying the techniques of the design science. Figure 2 illustrates the typical involvement of both art (in simulation) and design (in projects) in adding more value for the traditional STEM-based education for engineering courses that need practical labs.

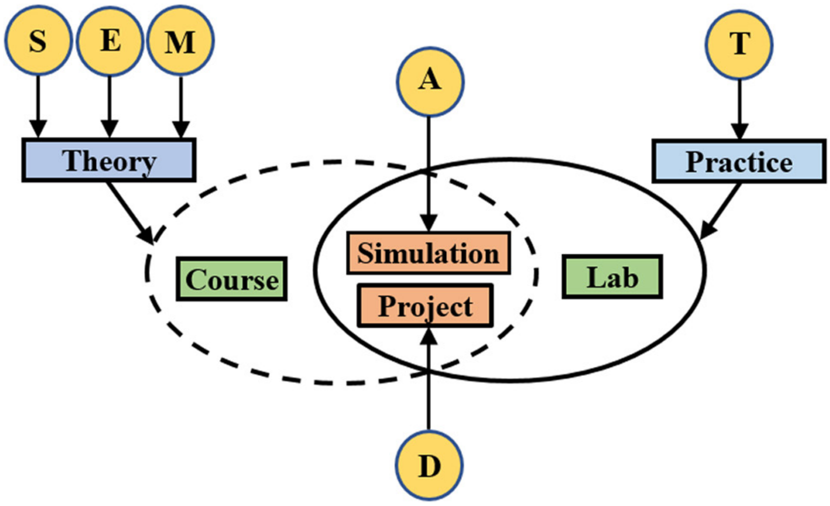


Fig. 2. The structure of STEAMD for a typical engineering course with a lab component

Accommodating the needs of the current job market, dictated by the companies and society, requires developing techniques for realistic value-driven design (VDD) in EE [30]. The challenge of value assessment is very important for students who want to become industrial practitioners. Addressing the complexity and uncertainty of a multidisciplinary early design analysis is a challenge that should be taken into consideration when designing the PBL component of EE. It is argued that engineering students, particularly those majoring in Systems Engineering, need to be engaged in scenarios that involve deciding on trade-offs, complexities, and restricted timeframes in order to cross the gap between theory and practice, and to be better prepared for assuming their future jobs. In order to inspire creativity and innovation in PBL, an experiential learning approach is often used [31], where students receive reflection on their doings through actions, results, and feedback. This technique can be reinforced by engaging students in extracurricular design competitions that involve long-term events. Students form multidisciplinary teams can build subjective experience, while receiving objective results, advice, and judgment from industry experts. The nature of the competitive framework motivates the students and triggers their passion for acquiring and mastering new skills, which results in the overall improvement of their academic performance.

2.3 Adding the entrepreneurship component to STEAMD: (STEAMeD)

According to [32], the idea of combining entrepreneurship with engineering is not new. This combination has garnered growing attention in the 21st century, with the emergence of both the World Wide Web and the Internet as a whole. Entrepreneurship has been utilized whenever the economy is slow. Consequently, it is a popular choice for courses at the undergraduate level, especially for students who see it as a necessary tool for venture creation. The Canadian Engineering Accreditation Board states that every aspiring engineer must acquire a certain set of skills and traits throughout the journey of their undergraduate degree. These skills must include design, investigation, problem analysis, life-long learning, communication skills, individual study and teamwork, economics, and project management. Additionally, students need to familiarize themselves with environmental and societal awareness, knowledge, ethics, and a sense of professionalism. The goal is for entrepreneurship to improve, at least, the first set of traits. The main purpose of teaching engineering entrepreneurship course is to develop entrepreneurial mindset and skills. These skills are proven to be essential tools to excel in their professional journey. For instance, 350 students at the University of Ottawa took an entrepreneurship course; as a result, 60 of them were successful in managing 60 simulated businesses, with some of those even evolved into real-world companies.

Promoting entrepreneurship development is one of the recommendations by both the Spanish and European socioeconomists to mitigate the impact of the rising number of unemployment among graduates [33]. Spanish students are aiming at local universities fostering entrepreneurial culture. This category has become essential in selecting a higher education institute attention due to job market demand and the need for innovative solutions. In addition, the promotion of entrepreneurial culture has led to creating a mindset of self-employment and start-ups of small and medium-sized enterprises. There are three different entrepreneurial traits that motivate students to enroll in entrepreneurship classes [34]. The first one is the "need for independence" while running their own established enterprise. Students seek job satisfaction while being successful professionally as they maintain autonomy by their own established venture. The second trait focuses on job stability, while maintaining financial security. Categorized as "financial motivation", students are motivated to achieve a high standard of living as a reflection in successful business.

The third trait, which is classified as "need for achievement", is associated with mastering all the skills needed to grow at both the personal and the professional levels.

Although entrepreneurship courses in EE witnessed a rise in emphasis within the engineering curriculum in the past two decades, some researchers argue that academic institutions do not have a standardized structure for teaching this topic [35]. As a result, students miss out on the potential opportunities offered by entrepreneurship education due to both subjectivity of the course content and the rationale of the instructor. For instance, academic faculty observed that "passion, vision, and drive" resemble some distinguishable characteristics of an entrepreneur. Additionally, interpersonal, or soft skills, risk taking, vision, and curiosity fall under the characteristics that faculty find it difficult to stimulate and hone within the students enrolled in entrepreneur courses, as these characteristics are more related to the student's personality. Other skills associated with "technical skills, business skills, problem solving, and communication" are attributes that were most easily developed or learned from the faculty perspectives.

Introducing a general framework for integrating entrepreneurship studies into different engineering curricula, which is motivated by the need to develop the economy, was introduced in [36]. This study argues that EE should provide more than the basic technical skills to help engineers become successful freelancers who can provide high-quality services in diverse domains. Benchmark examples of successful early integration of entrepreneurship were presented to illustrate the increased effectiveness of the engineering graduates to meet the demands of the job market and the required attributes of a talented engineer. Extending entrepreneurship education to many postgraduate studies in engineering was explored in [37]. This extension aimed at crossing the current gap between technical studies and business practices. A PBL approach was adopted to create a technology-based enterprise to improve the soft and entrepreneurial skills of the students. In addition, by introducing hot topics, such as the Internet of Things (IoT), AI, and smart cities, through common projects tools, it was observed that students were much more satisfied being exposed to new business-related topics that are traditionally considered as isolated blocks of knowledge and totally irrelevant to their field of study.

Figure 3 illustrates the complete program structure for a typical electrical engineering course, where all the STEAMeD-based EE block are shown. Of course, an overlap exists between individual elements, depending on the nature of the course/lab.

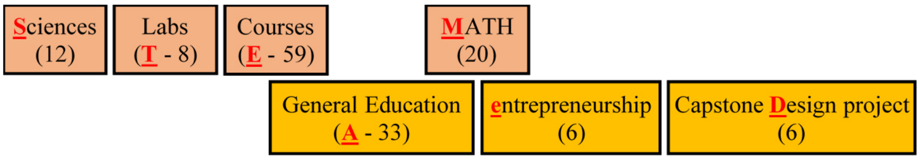
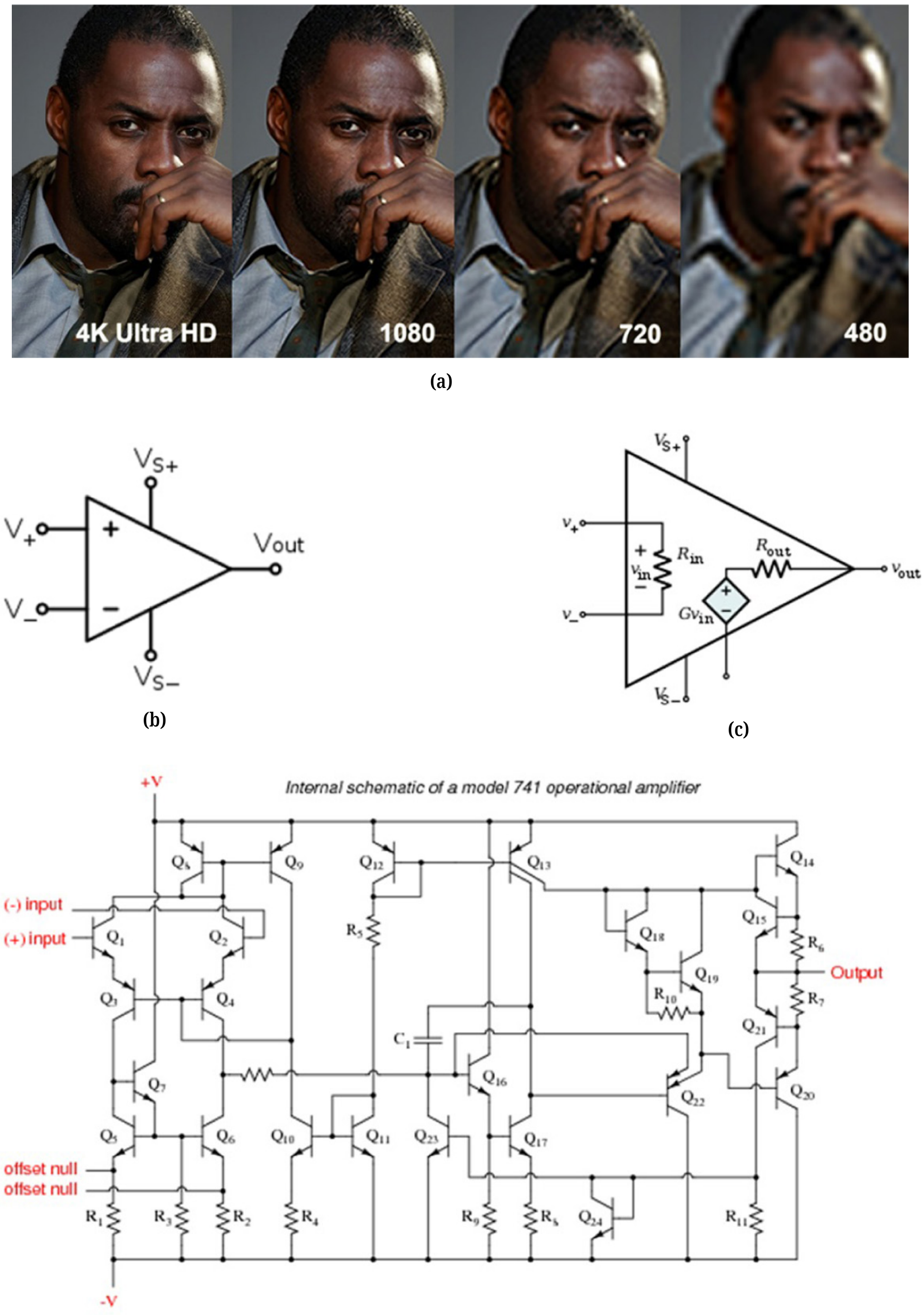


Fig. 3. Breakdown of the credit hours for an electrical engineering program (total = 144)

3 CASE STUDIES

3.1 Case study #1: op-amps, as analog devices

Figure 4a shows four different photos, for the same image, taken at different resolutions. In the art of photography, this is controlled by the depth of the camera sensor and the accuracy of the lens opening, among other factors that are known only to professional photographers. While all photos carry almost the same information, the amount of detail is very much dependent on the resolution uised. Deciding on the best resolution will surly depend on the aim of taking this image. Usually a conflict will exist between the accuracy and the cost of the hardware used, for which a compromise needs to be arrived at.



(a)

(b)

(c)

(d)

Fig. 4. Analogy between resolution and the details of the abstract model

The same scenario happens when deciding on the required accuracy for describing an electrical/electronic component. Figures 4b, c, d illustrate three different ways to deal with the famous operational amplifiers (op-amps), where the one shown in Figure 4b is usually used to account for the ideal conditions, where the Op-Amp is assumed to have an infinite input resistance, infinite gain, and almost zero output resistance. In basic courses of electrical circuits, this assumption is usually sufficient to analyze the circuits and arrive at easy and simplified mathematical equations to calculate both voltage and current. For intermediate courses in electrical circuits, or electronics, it might be necessary to use more practical assumptions, which are found in the corresponding data sheets of the 741 family; in such cases, the model depicted in Figure 4c might be used. For advanced courses in electronics, in which more details about the inner working of the op-amp is required, the model illustrated in Figure 4d will be required.

This similarity between art-based photography and science-based modeling is an illustration of applying a STEAM-based approach rather than the traditional STEM-based approach. To promote AL, students are usually asked to validate the differences between the models of Figure 4b, using calculation, Figure 4c, using simulation, and Figure 4d, using practical measurements to highlight the similarities and differences between them.

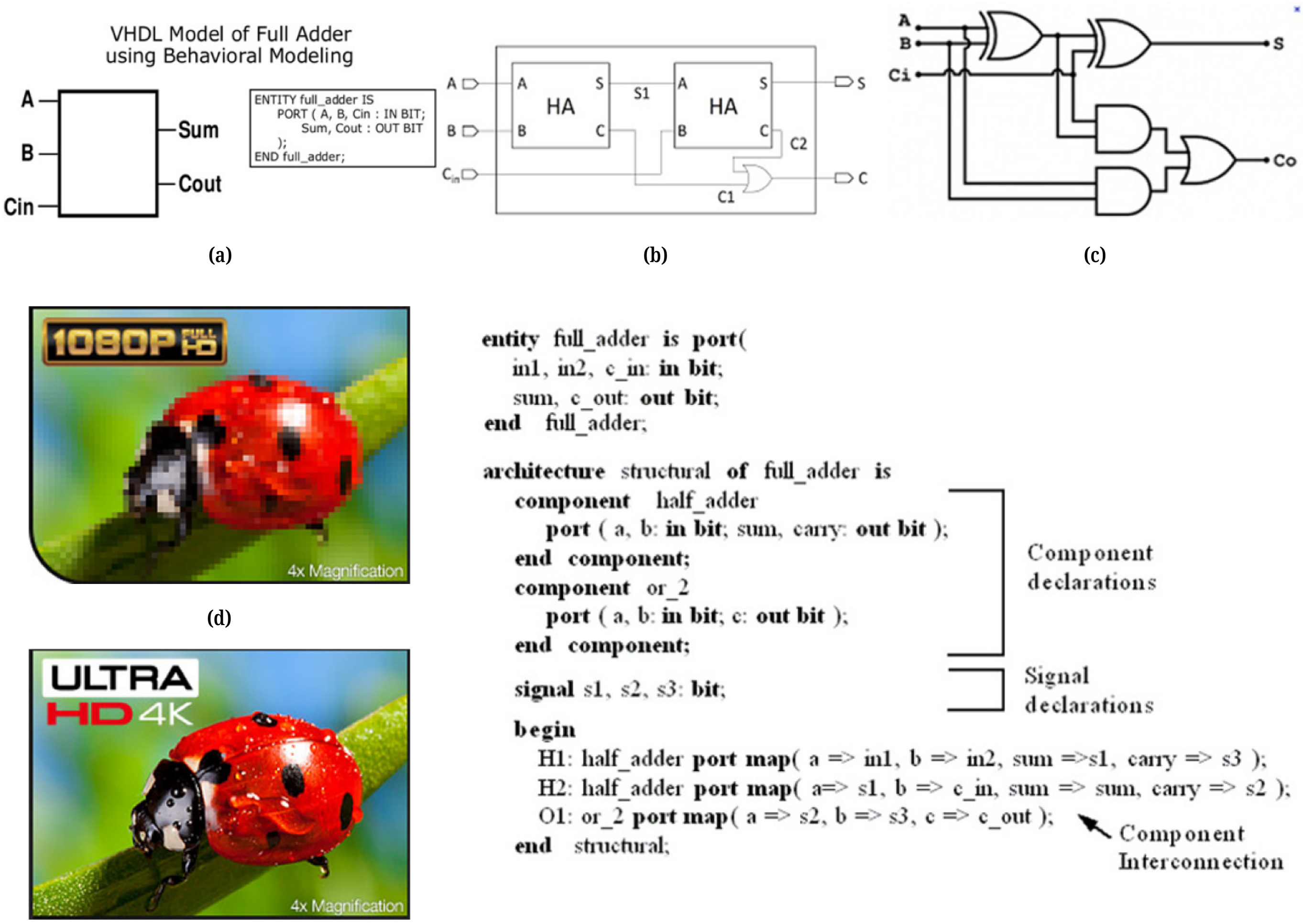
To further illustrate the art-related STEAM component in teaching courses in basic electrical circuits, the following collection of the course learning outcomes (CLOs) from a typical syllabus is introduced:

1. *Choose the preferred analytical approach for solving a particular circuit.*
2. *Use Multisim to simulate the behavior of electric circuits to verify analytical solutions.*
3. *Design electric circuits to perform a required function or satisfy given constraints.*
4. *Identify various components necessary to implement a simple electric circuit project.*

The first CLO is similar to using photography, painting, or sculpture to emphasize the details of an object. The second CLO provides a critic to judge the merits of the artistic work (the electrical circuit). The third CLO is related to the amount of details to be reflected by the artistic work, in terms of resolution, accuracy, budget, and/or any other limitations. Finally, the fourth CLO highlights the project-based approach, which is an important tool of AL; it is similar to deciding on the proper tools to build the artistic work.

3.2 Case study #2: half/full adders as digital devices

Another example for deciding on the level of abstraction is found in courses in digital logic, digital design, and embedded systems, which are typically found in curricula of both computer and electrical engineering. A full-adder (FA) digital circuit is usually a basic building block in many other digital circuits. It can be modeled in either software or hardware, with different degrees of resolution. Figure 5a illustrates a very-high-level software implementation of the FA, where only the input and output ports are illustrated, while skipping all the details about the inner workings and the interconnections between all the pins. Figure 5b, on the other hand, goes a little bit deeper via employing additional MSI components, such as the half-adder (HA) to add more details into the functionality of the FA. Figure 5c illustrates the SSI gate level that is used to construct the FA. Similar to the op-amps case, the two schematics in Figures 5b and c correspond to the low and high resolutions in Figures 5d and e, respectively. The art of adding details to a photo or a painting is extended to modeling, simulation, and synthesizing of electrical/electronic components, both analog and digital.



```
ENTITY full_adder IS
   PORT ( A, B, Cin : IN BIT;
        Sum, Cout : OUT BIT
    );
END full_adder;
```

```
entity full_adder is port(
   in1, in2, c_in: in bit;
   sum, c_out: out bit;
end full_adder;

architecture structural of full_adder is
   component half_adder
      port ( a, b: in bit; sum, carry: out bit );
   end component;
   component or_2
      port ( a, b: in bit; c: out bit );
   end component;
   signal s1, s2, s3: bit;
   begin
     H1: half_adder port map( a => in1, b => in2, sum =>s1, carry => s3 );
     H2: half_adder port map( a=> s1, b => c_in, sum => sum, carry => s2 );
     O1: or_2 port map( a => s2, b => s3, c => c_out );
   end structural;
```

(a) (b) (c)

(d)

(e) (f)

Fig. 5. Different abstract levels of digital full-adders

To extend the discussion regarding the art-related components in the syllabus, the following CLOs are highlighted:

1. *Apply gate-level minimization techniques.*
2. *Design combinational arithmetic and logic circuits.*
3. *Design synchronous sequential logic circuits.*
4. *Implement logic circuits using programmable logic devices and (PLDs/HDL).*

Again, and similar to the previous case study, each CLO could be looked at as a representative of art-related work. The first CLO is related to deciding on the amount of details; while both the second and third ones emphasize choosing the proper tool required for the design. The fourth CLO offers alternatives for representing the same artistic work, using other techniques (as shown in Figure 5f).

3.3 Case study #3: modeling & simulation in control engineering

Analysis and design of control systems are usually tough courses that are taught at the senior level of undergraduate engineering programs in both electrical and computer engineering. They require knowledge of various techniques of modeling and simulation, with deep understanding of systems dynamics for various STEM-based applications. Figure 6a illustrates the most important factors that affect the modeling process of control systems, including effects of the surrounding environment. Deciding on whether to include all these factors, or sacrificing some of them, depends on both the required accuracy and the needed simplicity, which is an obvious conflict. An important factor in finding a resolution to this conflict is the amount of information available about the model itself, as depicted in Figures 6a, b, c, and d, where the model is, respectively, completely known and deterministic, stochastic, partially known, or fully unknown. Other factors include the available computational power and whether a hardware, software, or co-design/hybrid system is required.

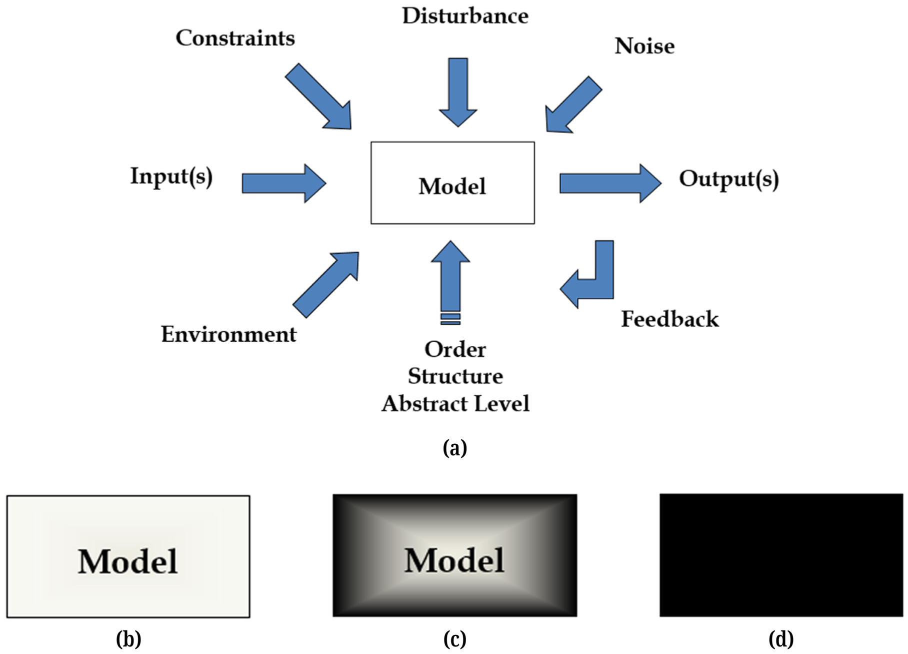


Fig. 6. Different abstract levels of control systems

The following two methods are usually adopted:

1. Model based (physics and math): Generating a mathematical model for the system under consideration with clear relationships between its variables, inputs, and outputs.
2. Nonmodel based (computer-based programming): Using multilayer interconnections between the input(s)/output(s) with tunable parameters, e.g., artificial neural networks (ANNs), genetic algorithms (GAs), and fuzzy systems.

While these two approaches are strongly dependent on the STEM-based paradigm, the added art-based component could be highlighted via investigating the following CLOs:

1. *Identify various components necessary to build a linear feedback-control system.*
2. *Develop math models for various electrical, mechanical, and electromechanical systems.*
3. *Use block diagrams and transfer functions to represent control systems in the S-domain.*
4. *Design different combinations of PID, lead, and lag compensators, using mini projects.*
5. *Use MATLAB/Simulink techniques for the analysis and design of LTI control systems.*

The first CLO is almost similar to the fourth CLO in the op-amps case study, where a choice must be made using critical thinking. Usually small groups of students are formed to compete against each other in determining which is the best choice. The second and third CLOs offer different techniques, with different pros and cons to choose from; usually each small group of students will adopt one choice and then interchange it with other groups to validate their model. Each group will act as a critic for other groups, and eventually a voting scheme is used to decide on the most suitable modeling technique for a given application. The last two CLOs require deep knowledge of both analytical techniques that are mostly STEM-based and CAD-based simulation tools that are more into the STEAM-based approach, as it requires a sense of art in building blocks, connecting them, configuring GUIs, and choosing layouts of the display materials.

3.4 Case study #4: adding an engineering entrepreneurship component

At the American University in Kuwait (AUK), students are offered two engineering entrepreneurship courses (ECs), where they experience AL using case studies in technology startups. Students are given different assignments that include readings, report writing, and in-class group exercises as some of the essential assessment tools. In addition, students are split into teams to complete term projects, which require them to prepare a business model canvas and/or business plan for a technology-based business that they create. Finally, students must perform either an “elevator pitch”or pitch deck to present their business in an appealing way that includes all key points.

AUK students typically take ECs in their junior or senior years of their undergraduate studies in the engineering department/college. The rationale behind that is for students to compile their acquired knowledge, as well as their accumulated skills and technical expertise, and integrate them effectively into their final CDPs, while still in college. As a result, and since academia is a safe, controlled environment to experience failure, students hone their skills to be ready for either the workforce or to initiate their own startups after graduation.

In ECs, students are assigned individual work to test one’s own intellectual abilities. Moreover, students are also given tasks to exercise their ability to collaborate with fellow colleagues in their work (as long as their own unique intellectual abilities are demonstrated in their final product). In addition to traditional lecturing, guest lecturers are invited to share their hands-on experience in entrepreneurship in different topics. Sharing personal and career experience, professional interest, and successes and failures are some of the significantly impacting topics that entice student interaction with the course content. These topics addressed by guest lecturers help in building an entrepreneurial mindset. Samples of assignments will be discussed in the following section.

Group assignments

- *Idea Sketch Pad*: students use this tool to assess their venture ideas in a relatively short period of time. Conducted in a group setting, they fill out boxes and answer questions addressing key parameters about their proposed ideas. In addition, students are asked to provide an initial sketch of their potential idea.
- *Business Model Canvas (BMC)*: students identify a venture idea, which has been assessed using the Idea Sketch Pad, to create their BMC. Students are given the option to use digital drawing tools, plain paper and sticky notes, or poster board to graphically illustrate the nine blocks of the BMC to ensure that they are all working together as they address their venture from different perspectives. Figure 7 depicts a sample of the BMC.

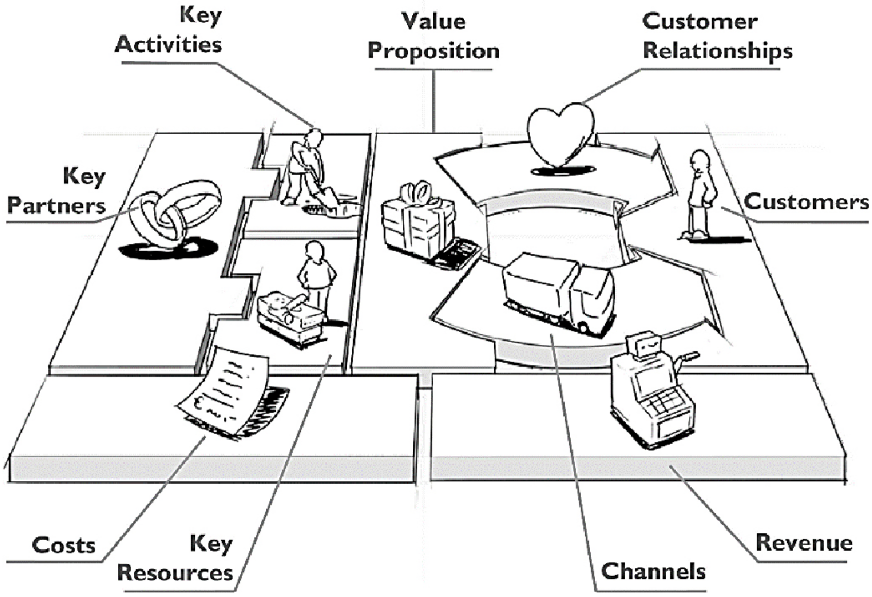


Fig. 7. A typical example of a BMC

- *Design thinking*: students are asked to identify an area of curiosity, such as exercising, video gaming, food, travel, education. Once the area is identified, students are requested to observe human activities in a related space that corresponds to their area of interest to detect customers' needs and desires. Notes are then recorded using a specific framework discussed during class.
- *Financial feasibility analysis*: students are required to conduct a feasibility analysis for their business idea. Basic calculations, such as breakeven point, forecasting, and total cost and revenues based on the projected demand, are demonstrated in the financial section of the report and presentation.
- *Pitch deck presentation*: students are allowed approximately twenty minutes to present their venture idea to the class. The presentation is a summary overview of the proposed product, marketing strategy, potential challenges, and projected revenues. The instructor acts as an investor, where the designated group will try to acquire his/her buy-in to fund for their proposed startup idea.
- *Team-building activities*: students learn to work in teams via various activities given to them in class. The aim is to hone their skills in communication, problem

solving, and conflict resolution. Additionally, while these activities are performed in a safe academic environment, students work under stress, manage time, and enhance their interpersonal relations with teammates. The marshmallow challenge [38], for instance, was performed in class as a demonstration of team-building activity.

- *Interview*: students are asked to schedule a meeting to conduct an interview with a successful entrepreneur. As a follow-up, the students draft a report reflecting on their experience along with a short video of the interview. Both the video and the report are supplementary materials for class discussion as they reflect hand-on experience and lessons learned.

Individual assignments

- *Reading assignment and summaries*: students are assigned book chapter(s) to read and summarize. Later, the students discuss them in class with their peers.
- *Exams*: students are evaluated via midterm and final exams. These exams assess students' learning and knowledge of the topics, in addition to other definitions and principles that were discussed throughout the course.
- *Written assignment*: students are assigned articles, videos clips, or mini case studies to analyze and discuss during class time. They are given time to come up with a brief report.
- *Networking assignment*: this assignment is done individually in class. Students are provided with a template and given supplemental instructions. The instructor explains the purpose of the activity and the expected outcome. Later, students are given 15–20 minutes to complete the assignment; then results are discussed in groups.

To further illustrate the integration of the STEAMeD-based EE in the engineering ECs, the following collection of the course learning outcomes (CLOs), from a typical syllabus, is introduced:

1. *Define "Mindset" and explain its importance to entrepreneurs and relate the mindset for entrepreneurship to entrepreneurial action.*
2. *Conduct a feasibility study and develop a technology business plan that describes all relevant internal/external elements and strategies for starting a new business.*
3. *Develop a technology-based Business Model Canvas and the corresponding set of processes involved in developing an idea and starting up a new technology-based company.*
4. *Demonstrate the value of networks for entrepreneurs and describe different ways of building networks.*
5. *Define "design thinking" and illustrate the key parts of its process.*

The significance of the integrative STEAMeD concept is demonstrated in the first CLO. It focuses on both creativity and innovation and their integral part in entrepreneurship. Basic psychology principles are introduced in this topic, such as how the two hemispheres of the human brain, as depicted in Figure 8, function and the role they play in creativity when both sides hemisphere of the brain overlap [39].

For instance, the acquired knowledge and set of STEM skills engrained in the brain's left hemisphereoverlap with the creative and out-of-the-ordinary right hemisphere. As a result, students come up with innovative and economically viable business models for an existing challenge.

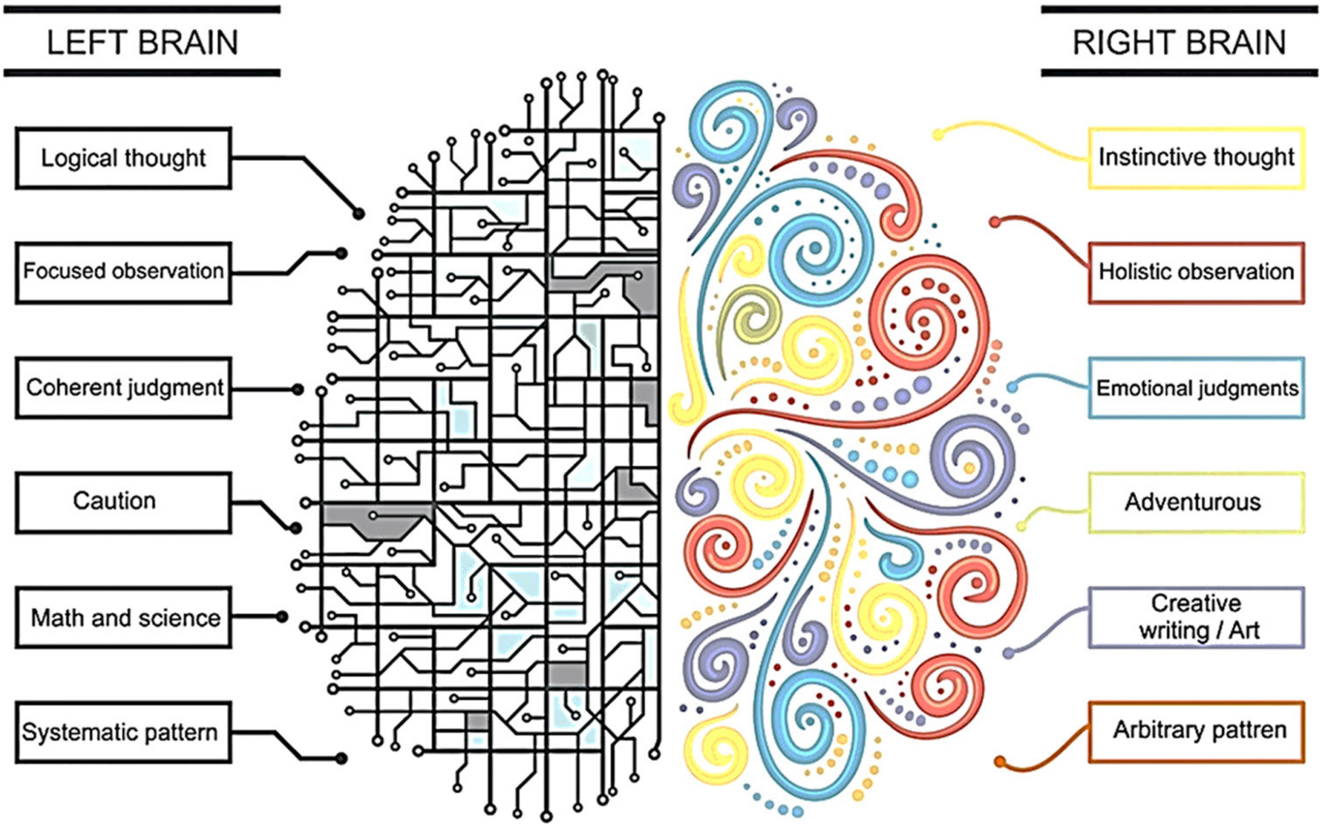


Fig. 8. Brain lateralization. (Illustration adapted from www.freevector.com.)

Both idea generation and assessment are the first phase of creating the business model in entrepreneurship course, demonstrated in CLO-3. During that phase, students gather information locally, regionally, or sometimes globally to evaluate potential needs within society. For instance, environment-friendly cooling systems, extended battery life, and optimized healthcare record keeping reflect some of the essential needs to improve human, or even animal, well-being.

Technology is integrated in engineering ECs, where students investigate the key elements of developing an innovative high-tech and/or engineering venture. The venture takes into consideration potential market requirement identification. In addition, students are introduced to strategy development for high-tech or engineering product positioning, marketing, distribution, sales, operations, management, and development. Within that process, students prepare a financial plan to mitigate potential risks as a lesson learned from business case studies (CLO-2). Furthermore, and by implementing various technology solutions, students formulate a survey to collect primary research data to identify customers' needs. The raw data is categorized based on a desired field that needs further enhancement; for instance, healthcare, environment, or technology advancement. The next step is for students to develop a technology-based business model canvas. At this stage, students explore corresponding set of processes involved in developing an idea and the viability of starting up a new technology-based company to promote their proposed solution.

Using art-based education promotes the diverse imaginative and creative expressions to problem solving. Unlike rigid technical solutions, art encompasses innovative skills acquired from engineering entrepreneurship, humanities, and other nontechnical courses. These skills consist of creativity, communication, brainstorming, sketching, prototyping, and website and app design, among many other related visual art and media. Students will utilize acquired artistic skills to implement aesthetics to the visionary prototype, whether it is an app interface, a website, a drone, or a physical shop layout. These skills are demonstrated in CLOs 3, 4, and 5, through different assessment components such as business model and business plan projects and reports, interviews, idea assessment pads (Figure 9), and more. All of the assessments are implemented in groups to emphasize the importance of team-building skills. Such skills are critical throughout the strudents' educational journey and, as they will discover, are very much in demand in small and large companies once they enter the workforce.

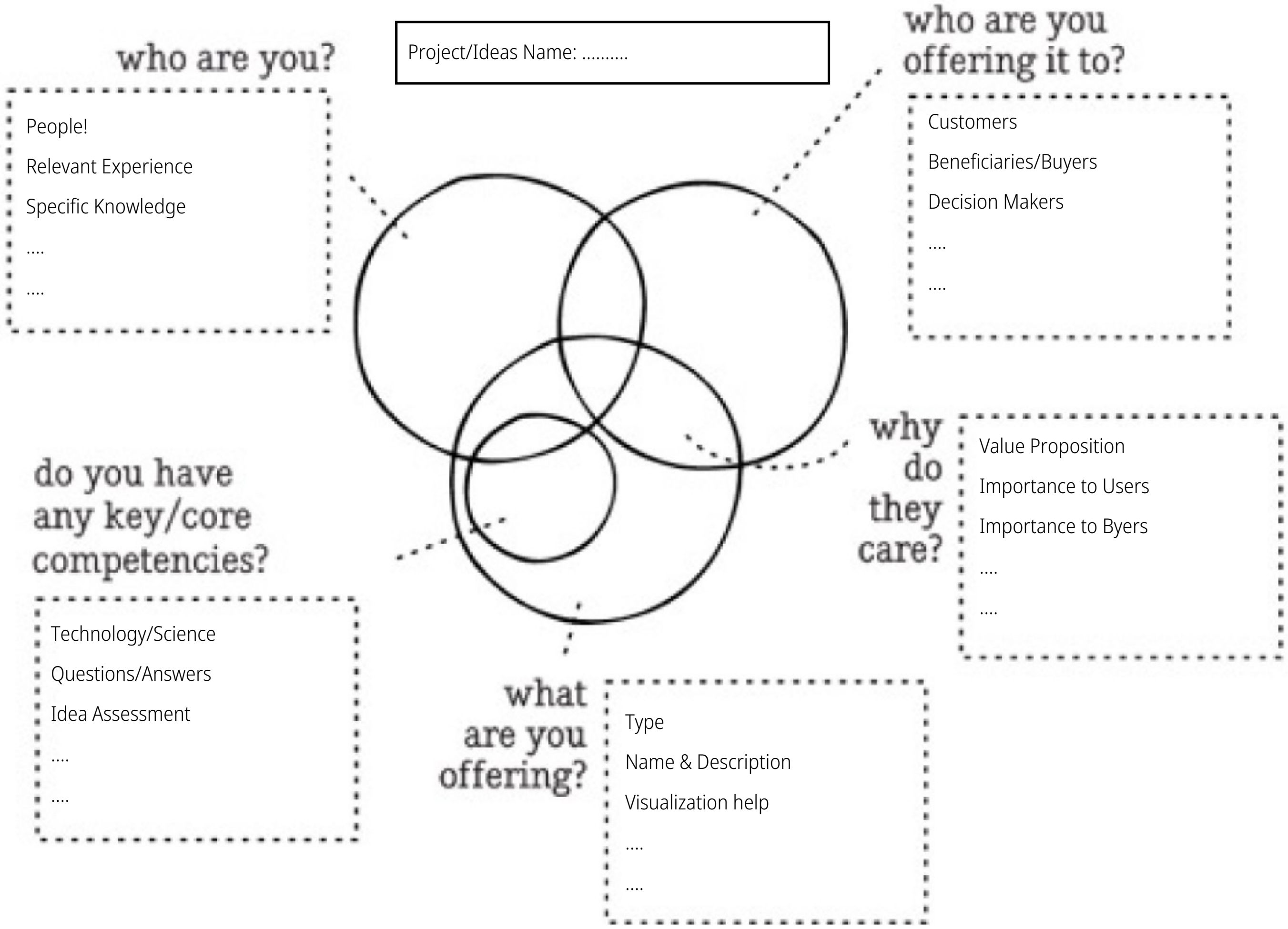


Fig. 9. Idea sketch pad

Students enrolled in ECs are privileged to conduct an artistic illustration (Figure 10) of their prototype such as photography, or physical assembly of their potential solution. Moreover, students attempt to pitch the technology business idea to the concerned audience through role play, a subcategory of the performing arts.

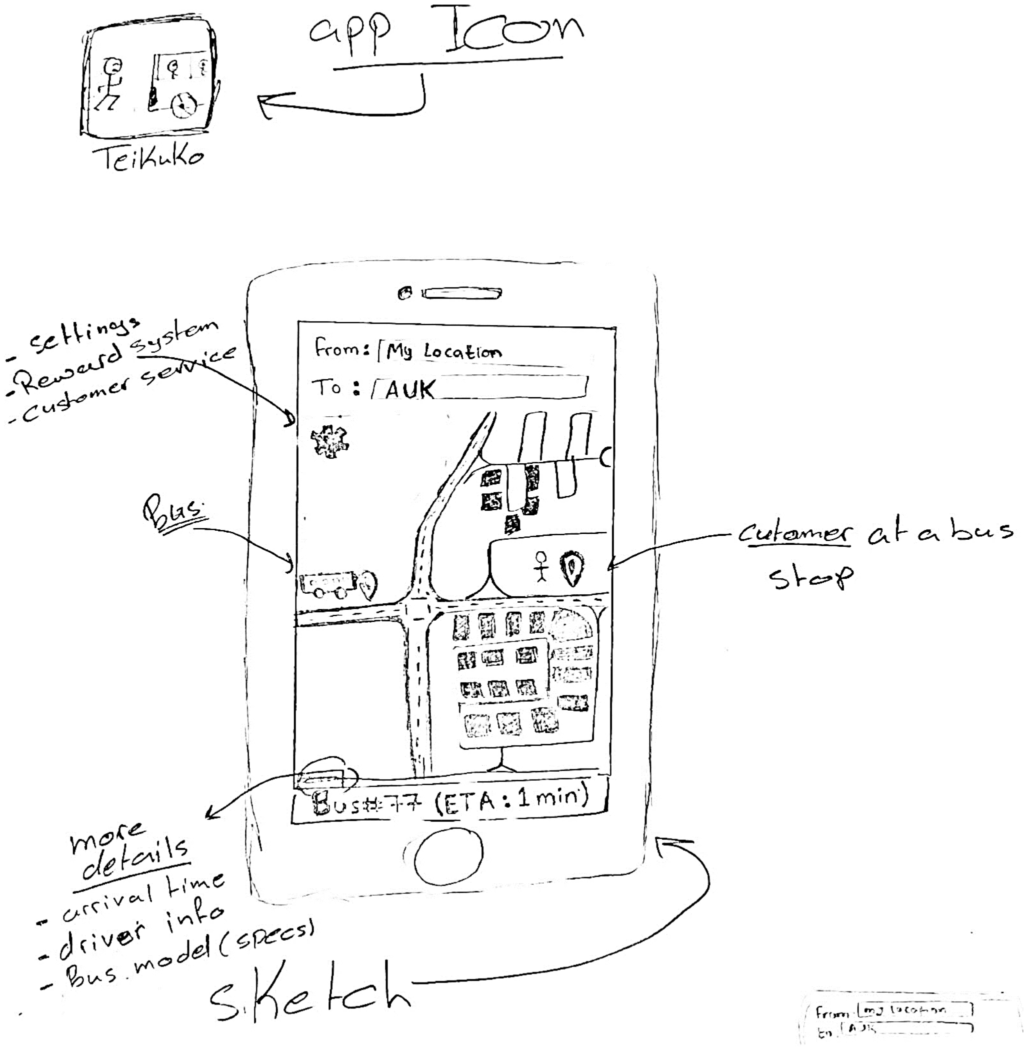


Fig. 10. Sample student product illustration

Another interesting value addition of art is exemplified in "design-thinking", which is an essential segment of entrepreneurship. Students merge both role-play and empathy as essential components of design thinking. For instance, they incorporate emotions and personal needs by empathizing the targeted customer base when designing and planning startups, a critical stage that can significantly influence the chances for success of any business.

The significant role of mathematics is infused within assorted focused topics that decompose challenges to reach a logical conclusion. These topics consist of financial analysis, feasibility studies, forecasts, cost estimation, profit calculation, and so forth. For instance, students apply statistical analysis to evaluate collected data during the early phase of data collection. The analysis can be extended even after pivoting the business model canvas based on customers' feedback. Similarly, students apply different economics concepts, and models, in order to evaluate the potential solutions' viability and profitability. Other tools, such as cost estimation and pricing, formulate the basis for demand projection and feasibility of the proposed solution.

4 CONCLUSION AND FUTURE WORK

AL was explored as an improved extension to traditional STEM-based EE, via adding art, design, and entrepreneurial components. The analogy between different art disciplines and corresponding engineering fields was explored to emphasize how modeling and simulation could be done with an artistic touch that improves its quality and helps in building virtual learning environments. With rapid advances in technology, it is expected that more artistic measures will be integrated to a wide range of applications in different industries. Currently, there is ongoing research in applying STEAM in the design of concept cars, smart cities, intelligent robots, and sophisticated microprocessors. Moreover, perception of things that are very difficult to model and technically difficult to sense will be available in the near future, thanks to the inventions of smart sensors and the rapid evolvement of the IoT. This will include sensing beauty, love; natural senses such as vision, hearing, taste, smell, and touch; and even predicting human behavior in trading and using the stock market. All these future trends will be candidates to using STEAM-based education.

Adding a design component, even at the 200-level (equivalent to semesters #3 and #4 in the European ECTS-based system) courses in undergraduate programs, proves helpful and allows students to gain hands-on experience, through AL and many other research-based PBL. Courses such as engineering design, as well as the capstone design projects can cover this area, via carefully designing their syllabi, rubrics, and assessment methods. Finally, adding an entrepreneurial component to the engineering curriculum helps the students in applying many useful business and management concepts in their studies, such as SWOT (strengths/weaknesses/opportunities/threats) and BOCR (benefits, opportunities, costs, and risks) analysis.

It is expected that (1) STEAMeD-based education will eventually replace traditional STEM-based education, as the positive effects of the added components can be profound and that (2) academic institutions, which adopt liberal-arts concepts, will be the most likely beneficiaries from applying STEAMeD-based AL approaches.

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