International Journal of Engineering Education Vol. 36, No. 1(A), pp. 66–83, 2020
Printed in Great Britain

0949-149X/91 $3.00+0.00

Engineering Education in Cambodia: Investigating Undergraduate Engineering Students' Understanding of the Engineering Design Process*

DO-YONG PARK
College of Education, Illinois State University, Normal, IL 61790-5330, USA. E-mail: dpark@ilstu.edu

DAE HWAN BAE
Department of Telecommunication and Electronic Engineering, Faculty of Engineering at Royal University of Phnom Penh, Russian Federation Blvd, Toul Kork, Phnom Penh, Cambodia. E-mail: whymper@gmail.com

The purpose of this study was to investigate the scope and depth of the engineering design process understood by Cambodian engineering students. An activity involving the building of a mobile phone battery charger system was designed and implemented for the study. Ten undergraduate engineering students participated, and data were collected from focus group interviews, photocopies of protocols and initial products, and observation notes throughout a three-week long project. Data were analyzed by coding and finding patterns and themes in major storylines focusing on the engineering design process. The results were fourfold: (a) Cambodian undergraduate engineering students expanded their understanding of engineering design benefits from an individual to a national level; (b) students felt they were not adequately prepared in mathematics and science in high school; (c) the learning environment, that is, the problem-based context, and the culture of the Cambodian classroom influenced students' learning in engineering design; and (d) students also recognized the iterative nature of the engineering design process and associated challenges to overcome. Thus, experiencing engineering design in a practical, engineering problem-based context helped strengthen their career goal of becoming engineers. The implications for engineering education in Cambodia are discussed in the paper.

Keywords: engineering design process; engineering education; STEM education; problem solving; mobile phone charger; Cambodia

1. Introduction

Amid increasing interest in science, technology, engineering, and mathematics (STEM) education around the world and because engineers are in great demand in Cambodia, the Cambodian government has begun to emphasize engineering education [1–4]. However, the field of electrical engineering faces many specific problems, including the lack of a competent engineering workforce both in industries and at universities, a small number of engineering majors, a less compatible engineering curriculum, and a lack of facilities for engineering education [2, 3]. Currently, Cambodia requires 35,000 engineers to sustain the country's GDP growth of 6-8% over the next five years [2, 4]. However, Cambodian colleges of engineering only produce around 1,000 graduates each year. Simply put, it would take around 35 years to fulfill the need for engineers in the country. Recently, the Ministry of Education, Youth and Sports (MOEYS) published a policy on STEM education in 2016 that guides the direction of STEM education for not only K-12 schools but also for higher education in Cambodia in order to meet the needs of the society. The policy stipulates [3] that the goal of STEM education is to "develop general education and higher education students with strong competence of science, technology, engineering and mathematics to meet labor market needs and ASEAN Community" (p. 2). Based on this policy, the Cambodian government invites collaborative work among scholars from international higher education institutions.

Through the Core Fulbright U.S. Scholar Program, one of the authors in this research was invited to Cambodia to help MOEYS lay a foundation of systematic STEM education by assisting seven selected university faculty members (i.e., three engineering, one mathematics, one chemistry, one physics, and one computer science instructor) for five months so that they could teach STEM education in their own discipline areas. The authors selected one of the engineering design projects in telecommunications to investigate how engineering undergraduates understand the engineering design process.

This study provided a context in which Cambodian engineering students could have the authentic experience of applying the engineering design process to solving practical engineering problems. Currently, many problems challenge Cambodian people in everyday life. In recent years, for example, mobile phones have become widely available for all generations to use in Cambodia. However, the main problem of mobile phone use involves having a battery charger system, especially for those who live in rural and remote areas with little or no

* Accepted 26 September 2019.

access to electricity. Many rural subscribers inevitably must travel many kilometers to get their phones charged or to use charger stations. As one solution to the battery problem of a mobile phone in remote areas, we chose a direct current (DC) gear motor, which can dynamically generate electricity by itself without needing electric supply. A gear motor is also small and easy to maintain, and anyone can learn to operate one without much knowledge of engineering techniques. Generating and providing electricity to households is highly related to STEM fields in terms of knowledge and skills. It is acknowledged that a mobile phone charger using a DC gear motor may not be a complete and permanent solution to the problem; however, it is a useful and reasonable tool to meet the imminent needs of Cambodian households in remote areas. In classroom settings, designing this device promotes engineering education in the Cambodian context. However, little research has been conducted in Cambodia about engineering education or STEM education. Moreover, little was found regarding research on the engineering design process at the university level. Studies remain scarce on engineering education concerning its teaching, student learning, assessment, and professional development in formal and informal educational settings in Cambodia. Therefore, we proposed this study, guided by the following research question, to investigate Cambodian engineering students' understanding of the engineering design process through a problem-based design project of building a mobile phone battery charger system:

> What is the understanding of Cambodian undergraduate engineering students about the engineering design process?

To answer this question, the research focused on how Cambodian undergraduate engineering students perceive (a) the phases of the engineering design process, (b) the impact of activity, context, and culture, (c) challenges and benefits of the engineering design process in Cambodian context, and (d) their career goal as an engineer for the country. All of these foci constitute the understanding of the engineering design process in this study.

2. Background of Literature

2.1 Conceptual Framework

Because our research involved the context of an electricity problem, the authentic activity of engineering design, and the culture of Cambodia, we adopted a theory of situated cognition to frame this study. Brown, Collins, and Duguid [5] stated that situated cognition is a theory of instruction in which learning occurs in relation to authentic *activity*, *context*, and *culture*. Primarily, this theory provides a lens to understand how people learn with two foci. First, knowledge is constructed within and linked to the activity, context, and culture in which learning occurs. Second, learning is socially acquired as learners collaborate, communicate, discuss, and share knowledge through problem-solving tasks. Secondarily, this theory offers a conceptual framework for educators and researchers to understand how to capitalize on learners' prior knowledge and skills in order to help them learn new knowledge and skills. Using this framework, we engaged Cambodian engineering undergraduates in the engineering design challenges of a smartphone battery charger system so that they can learn new content and skills by constantly communicating and collaborating with peers and experts (e.g., instructors) while carrying out the authentic activity situated in meaningful contexts and relevant culture. They then apply their prior engineering knowledge and skills to solving practical problems using the engineering design process. Research has shown that such authentic experiences that are socially and culturally situated are likely highly optimal for learning [5].

2.2 Engineering Design Process

The study of the contemporary understanding of undergraduate engineering majors in regard to the engineering design process is scarce in literature [6, 7]. However, one study compared the difference of engineering student approaches to two open-ended design problems between senior engineering students and freshmen [6]. Researchers found that "seniors produced higher quality solutions, spent more time solving the problem, considered more alternative solutions and made more transitions between design steps than the freshmen" (p. 325). In other words, senior students' design behaviors were more sophisticated than freshmen's although individual design behaviors varied by problem. Researchers also found that both the freshmen and seniors spent little time "defining the problem" and a lot of time developing alternative solutions [6]. This result implies that engineering students' conception of the engineering design process is different depending on their level of understanding and experiences, and that they tend not to realize how important it is to define the problem in the engineering design process. Walker et al. [7] studied key concepts and developmental differences in people's conceptions of the engineering design process between experts and senior undergraduates in engineering fields. They concluded that "experts not only have extensive domain knowledge, they also situate that knowledge in a social and cultural context (i.e., they understand when and how to use what they know)" (p. 472); whereas, over the year-long course, undergraduates "increased their knowledge of the design process; however, their knowledge did not appear to become more integrated or accurate" (p. 475). Thus, compared to college students, experts demonstrated a more comprehensive conception of design by knowing when, where, and how to use their knowledge and skills in a realistic way than did engineering students. They constricted themselves to the generic view of the engineering design process, while experts encompassed areas outside of the generic design process (i.e., ethics and marketplace). Given that there are multiple conceptualizations at different levels, the common core elements of the engineering design process can be summarized as (a) defining and delimiting engineering problems in an authentic context related to various problems in society and in the nation; (b) designing and prototyping solutions wherein one goes back and forth finding, testing, revising, and redesigning solutions to engineering problems based on feedback and further research; and (c) optimizing the design solutions. These component ideas are non-linear, and the design process is iterative and open to multiple solutions through revisions and tests.

2.3 Readiness of the Engineering Design Process Education in Cambodia

In Cambodia, the engineering design process education at the college level faced a couple of challenges. First, there is a curriculum challenge. The engineering curriculum continues to evolve in terms of the engineering design process at the college level. However, STEM education, including engineering education, is still new to most college students and faculty because there was no formal STEM education implemented in K-16 classes before this project. Thus, little has been documented in terms of engineering education research as well as STEM education in Cambodia. Even the term *engineering design process* was new to students, although they tacitly used the process of engineering design. Since 2017, only one Department of Engineering at a Cambodian university has offered students a Project Management course in their last semester, which is a sort of capstone course about how to design and manage a project and produce a final prototype guided by prototyping practical engineering problems. Second challenge lies in the university instruction and faculty. Across the country, the typical engineering class was provided when modeling their design projects with full lectures but little practice of the engineering design process due to various limited factors, including a lack of engineering facilities and a shortage of competent faculty. In fact, approximately 85% of the entire engineering faculty across the country held a master's degree as their terminal degree (personal conversation with a director of Institute of Technology of Cambodia, 2018). This fact implies that students may have limited experience with the engineering design process and with using engineering knowledge and skills at an in-depth level. Third, university supplementation to purchase materials is not promising because revenue is limited. The government's annual expenditure per student for tertiary education in Cambodia was USD $206.96 (2009), $162.52 (2010), and $139.68 (2011) [8]. Currently, improvement of this situation is not promising. Roath [9] reported that the Cambodian government funding to support instructional materials and resources is limited, which results in a shortage of teaching material and school facilities. He went on to report that with only 1.6% of Cambodia's GDP spent on education, MOEYS provides USD $1.50–$1.75 per student per year for teaching materials in K-12, which is effectively minimal. Fourth, grade school math textbooks are a problem to prepare for studying engineering at the college level. Typically, the math curriculum is written by several local experienced teachers with little quality assurance measure systems in place. Consequently, Cambodian mathematics textbooks are criticized for the following problems: "(a) Text books often contain mathematical errors and less experienced teachers do not recognize these mistakes and may teach incorrect mathematics to students. (b) Text books may not reflect modern educational psychology and pedagogy. (c) Teachers' guides are not widely available and there is a lack of reference books for teachers in Khmer as most teachers can only speak, read and write in Khmer. (d) Text is printed only in black and white. There are no high-quality color graphics typically found in international text books. (e) There is little correlation between the mathematical content taught and its application to real life situations" [9, p. 1151].

3. Methodology

By applying the situated cognition conceptual framework, we delineate the *activity, context, and culture* under the methodology section and discuss the impact of these three components in the discussion section. We also discuss how the instructional theory of situated cognition helped participants acquire a meaningful understanding of the engineering design process.

3.1 Research design

We chose a qualitative research design with a purposeful sampling design [10] for two reasons:

First, the engineering design took time to figure out solutions and make the battery charger work, which created a lot of qualitative data, such as observations, informal conversations, and photocopies. Second, this task required in-depth knowledge of electrical engineering and experiences and thus required adequate contextualization [11]. A three-week long task applying the engineering design process was designed as an intervention *activity* for students to complete within the *context* and *culture* of Cambodia to produce thick data to answer the research question.

Based on the review of literature (see the Engineering Design Process section), we adopted and revised three phases to our intervention activity of the engineering design process that were tailored to the needs of this study [12–15].

Phase I. Identify: Defining and Delimiting Engineering Problems in an Authentic Context. This phase involves stating and refining the problem to be solved as clearly as possible in terms of criteria for success, constraints, or limits. The problem is identified in the practical engineering context of the society and nation.

Phase II. Design and Prototype: Designing and Prototyping Solutions. This phase begins with generating different possible solutions with prototypes and building and testing prototypes to see which one best meets the criteria and constraints of the problem. Prototypes allow students to test how their solutions work and show the solution to professors and classmates for feedback.

Phase III. Optimize: Optimizing the Design Solutions. This phase involves a process of tradeoffs, in which the final design is improved by trading off less important features for those that are more important. The best solution is selected, tested, and finally implemented to solve the problem.

Phases I and II were collaboratively completed in two groups with help from the instructor regarding mathematical and scientific knowledge in finding the solutions to the battery charger system. Phase III was carried out by each group separately using guided inquiry [16], in which there was little help from the instructor (see Phase III).

3.2 Participants

The participants were ten Cambodian engineering majors (ages 21–25; two groups of five – Group 1 and Group 2) in their senior year in telecommunication and electronic engineering at a college located in the capital city of Phnom Penh, Cambodia. This study used a small number of participants. A qualitative study "typically focuses in depth on relatively small samples, even single cases (n = 1), selected for a quite specific purpose" [10, p. 264]. Participants had a background knowledge of circuit theory, control engineering, electronic engineering, electromagnetic theory, digital theory, and microprocessor systems. One engineering instructor holding his Ph.D. in telecommunication was mentored and trained about STEM education in its entirety for eight consecutive weeks by meeting twice a week for two hours each so that he could teach STEM education to his engineering class. The training was provided by a Fulbright U.S. Scholar of STEM education in Cambodia. The instructor went through the introduction of STEM education, pedagogy, methods of teaching and implementation in his other class (two lessons of teaching), completion and presentation of one two-month-long project, and evaluation by his students and in-service STEM teachers in one full-day workshop organized by the Education Secretary of the Ministry, Cambodia. Finally, the instructor was certified as a STEM Education Expert by the Minister of Education, Youth, and Sport upon successful completion of the training.

3.3 Data Collection

We collected data sets, including focus group interviews, photocopies, and observational field notes throughout the task in each session.

Interview. A focus group interview (N = 3; two males and one female, ages 23–25) was conducted to understand the experiences, perceptions, and interpretations of Cambodian engineering students in regard to the engineering design process [11]. The interview was in English since participants' English was acceptable. Though their English was not perfect, communication was not an issue. The interview lasted approximately 40 minutes to make sure that every single participant within the focus group had a chance to respond. All the interview responses were audiotaped, and their purpose was to provide "thick descriptions" of data and detailed contextual data [17, p. 47]. We then transcribed all responses into text for analysis.

Photo copies. We took multiple pictures of the trials and errors of the battery charger system prototypes that each group constructed.

Observational field notes. We used our observational field notes to collect data while participants built several designs over time. To each picture, we added a quick and fragmentary jotting of key words, anecdotal information, and even sketches that helped us match the battery system and the group builder in each trial. The observation notes helped us to remember conversations and emotions that participants expressed at the time of critical event occurrences [18].

3.4 Data Analysis

The researcher, participating engineering majors, and the instructor individually read and reread each group's data set until they identified "any meaningful segment of data" in terms of this study's research question [11, p. 179]. We then again reviewed all data, including photocopies of students' systems, interviews, observation notes, and informal conversations and attempted to develop preliminary patterns and themes. Finally, we manually coded the matching data to produce themes based on the preliminary codes and brief memos. In a table, we numbered themes as we discovered them and wrote coding numbers next to the themes within each group's and student's data set. We then created a Word table to visualize the entire themes developed by combining similar ones that emerged from the analyzed data [19]. We also conducted member checks [20, 21], in order to garner participants' feedback on interview transcripts, photocopies, and observational notes before publication. This process helped to further ensure our interpretation of the data was trustworthy and meaningful and to test our understanding [11].

3.5 Activity: Building a Battery Charger using a DC-shaft Generator

Overview: For this study, we developed a project of building a mobile phone battery charger system in order for the participants to practice using the engineering design process. The mobile phone battery problem is not only a very practical engineering problem within a Cambodian context (see 1. Introduction), but also requires a good knowledge of scientific, technological, engineering, and mathematics (STEM) principles to find the solution. It is an intervention project of the capstone course that engineering seniors take as part of their engineering program at a Cambodian university. This project is new to Cambodian engineering undergraduates and faculty because it is developed using a STEM integrated engineering education never seen before in their curriculum. Using a STEM approach, the activity began with a meaningful problem to solve through engineering design. After being introduced to the electricity access problem across the nation, participants were asked the following probing question: "How would you build a mobile phone charger system without using commercial electricity?" The engineering design process was examined by the three phases (see 3.1 Research Design) and the solutions (Fig. 1–9) that the participants went through and created.

Teaching: During class, participants were reminded of electricity-generating motors and how they apply to a mobile phone based on a background of circuit theory, electronic engineering, and electromagnetic theory. The instructor guided participants to begin with a framework of the battery charger system as follows:

$$\text{Generator} \rightarrow \text{Regulator} \rightarrow \text{Load}$$

In the first phase of defining and delimiting engineering problems in an authentic context, the five participants in each group received brief instruction about the task and were asked to explore as many designs as possible through trial and error and testing. Participants identified problems with their own mobile phones through research. In the next session, participants were led to the second phase of designing and prototyping solutions to engineering problems. After identifying problem(s) with their own mobile phones, they began to explore potential solutions. Participants made as many solution prototypes as possible and tested them. At this point, the instructor emphasized going back to the criteria that each group identified in the first phase of instruction. During this process, all team members went to a real market to purchase a motor according to their solutions and test it. In most cases, it did not work well, so they went back to the market and purchased a different component, such as a shaft and right-sized motor (RPM versus voltage), for their design to work well. This process took time and was often repeated a couple times until they found the best way to solve the problem. After a few trials of designing, testing, revising, and redesigning their battery charger system, participants evaluated which design best met the criteria to successfully charge the phone. In the last phase, optimizing the design solution, each group tested and revised multiple designs. During this process, participants often changed their designs before finally arriving at the best possible solution for their mobile phone charger system. These three phases of instruction went seamlessly, but each group's pace of performance varied. Basically, this task was designed to be completed within three weeks.

In teaching engineering design in the engineering class, we attended to the principle of a direct current (DC) gear motor and regulator, which is a key idea for solving the problem raised in this research. Besides a mobile phone, the full components of a battery charger system consist of a DC gear motor, a capacitor, and a voltage regulator.

Gear Motor: The DC gear motor for charging the mobile phone is a portable manual type. When the voltage is generated, the gear motor of a low speed RPM is less than a high-speed RPM. Therefore, we selected a gearmotor that generates a voltage of 12V–100V at a low speed RPM (100–) based on a 5V charging voltage of a mobile phone. *Voltage Regulator*: Good quality DC power is very important in mobile phones. DC stabilization IC (DC voltage regulator) was used to obtain high quality DC power. This is because the DC power generated from the gear motor is subject to voltage fluctuation according to the RPM, so a constant power supply is required regardless of the rotation of the gear motor. However, the maximum voltage that can be generated by human hands is usually 20–30V. The L7805 is a positive DC voltage regulator with an input voltage of 7V–35V, an output maximum current of 1.5A and an output voltage of DC5V. Therefore, it can supply a constant positive 5V to mobile phones. *Capacitor*: The capacitor serves to protect the device from shocks caused by the transient voltage generated from the gear motor and the noise component included in the DC voltage, thereby providing stable power supply to the mobile phone. The regulator IC's input and output stage capacitors are 0.33uF and 0.1uF; they stabilize the output DC voltage with a low pass filter that prevents transient voltages caused by all rotations, and filters AC voltages including frequencies above 300KHz.

3.6 Context: The Evolution of the Cambodian Electric Infrastructure

Cambodia's population is very young, with an average age of 23.5 years for the entire population of 15.1 million. Younger generations tend more than ever to use mobile phones and social networking systems such as Facebook, Telegram, and instant messages. Cambodia is an agricultural country, with more than 85% of the population living in rural areas. The major heating energy for them comes from fuel – wood, charcoal, and agricultural residues. Around 1.6 million of the 2.3 million rural households rely on car batteries for mobile phone chargers [22]. Unfortunately, many households have no car batteries and no access to electricity. Even the capital city of Phnom Penh goes through a couple blackouts every day due to an insufficient supply of electricity. Throughout the nation, Cambodia has limited electricity access due to an incomplete infrastructure. In 2018, Cambodia's electrification rate was 58% across the nation, and 6.62 million people are still without electricity. This figure implies that the electricity industry in Cambodia is still underdeveloped compared to neighboring countries, such as Laos (81% electrification rate), Thailand (100%), and Vietnam (99.2%) [23].

3.7 Culture: Lack of both qsking questions and having discussion during class in Cambodia

We provided participants with argumentation training that facilitates critical thinking, asking questions, and argumentation skills. Cambodian students were not used to asking questions, had very little discussion during class time, and professors were not readily available for consultation [24]. This is a typical example of "D-power (Order-giving power)" culture [25, p. 284]. In the D-Power culture, students are stratified under teachers in classrooms where they passively learn. Unfortunately, this type of culture was widespread across schools in the nation, and it was apparently part of the culturally established learning environment from K-12 and even up to college; such an atmosphere does not produce meaningful learning in students. As part of the scaffolding strategy to help change the classroom culture, we provided participants with a chance to observe how discussion is supposed to proceed among students and between student and professor. We used the framework of argumentation, including claim, evidence, and reasoning followed by rebuttal and justification [26]. At the same time, participants were reminded of the extra credit that the instructor offered to those who would ask questions and actively participate in class discussions. This policy was newly implemented to create and promote an active learning environment of asking questions and holding meaningful discussions. By allowing the professor to be available at any time during and after class, students had a chance to freely ask questions about the project.

4. Results

Through the project of the engineering design process, participants created a complete battery charger system within the context of an electricity shortage in remote places, thereby helping to solve a problem germane to the people of Cambodia. Results were presented into four categories: how Cambodian undergraduate engineering students perceive (a) the phases of the engineering design process, (b) the impact of activity, context, and culture, and (c) challenges and benefits of the engineering design process within a Cambodian context, and (d) their career goals as engineers for the country.

Table 1 shows how students proceeded during the engineering design process in terms of time. As seen in Table 1, identifying the problem did not take long because students were given the context of the problem to focus on, but the delimiting constraints of the DC motor, regulator, and Female USB took most of that two-day period. However, generating and designing the solutions, as well as building and testing protypes, took the longest time, while the optimizing phase took the least.

4.1 Phases of the Engineering Design Process

4.1.1 Design Methodology

Group 1 and Group 2 came up with the following design together, wherein the mobile phone charger system was established with four steps. First, they

Table 1. Engineering design process and the amount of time taken

Phase	Process	1st day	2nd day	3rd day	4th day	5th day	6th day
I	• Identify: Define problems/Delimit constraints	▨					
	• Design: Generate and design different solutions	▨	▨				
II	• Prototype: Build and test multiple protypes		▨	▨	▨		
	• Feedback: Provide feedback				▨		
III	• Optimize: Make trade-offs;					▨	▨
	• Select, test, implement solution						▨

prepared two wires – one that connects to the ground and the other one that connects to the positive to carry 5V. Second, they then connected the input pin of the regulator to the positive pin of the motor. Third, they connected the output pin of the regulator to the male-female USB cable at the positive. Last, then connected all grounds of the motor, regulator, and male-female USB together by soldering. After discussions, participants reached the final design as an emerging system. As shown in Fig. 3, students presented the emerging system that met the requirement suggested by the instructor, as follows:

Generator (gear motor) → Regulator (L7805) → Load (female USB to a mobile phone)

Most importantly, participants were able to apply STEM knowledge and skills into building their mobile phone charger systems with instructor's guidance. First, they used scientific knowledge (S) in the mobile phone charger system; thus, by rotating the shaft of the motor, DC voltages and currents are generated, which creates the power ($P = I \times V$). Second, they incorporated technology (T) into improving the performance and protecting the system. They used the technical methods including soldering, gluing, and other mechanical efforts used to protect and sustain the system from rotating or moving. For mathematics (M), participants applied the equation-driven calculation to the system to determine specific values for any functions they targeted. For example, in this system, mathematics was applied for calculating the value of the voltage generated by the generator (gear motor) according to the formula, $P = V \times I$. Finally, they utilized the concept of engineering (E) in the process of designing the system. Specifically, participants designed the charger system by using the hand-rotating shaft of a gear motor to generate voltage sources. Participants figured out that using a gear motor box helped to reduce hand-rotating speed and yet increased the motor speed to produce high voltages that are enough to charge a mobile phone in a few moments. Thus, integrating the four fields of STEM helped the participants to improve the performance of the gear motor-based battery charger system, which contributed to solving a problem for people in areas with little or no access to electricity.

4.1.2 Phase I. Identify: Defining and Delimiting Engineering Problems in an Authentic Context

During Phase I, with a little guidance from the instructor, Groups 1 and 2 together explored criteria for success and constraints, or limits, based on what they found through their research. Fig. 1 shows the schematic of the L7805 regulator that they learned about [27]. The existence of input Capacitor Ci is required [28].

In Fig. 1, if the regulator is located an appreciable distance from the power supply filter, the output capacitor Co is not needed for stability, but it does improve transient response. Students found one limit that values less than 0.1 μF could cause

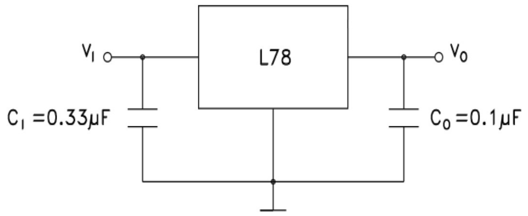

Fig. 1. Testing Circuit to Secure the Stability of a Battery Charger System.

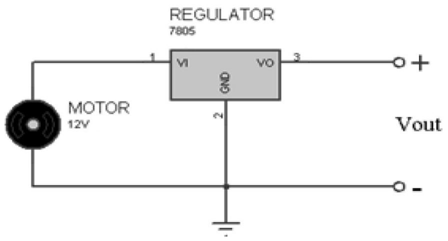

Fig. 2. Circuit Analysis to Regulate the Output Voltage for the Mobile Phone Charger System.

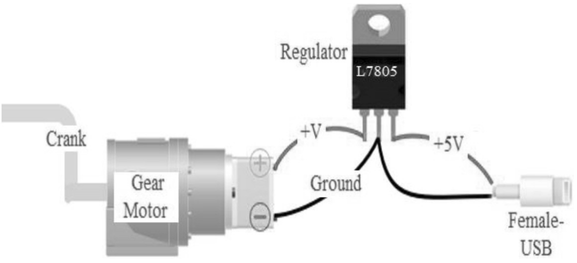

Fig. 3. Emerging System of Battery Charger System.

instability [27]. As illustrated in Fig. 2, 12V DC voltage is generated from a motor. When the shaft of a motor rotates at a speed of 100 RPM, it inducts 12V maximum or less. In the mobile phone charger system, the factor of both success and constraint is that the output voltage is limited to 5V only. This is the critical information that participants in both groups required to successfully design their system. Thus, a voltage regulator is required for this condition. Appendix 1 shows the electrical characteristics of L7805 IC within the testing condition, which is another limit of the design [29]. The charger rate depends on power which is calculated by the give formula: P(power) = I(current) × V(voltage). The L7805 regulator produces the maximum current at 1.0A. The maximum time to fully charge is determined by the equations in Appendix 2 [30, 31]. The charging time (MTFC) of the rechargeable battery to the maximum charge is essentially determined by the battery capacity (BC) and the charging current amount (CRC). However, the charging efficiency decreases according to the chemical and physical state of the charger, and as a result, the charging time gradually increases. The formula of the efficiency of the charger is shown in Appendix 2.

4.1.3 Phase II. Design and Prototype: Designing and Prototyping Solutions

As both groups designed their solution with the help of the instructor, they went back and forth between Phases I and II trying out their solution and rechecking the criteria, constraints, and limits when it did not work well. For example, in Group 1's initial system design, students chose a mini-electric motor (DC 1.5–6V with 15000 RPM) to use as a generator for the system (see Fig. 4). Their choice was natural because it was easy to purchase at a local hardware store and was handy since people use it in children's toys. However, Group 1 learned that it was not enough to charge the mobile phone when they tested it. There was no way to provide 5-6V because it required rotating the motor 15,000 times per minute by hand. This selection of a motor occurred because the instructor did not provide a gear motor. Instead, the instructor gave all participants the freedom to find one on their own at the local hardware store in Phnom Penh, Cambodia. As shown in Fig. 4, Group 1 used a mini-motor, two capacitors, and a plastic wheel to complete their prototype. Capacitor 1 was used to stabilize the input and output voltage. Capacitor 2 was used to stabilize the constant voltage IC by buffering the shocks from the DC motor. However, we observed that Group 1 managed to identify two problems from the initial system. First, it produced around 2.5V at the best speed when the group rotated it, which was not enough (i.e., less than 5V). Second, when rotating the wheel with increasing speed, the rubber band went off the track easily and could not keep pace with the speedy rotation. Thus, they had to redesign the shaft (crank) with a more powerful motor. On the other hand, Group 2 created a prototype of their own initial system, as shown in Fig. 5. The group used a gear motor, regulator, and female USB, which is what the instructor suggested. The shaft was made from bamboo because it was strong yet could easily be drilled through. It worked well for a couple of minutes, producing 5V as an output power. The crank (shaft) was made from bamboo because it was straight and strong. However, we observed that

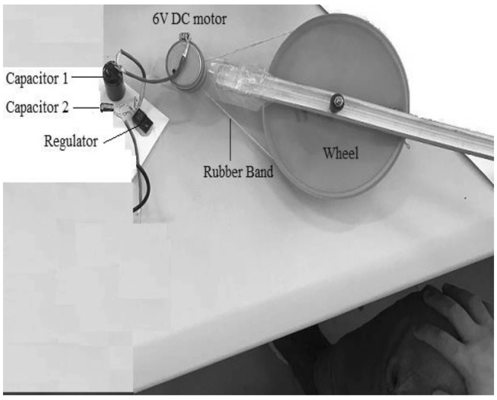

Fig. 4. Group 1's Prototype of Initial System of Battery Charger.

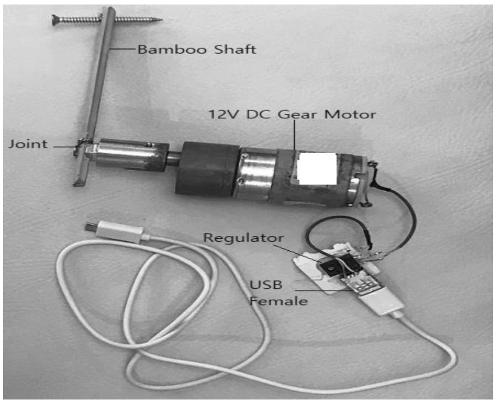

Fig. 5. Group 2's Prototype of Initial System of Battery Charger.

Group 2 identified the problem, which was that it was hard to keep a speedy rotation due to the flimsy joint of the shaft.

Once the students finished redesigning, they had to go back and forth to the local electronics hardware store until they found a better, more appropriate tool to create a prototype. After the gear motor that produced enough voltage was obtained, the students needed to find a regulator that worked. The instructor again facilitated and led a discussion for Groups 1 and 2 on what the correct capacity of a regulator was for the system and how to test it to see if it produced enough output constant voltage (power). Participants found L7802 chosen in Phase I at a local electronics store and tested it. The testing result was as follows: The maximum output voltage observed at the output port of the regulator was 5.01V DC, as shown in Fig. 6. When the motor was cranked at 100 RPM (approximately), the output voltage was approximately 5.01V DC (see arrow). The output current was maximized at 0.82 amps (see arrow), or 820 mA, as illustrated in Fig. 7. The data were collected from the simulation by using ISIS professional advance simulation software. Based on the simulation, the maximum voltage was 5.01V DC, and the maximum current was 820 mA.

The capacity of the charger rate can be calculated by P = I × V. When the output voltage 5.01V is multiplied by the output current 0.82 amps, the charger capacity of the mobile phone charger system is around 4.11W. That is, the capacity of the charger rate of the system is 4.11W. For example, for a mobile phone battery within the capacity of 1650 mAh, the charge duration can be calculated by the equations shown in Appendix 2. If the efficiency loss is 10%, then the duration of the charge is denoted by the following equation:

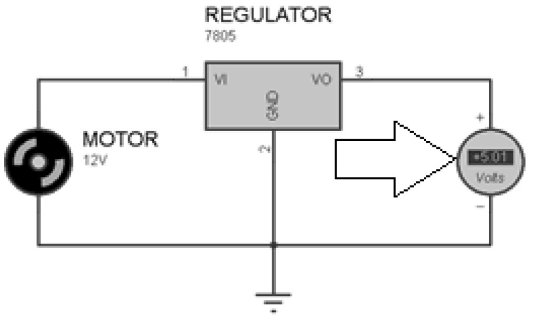

Fig. 6. Measurement of the Output Voltage of Mobile Phone Charger System Circuit.

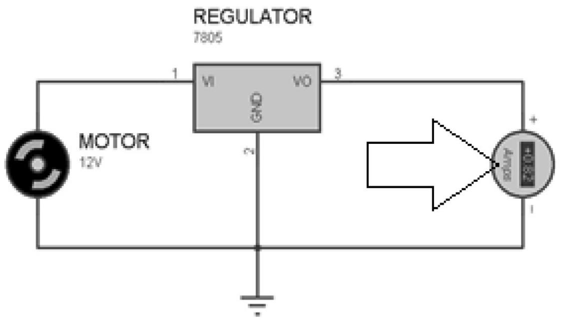

Fig. 7. Measurement of the Output Current of Mobile Phone Charger System Circuit.

$$\mathrm{MTFC} = ((1650 / 820) \times 11) / 10 = 2.21\mathrm{h}$$

As such, the duration of a fully charged phone can be calculated. According to the calculation result, a capacity battery of 1650 mAh lasts around 2 hours and 12 minutes.

In engineering, consideration of the cost of the final product is also important. If the cost of the system is high, it will not sell very well. [7] found that college students showed a tendency not to recognize this aspect of the engineering design process. Following this result, we decided to give the participants homework to determine how to construct their prototypes more cost efficiently by reducing the material costs. Students began to do some market analysis and considered the cost efficiency of the equipment required to make a mobile phone charger system. The following equipment was found at a Cambodia market. A DC Gear Motor 12V 60 RPM was $12.98; an L7805 regulator, $0.5; a male and female USB cable, $3; a pair of wire, $0.1; glue $0.1; casing $0.2; and transportation from the university to the market was $3.00, round-trip. The total cost was $19.88 for purchasing one set of materials to build a battery charger system.

4.1.4 Phase III. Optimize: Optimizing the Design Solutions

After evaluating their prototypes, both Groups 1 and 2 recognized that the output voltage (regulated voltage) varied depending on the speed of hand-cranking. It needed to be optimized. A strong and stable crank is critical to rotate the motor of this battery charger system. With their current prototypes, an unstable and weak crank was a problem. Because of this problem, the instructor decided to use guided inquiry (Level 2) to make a strong and stable crank as part of the students' engineering education. Guided inquiry provides a *problem* to be solved and leaves the procedure and solution to solve it open [16, 32] Therefore, the participants needed to establish the *procedure* of how to carry on the investigation and produce the *solution* to resolve the problem of a weak and unstable crank. Each group worked through trial and error by going back and forth to the local hardware stores to find a tool that worked best as a stable and strong crank. Finally, Group 1 produced Crank A and Group 2

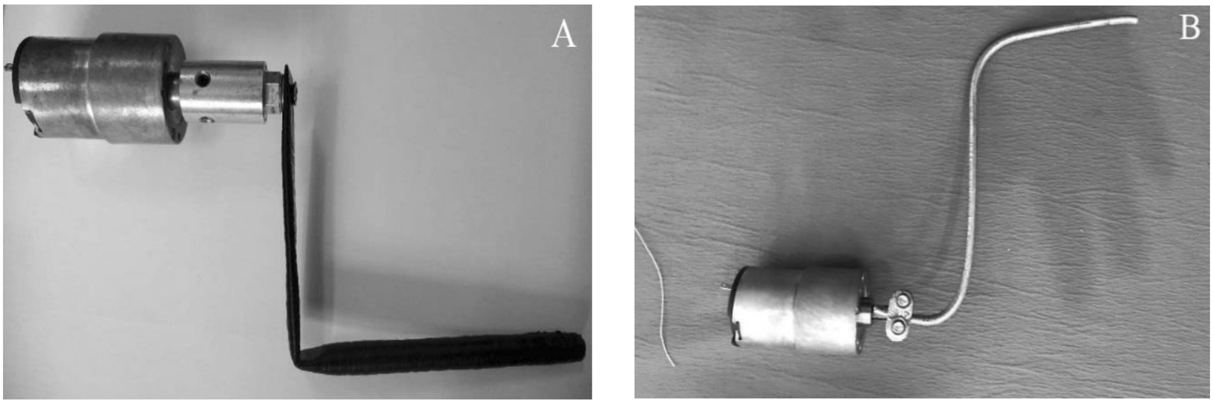

Fig. 8. Cranks of Mobile Phone Battery System Constructed by Two Groups through Guided Inquiry (Note. A is Group 1's Crank; B is Group 2's Crank).

produced Crank B – both shown in Fig. 8. This crank activity took one full session.

With newly created shafts, Groups A and B tested again and found that the input voltage ranged from 7 to 35V, and the regulated voltage was 5V. The participants learned that Crank B was not efficient and decided to use Crank A. During the experiment with Crank A, when the rotating speed reached approximately 50% of the maximum motor RPM, the regulated voltage was from 5V to 5.03V. After a couple of trials, the maximum voltage reached 5.03V and the output current ranged from 500 mA to 1A. The measurement of output current went up to 1.17A when the rotating speed reached around 50% of the maximum speed of the motor RPM. Both groups calculated the charger capacity of the mobile phone charger system, P(out) = 5.89W. Based on the power of 5.89W, voltage of 5.03V, and output current of 1.17A, both groups decided that the battery charger system could be used for any type of cellular phone. Fig. 9 shows the view of the entire mobile phone battery charger system developed through this project.

After completing the system, both groups actually tested charging a mobile phone (Samsung) with a battery voltage of 3.7V and battery capacity of 1650 mA. The maximum time taken to fully charge the phone was 1 hour and 24 minutes with no efficiency loss. This result may not be attractive to people who live in places where electricity is always accessible, but it certainly serves as one solution for people who live in places with no electricity access.

Fig. 9. View of the Entire Mobile Phone Battery Charger System Created Through the Project.

4.2 Focus Group Interview: Cambodian Undergraduate Engineering Students' Understanding of Engineering

The focus group interview with three participants (N = 3) revealed the impact of a well-designed engineering project directly placed within an authentic and practical context in a unique learning environment (culture). The interview also elucidated not only how participants felt challenged by their weak background of STEM knowledge and skills, but also how they benefited through the engineering design project (Note: S means student interviewee):

4.2.1 Impact of Activity, Context, and Culture

Cambodian undergraduate engineering students showed frustration when their work did not work well. They collaborated, communicated, and shared knowledge toward solving the practical engineering project. They shared the excitement of learning when they successfully found the designed solution to the engineering problems of a mobile phone charger system, designed within context and culture. One student (S2) shared his excitement of learning that he felt from the project after experiencing the success and the onerous moment that required a great deal of patience during the iterative process of the engineering design process.

> S2: When we went to the local hardware stores and found one that worked, I was so excited because I felt we were moving toward the final solution. . . We too worked so hard through a couple of times of redesigns and failures and finally were able to see it work well, for

> example, with L7805. . . Finally, when we were able to create 5V displayed on the multimeter, we all clapped and shouted with joy because. . . I felt like I became a real engineer solving a daily life problem of our society.

Due to limited experience and a lack of knowledge, S2 was not initially sure that he could successfully make it work. When he found that the system worked well, displaying 5.03 V on a multimeter, his group was excited because it showed progress toward the successful completion of the system. S2's response showed the positive impact of a well-designed engineering project on his meaningful experience. S2 also shared his experience of a field trip with his telecommunication class to the north-eastern part of Cambodia near the border of Vietnam before the battery charger project. He was excited about the antenna project because he was able to newly learn how to use a Spectrum Analyzer (0.01 to 22 GHz) to calculate the lambda (λ) of the wavelength to build the right size of antenna, which was $\lambda = C/f$ (C = Speed of light; f = frequency). The purpose of the project was to detect the telecommunication signals that crossed over to Cambodia. As such, S2's learning experience was acquired while carrying out the authentic activity situated within meaningful Cambodian contexts and culture. Regarding the cultural influence, on the other hand, Cambodian engineering undergraduates felt that the Cambodian classroom learning environment has a unique culture, which impacts their learning.

For example, S1 commented, "In this class, I was very happy because the professor was freely available so that we could ask anything we weren't sure of. As you may know, in Cambodian high schools and other college classes, we were not free to ask the teachers, and sometimes we were not allowed to ask questions." He went on to say that he did not feel free to ask questions in class because "it just has been the way, so we were used to it. Sometimes teachers showed their anger to students who asked a question rather than answered. . . I think many wanted to ask questions, not just me. But we were not freely asking questions. It is Cambodian culture." Regarding ways to improve this type of negative learning environment, S1 suggested that high school teaching should focus on bridging the gap between theory and practice. He expressed his wish that many opportunities should be offered to learn how to apply science and mathematics in solving engineering problems in high school as well as at the university level rather than focusing on theories over theories. The following comment of S1 signified the importance of an open environment for inquiry, "I could have done better if I could freely ask questions in class because I love asking questions." As seen in the comments of all three participants, learning can be meaningful and novel when they are engaged in the engineering design challenges because they can learn new content and skills by constantly communicating and collaborating with peers and experts.

4.2.2 Challenges and Benefits

Cambodian engineering undergraduates felt several challenges while they were working on the engineering project of a mobile phone charger system. Primarily, they lacked "background knowledge of science and mathematics." S1 elaborated on the challenges that he felt during the engineering design process:

> S1: For me, the most difficult challenge was mathematics. We studied mathematics in high school without getting what it means and how to apply it into daily life problems. We just memorized mathematical concepts and took a test. We forgot most of it after the test. We just learned a theory and never talked about how to use mathematics to solve societal problems. For example, I remember I learned Ohm's law $V = I \times R$ and Power = $I \times V$, but I was not able to apply it to solving our battery system problem. Like this, I felt that my background knowledge of science and mathematics was almost useless when working on this project. . . So, we asked the professor for help.

The above student (S1) was one of the top students in the class participating in this project. He recognized his lack of mathematical background knowledge when he had to come up with the solution. He also criticized the fact that high school mathematics courses were heavily focused on theories and offered little opportunity for high school students to apply science and mathematical concepts into solving daily life problems such as the mobile phone battery charger system. Unlike S1, S2 specifically pointed out his lack of technological knowledge and materials he needed for the battery charger project. He disclosed that he did not have any idea what he needed to solve the battery charger problem because he had never seen the gear motor in the past. His professor guided him to use it later. S2 also pointed out that in Cambodian markets, he could not find the materials required to solve engineering problems, especially technological problems. Even though the materials are available in the market, those tend to be cheap, low quality, and not likely to work well. Thus, S2 expressed his concern about the technological materials in engineering: "I was confused whether it is my problem or material problem, so it took more time unnecessarily than it should." S2 also shared his concern about engineering studies because he felt he learned too little about the basics of engineering concepts. He went on to say, "When I work on engineering projects, I felt I was seriously lacking in my science, technology, and engineering background knowledge. Like my friend (S1), I felt the same that my mathematical background was lacking in studying engineering. I think this is a huge problem in Cambodia, especially in engineering fields of study." On the other hand, S3 pointed out that she felt behind in computer technology as a future engineer. She stated that she was not confident about using a computer in engineering studies at the university because she was offered very little experience of software and coding. She went on to say that little experience of applying computer technology into solving the engineering problems made her engineering study most difficult. S3 recognized that engineering study required a good knowledge of technology, especially in computer science. However, her technological background was not enough to solve engineering problems. One of the authors of this research had a chance to talk to three lecturers in computer science at a Cambodian university during this study. They acknowledged the students' comments, but they felt helpless due to a lack of support in equipping the necessary computer technologies, which likely rely on Official Development Assistance (ODA) from advanced countries.

On the other hand, Cambodian undergraduate engineering students realized that engineering could bring benefits for individuals, society, and the country. Through the mobile phone engineering design project, they realized why they needed to study mathematics and science to achieve the defined solutions. They also extended their view of engineering design from an individual to national dimension in terms of how they could contribute to the advancement of the country [33]. For example, S3 fully appreciated the application of STEM principles and skills into creating the battery charger system, which was evident in the following comment, "We learned that iPhone and Samsung Smartphone need 5V to run. I was most excited when I learned that I was able to apply the physics equation ($P = I \times V$; Science), calculate the charger capacity and charger time (Mathematics), use technology like shaft and gear motor and soldering (Technology), and define the problems of the battery and design the solution (Engineering), which benefit people who need to resolve their mobile phone battery problem in rural areas." She developed an idea connecting her individual benefits to her aspiration for contributing to the nation. S3 shared her vision and dream as a future engineer as follows: "I like engineering because my dream is to help people who are poor and in need of help, so I would like to design solutions to many problems for them. This project was an eye-opening experience for me. Through this project, I learned that engineering could make a big contribution to our country." She concluded with an unwavering hope that her country could compete with Vietnam and Thailand in STEM fields. In the same context, S1 also appreciated the benefits of using a STEM education approach through the engineering design process. S1 stated that he learned how to calculate electric power (P) by using Ohm's law and the efficiency loss (Appendix 2). He went on to say, "When it generated 5V, I felt like I became someone else. I learned that I needed a strong background of physics and mathematics to solve engineering problems. Further, I realized why we needed to learn calculus and complex numbers and imaginary numbers, in order to succeed in studying engineering."

S1, S2, and S3 all stated that they learned why science and mathematics are important in solving engineering problems in daily life [34] Clearly, an integrated STEM education approach helps them to design multiple solutions to daily life engineering problems. They appreciated the benefits of using a STEM education through the engineering design process.

4.2.3 Career Goals as Engineers

Practicing the engineering design process provided an eye-opening experience for Cambodian engineering students. As noted in the participants' responses, applying engineering design into solving daily life problems was a powerful motivator that made them excited and helped increase their deep-rooted aspirations for further engineering tasks and strengthen their goals in becoming engineers. Both S2 and S3 shared their excitement of learning new knowledge and skills through the engineering design process. S2 stated, "Working on the mobile phone battery charger system got me so excited. It opened my eyes to see how I as an engineer can solve problems in my house and my country. So, I would like to say thank you for introducing STEM education to us." S3 also shared that she was so happy because she saw how each component of STEM was applied to solve a problem in daily life. She said, "This project was an eye-opening experience. . . This is so cool. I love engineering. I learned that we could apply engineering and technology to solving a lot of our life problems in Cambodia." On the other hand, S1 shared his experience with a deep-rooted aspiration for becoming an engineer who knows the scope and depth of the engineering design process. S1 stated that he had the most exciting moment when he conducted an experiment with his peers and a knowledgeable instructor who can answer his questions. For example, he said, "We collected and analyzed the data from the battery charger system we designed. We tried our initial design many times to make it work. But the regulator did not work initially because of a bad connection done by soldering. We checked the wire using a multimeter, connected seven joints by carefully soldering, and tested the system. We went to the local hardware stores back and forth (one way takes around 30 min.) a couple of times to change parts that did not work. After several trial and errors, we analyzed our data and changed the designs by taking out transistor and adding L7805 regulator. We finally found a solution to the problem. When it worked well, we were all more than excited and satisfied." This comment showed the iterative and collaborative nature of the engineering design process.

During the project, when he was stuck in problems going nowhere, he asked for help from his professor. He realized that there were numerous multiple problems which could come from the lack of STEM knowledge and skills and also from low quality materials. S1 elaborated on this aspect as follows: "Our group initially tested it with a multimeter. Then later, we were not able to figure out what was going on. So, we asked the professor for help. He told us to check the wires in the beginning, but later he said the problems may be with soldering, because we used low-quality lead. We learned a lesson that we got to double check if the materials have good quality. We finally had to redo the soldering after failures."

As shown by these participants' responses, they experienced the onerous moments that required a great deal of patience and failures during the iterative process of engineering design. They successfully solved the engineering design problems by constantly interacting, communicating, collaborating, and sharing knowledge and ideas with their peers and instructors. Finally, they were excited and satisfied when their battery charger system worked well. These experiences were novel in their eyes and of great assistance to elevating their aspiration for becoming an engineer. In other words, the experience of solving practical engineering problems by applying STEM knowledge and skills seem to help students solidify their career goals as engineers.

5. Discussion

We discussed Cambodian undergraduates' understanding of the engineering design process through four central components presented in the Result section.

5.1 Perception of the Phases of the Engineering Design Process

Going through Phases I, II, and III, Cambodian undergraduate engineering students learned a formal lesson about how to enact the engineering design process to solve the problem of a mobile phone charger system for three weeks. Although they had learned how to solve engineering problems in telecommunication through course projects, most participants have never had this type of problem-solving experience in other courses. Solving a practical engineering problem through a STEM approach was an eye-opening experience and evidently novel to Cambodian engineering majors. Upon the successful completion of the project, the interviewed students realized that engineering and the engineering design process are specifically concerned about human problems, which is in line with what is documented in literature, "to solve problems that arise from a specific human need or desire . . . engineers rely on their knowledge of science and mathematics, as well as their understanding of the engineering design process" [9, p. 27]. Cambodian engineering students perceived that the engineering design process stimulated excitement when they achieved the solution, even though it took time. They were excited when the task worked well and realized that new learning can be acquired while collaborating with each other through sharing new ideas, trying out, and redesigning as they discussed, argued, and problem-solved during the activity of creating a battery system [5]. They also perceived that the process was not always successful. As shown in the interview responses from S1 and S2, sometimes it took them nowhere, and they felt frustrated. They realized that trial and error was part of the engineering design process, which required students' persistence, self-directed strategies, and their own choices. Just like the study discussed herein, the engineering design process is non-linear but rather iterative and continuous and flexible [35, 36]. The contemporary understanding of learners' conceptions about the engineering design process includes (a) iterations in which learners go back and forth designing solutions to the engineering problems, (b) providing an authentic context for engaging learners to learn STEM concepts, applying knowledge into solving the problems and creating a prototype, and (c) developing a perspective connecting to the end users of daily life, marketplace, and society, and the role of engineering for the nation [7, 12–13, 33, 37]. This generic view of the engineering design process was manifested in the Cambodian engineering students' practices of the design process, as shown in Phases I, II, and III. Anderson and Shattuck [38] summarized this generic view of the engineering design process as follows: "design practice usually evolves through the creation and testing of prototypes, iterative refinement, and continuous evolution of the design, as it is tested in authentic practice" (p. 17). However, even at the end of project completion, Cambodian engineering majors remained in a generic view, rather than a developed, sophisticated view that explored aspects outside of the generic process (e.g., consumers' aspect, cost efficiency, technological aspect, ethics, market trends, etc.) [7].

5.2 Impact of Activity, Context, and Culture in Engineering Education

Impact of Activity and Context: One student, S3, stated with exuberance that "I love engineering." This result of learning occurred in the *authentic activity* that offered the practice of engineering design. Students then found solutions by designing and revising through multiple tests and optimizing the final product (e.g., making a stable and strong crank). Moreover, this learning process occurred in the *context* of everyday life in Cambodia. S1, S2, and S3 all mentioned that they learned why science and mathematics are important in solving engineering problems in daily life [34]. These students learned why and how engineering is critical in solving human problems through meaningful experience in authentic context, which serves as one of the goals of STEM education. For example, S1 and S2 explicitly stated that they learned how knowledge in each discipline of STEM was applied to the process of resolving the problems with the mobile phone battery charger problem. S1 specifically mentioned using a physics equation ($P = I \times V$), using mathematics to calculate the charger capacity and charger time, using technology like the shaft and gear motor and soldering, and defining and solving the problems of the battery and designing the solution to help people in rural areas. S2 explicitly explained how excited he was to learn engineering both through this project and a field trip to northeastern Cambodia because he witnessed the usability and functionality of engineering to help solve many problems of daily life in communities, society, and the nation (telecommunication problems on the borderline between Cambodia and Vietnam). Enacting the engineering design process provided an opportunity for learners to help understand how STEM knowledge is applied to solving engineering problems within a Cambodian context through continuous dialogue and collaboration with peers and professors. In addition, learning how to apply learned knowledge and achieving the successful completion of a project within the context of an engineering problem helped to solidify their interests in entering STEM fields in their future career and will improve the engineering student retention rate [39]. Currently, the engineering attrition rate in colleges is high in the United States; 60% of freshmen engineering students drop out or change majors, and more than 40% don't even make it through Year 1 [40]. Primarily, the reasons for the dropouts or change are attributed to a lack of preparedness in high school for the high level of rigor required in mathematics, physics, and chemistry preparation [41, p. 917]. At the same time, a lack of a sense of engagement in an authentic context is claimed for another reason. Although multiple reasons exist for the attrition, it can be surmised that college students are more likely to remain in engineering fields when they experience applying STEM knowledge toward solving practical engineering problems.

Impact of Culture: We claim that the *culture* of students' school life impacts their study of engineering. In our study, the culture specifically means a learning environment that permits freely asking and answering questions in class. In the interview, one student (S1) indicated that he wanted to ask questions in high school classes but could not do it because the teacher did not allow it. This type of culture is called "D-power (Deference-power or Order-giving power)" in situational stratification [25, p. 284]. According to Collins's theory, the student (S1) was under a D-power situation in which the teacher gave an order, "Do not ask questions in class," in extreme cases with an imperious tone. The D-power of the teacher was influential to that student's school experience, "shaping the 'culture' of personal relations" [25, p. 284]. He (S1) went on to say, "I love asking questions," but he could not ask because of the established situational environment in the Cambodian classroom. No one asked questions in class; thus, he just remained silent, too. This quote is in line with what Nisbett argued, that Asians faced more "*situational* factors" than Americans in determining behavior [42, 42p. 120]. In fact, Chen, Sok, & Sok [24] reported that in Cambodian culture professors are not easily available for student consultation. However, in our research's class, the professor was freely available when students had any questions regarding the project. This culture is signified by S1's comment, "This engineering class, I love it because the professor is available whenever I have a question." An engineering learning environment in which students feel free to ask, clarify, and answer questions clearly benefits students to construct meaningful learning. This perspective may well apply to those in similar learning environments around the world.

5.3 Benefits and Challenges

Benefits – Developing a Perspective from Individual to Society with Enthusiasm: In general, STEM education has two goals [43] First, STEM education seeks to build a workforce within STEM fields dedicated to increased global competitiveness nationwide. Second, STEM education seeks to increase students' interests in STEM fields. As indicated explicitly in interviews, the experience of solving a practical engineering problem helped to elevate participants' perspective from an individual to a societal and national level [33]. S3's comment about the role and benefits of engineering in STEM education connected to national interest. Because she was able to experience how her knowledge can help others in Cambodian society, she became excited at identifying as an engineer who could contribute to the society. S3's statement of "I love engineering" summarized her enthusiasm of that tacit emotion. By successfully completing such practical engineering projects, students will develop and increase their career interests in STEM discipline areas.

Challenges – Weak STEM Knowledge and Skills and Teaching Resources: Despite having completed the project successfully, Cambodian undergraduate engineering students realized that there were some challenges throughout the engineering design process. First, there is a lack of good quality materials for solving engineering problems. For example, as S2 indicated, there are not a lot of good quality materials available in the markets in Cambodia. Sometimes when engineering students need some materials (e.g., soldering lead, L7805) for solving engineering and technology problems on a project, it takes a while to find good ones. Even if materials are available in the market, they tend to be cheap and low quality and do not work well, which means that projects unnecessarily take more time to complete. In other words, participants often had to bus a couple times between the university lab and the local hardware stores to find the right parts for the system. In this Cambodian context, it was a bit hard for students to carry out engineering tasks. Second, Cambodian engineering students feel that they lack scientific and mathematical background knowledge when studying engineering. S1, S2, and S3 all mentioned the same problem as a challenge they faced throughout the mobile phone battery charger system project. For example, they mentioned the problems of mathematics study in their high school, in which they received instruction focusing on the understanding of theories and concepts with little practice pertaining to what it means and how it is applied to daily life problems. This type of problem in mathematics is well documented in Cambodia. The Ministry of Education reported that mathematics education in Cambodia currently faces problems such as "a lack of well qualified teachers, a lack of knowledge in curriculum development, text book writing, methodology of teaching and use of ICT. Currently no quality assurance mechanism is available to ensure Cambodia's mathematics curriculum is up to international standards" [9, p. 1147]. Based on these and other multiple extant problems in Cambodia – for example, a low teacher salary of USD $150 a month in 2015 and little governmental support [see Section 2.3 for more details] – mathematics teaching likely remains stuck in an outdated narrative mode rather than moving toward pedagogy-based exploratory activities and applications that center on problem-based, daily life context.

5.4 Career Goal as an Engineer for the Country

As shown in the interview, the engineering design process was an eye-opening experience for Cambodian engineering majors who participated in this study. They had never heard of the engineering design process or STEM education before. After experiencing the engineering design process, they were able to expand their perspective to visualize how engineering design can benefit their daily life and their country [7, 33]. Their learning experiences helped to strengthen their goals as future engineers. S1, S2, and S3 were able to connect their individual engineering experience to a broader context – "I felt like I became someone else" (S1), "I felt like I became a real engineer solving a daily life problem of our society" (S2) and "as a future engineer, I would be so happy if we could contribute to solving our societal problems in our country. I hope that engineering can make our country stronger" (S3). Given that Cambodia currently suffers from a severe shortage of competent engineers in engineering fields including electrical engineering, telecommunication engineering, natural resources, and bio- and chemical engineering, such engineering education with a problem-based context can ultimately lead to achieving one of the STEM education goals: to increase global competitiveness. As seen in Cambodian engineering education, other developing countries are well situated to simulate STEM-based engineering education so that engineering students have an eye-opening experience and continue to remain in the engineering fields in the future. This perspective is likely obtained when the learning environment of engineering is situated in authentic activity, context, and culture.

6. Limitation and Further Study

A small sample size is one limitation of this qualitative study. The results are reported as being limited to a generalization of this study because the small sample size may account for a lack of significant variability in the data. Thus, it may skew the data of what Cambodian undergraduate engineering students perceive and do in engineering design activity. Further study should seek to understand the greater number of students' understanding of the engineering design process. Second, further study should be carried out on how culture impacts students' learning of the engineering design process with a greater group size. Culture can be broad: it refers to classroom culture and individual learner's culture at the micro level and to culture of the entire education of a country at the macro level. As S1 mentioned, freely asking questions typically is not culturally allowed in Cambodian classrooms. In the engineering design process, however, every single calculation and physical law must be correctly performed and applied. As witnessed in the 1986 Challenger disaster, just a minor mistake or error of analysis associated with a cognitive and social-psychological error may cause a serious failure or catastrophic event in engineering [44]. Therefore, through active group collaborations, questions should be freely and explicitly asked and answered to ensure the safety and reliability of processes and systems to the greatest extent possible. Third, engineering is a discipline of problem-solving using STEM knowledge and skills. Thus, engineering students naturally collaborate with each other to solve practical problems. Group collaborations can be used to enhance critical thinking [45], create team support [46], and increase academic abilities [47] at the grade school level. However, little has been studied in engineering at the tertiary level. Therefore, further study should explore how group work and collaborations in the collaborative learning environment impact student engagement in engineering with a larger sample.

7. Conclusion

Cambodian undergraduate engineering students acquired an understanding of the engineering design process by successfully creating a mobile phone battery charger system. Regarding the phases of the engineering design process, they learned that the design process is non-linear and not always successful. Rather, the process requires persistence, self-directed strategies, iterative and continuous collaboration as well as being open to multiple solutions through revisions and tests. The impact of this project was that Cambodian engineering students gained an eye-opening learning experience in engineering. It was possible through authentic context and practical engineering problems that were cognitively situated in learning the engineering design process, especially in a culture where students feel free to ask, clarify, and answer questions. The benefit was that they gained insights into why they need to study science and mathematics at a high level of rigor in high school, which helps bridge the gap between theory and practice. Students also realized that solving engineering problems can contribute to society and the country. As demonstrated in the interview, it implies that shifting educational focus to a STEM-based approach for engineering education could stimulate more students to pursue engineering for their future career and thus help expedite closing the gap between the current lack of engineers and the need for engineers in Cambodia. The methodology adopted in this study may well apply to similarly-situated developing countries as the learning experience was evidently novel in their eyes and of great benefit to Cambodian undergraduate engineering students.

Acknowledgements – This project is based upon work supported by the Fulbright U.S. Scholar Program (U.S. Department of State Grant No. PS00254461). Any opinions, findings, and conclusions expressed in this paper are those of the authors and do not necessarily reflect the views of the Fulbright Program. We are grateful to Cambodian college students who participated in this project of engineering education and the administrative support of the Royal University of Phnom Penh to make this project run smoothly.

References

1. H. P. Brixie, *Matching aspirations: Skills for implementing Cambodia's growth strategy*, Washington DC: World Bank, 2012.
2. S. Madhur, *Cambodia's skill gap: An anatomy of issues and policy options*, Phnom Penh: Cambodia Development Resource Institute, 2014.
3. Ministry of Education, Youth and Sport [MOEYS], *Policy on Science, Technology, Engineering and Mathematics (STEM) Education*, Document published by MOEYS, Phnom Penh, Cambodia, 2016.
4. S. Khieng, S. Madhur and R. Chhem, *Cambodia education 2015: Employment and empowerment*, Phnom Penh: Cambodia Development Resource Institute, 2015.
5. J. Brown, A. Collins and P. Duguid, Situated cognition and the culture of learning, *Educational Researcher*, **18**(1), pp. 32–42, 1989.
6. C. Atman, M. E. Cardella, J. Turns and R. S. Adams, A comparison of freshman and senior engineering design processes: an in-depth follow-up study, *Design Studies*, **26**(4), pp. 325–357, 2005.
7. J. M. Walker, D. S. Cordray, P. H. King and R. C. Fries, Expert and student conceptions of the design process: Developmental differences with implications for educators, *International Journal of Engineering Education*, **21**(3), pp. 467–479, 2005.
8. UNESCO, *Education and literacy – Cambodia*, 2018. Accessed on March 15, 2018 from http://uis.unesco.org/country/KH/
9. C. Roath, Mathematics education in Cambodia from 1980 to 2012: Challenges and perspectives 2025, *Journal of Modern Education Review*, **5**(12), pp. 1147–1153, 2015.
10. M. Q. Patton, *Qualitative evaluation and research methods (4th ed.)*, Los Angeles, CA: Sage, 2015.
11. S. B. Merriam, *Qualitative research and case study applications in education*, San Francisco, CA: Jossey-Bass, 1998.
12. T. J. Moore, A. W. Glancy, K. M. Tank, J. A. Kersten, K. A. Smith and M. S. Stohlmann, A framework for quality K-12 engineering education: Research and development, *Journal of Pre-College Engineering Education Research (JPEER)*, **4**(1), pp. 1–13, 2014.
13. National Research Council [NRC], *A Framework for K-12 science education: Practices, crosscutting concepts, and core ideas,* Washington D.C.: The National Academies Press, 2012.

14. S. A. Wind, M. Alemdar, J. A. Lingle, R. Moore and A. Asilkalkan, Exploring student understanding of the engineering design process using distractor analysis, *International Journal of Engineering Education*, **6**(4), pp. 1–18, 2019.
15. D. J. Jonassen, J. Strobel and C. B. Lee, Everyday problem solving in engineering: Lessons for engineering educators, *Journal of Engineering Education*, **95**(2), pp. 139–151, 2006.
16. R. L. Bell, L. Smetana and I. Binns, Simplifying inquiry instruction, *The Science Teacher*, **72**(7), pp. 30–33, 2005.
17. P. E. Carspecken, *Critical ethnography in educational research*, London, UK: Routledge, 1996.
18. R. G. Bogdan and S. K. Biklen, *Qualitative research for education: An introduction to theories and methods (4th Ed.)*, Boston: Allyn & Bacon, 2013.
19. R. K. Yin, *Case study research design and methods (3rd ed.)*, Thousand Oaks, CA: Sage, 2003.
20. J. A. Maxwell, *Qualitative research design: An interactive approach*, Thousand Oaks: Sage, 1996.
21. L. Birt, S. Scott, D. Cavers, C. Campbell and F. Walter, Member Checking: A tool to enhance trustworthiness or merely a nod to validation? *Qualitative Health Research*, **26**(13), pp. 1802–1811, 2016.
22. United Nation, *Cambodia energy sector strategy*, 2018. Accessed on April 10, 2018 from http://www.un.org/esa/agenda21/natlinfo/countr/cambodia/energy.pdf/
23. VDB/LOI, *Cambodia power sector update*, 2018. Accessed on March 17, 2018 from http://www.vdb-loi.com/wp-content/uploads/2018/04/Cambodia-Power-Update-April-2018.pdf/
24. C. Chen, P. Sok and K. Sok, Benchmarking potential factors leading to education quality: A study of Cambodian higher education, *Quality Assurance in Education*, **15**(2), pp. 128–148, 2007.
25. R. Collins, *Interaction ritual chains*, Princeton, NJ: Princeton University Press, pp. 258–296, 2005.
26. Achieve, Inc., *The next generation science standards (NGSS), 2013.* Accessed 27 January 2018 from http://www.nextgenscience.org.
27. T. Floyd, *Electronic devices (9th ed.)*, Prentice Hall, NY, pp. 870–882, 2012.
28. D. Johnson, *Fundamentals of electrical engineering I*, Texas: CONNEXIONS, Rice University, pp. 47–93, 2008.
29. STMicroelectronics, *The output current of IC L7805 regulator*, 2018. Accessed on March 24, 2018 from http://pdf1.alldatasheet.com/datasheet-pdf/view/243283/STMICROELECTRONICS/L7805CV.html
30. nTimer Web Solution, *The battery charge time duration*, 2011. Accessed on April 24, 2018 from http://www.meracalculator.com/physics/classical/batteries-charge-time.php.
31. J. W. Stevens and G. P. Corey, A Study of Lead-Acid Battery Efficiency Near Top-of-Charge and the Impact on PV System Design. 13–17 May 1996. Accessed on Aug. 1, 2019 from https://ieeexplore.ieee.org/abstract/document/564417.
32. M. G. Herron, The nature of scientific enquiry, *School Review*, **79**, pp. 171–212, 1971.
33. D. Duncan, H. Diefes-Dux and M. Gentry, Professional development through engineering academies: An examination of elementary teachers' recognition and understanding of engineering, *Journal of Engineering Education*, **100**(3), pp. 520–539, 2011.
34. R. W. Bybee, Advancing STEM education: A 2020 vision, *Technology and Engineering Teacher*, **70**(1), pp. 30–35, 2010.
35. D. P. Crismond and R. S. Adams, The informed design teaching and learning matrix, *Journal of Engineering Education*, **101**(4), pp. 738–797, 2012.
36. C. Atman, J. Chimka, K. Bursic and H. Nachtmann, A comparison of freshman and senior engineering design processes, *Design Studies*, **20**(2), pp. 131–152, 1999.
37. Yaşar, D. Baker, S. Robinson-Kurpius, S. Krause and C. Roberts, Development of a survey to assess K-12 teachers' perceptions of engineers and familiarity with teaching design, engineering, and technology. *Journal of Engineering Education*, **95**(3), pp. 205–216, 2006.
38. T. Anderson and J. Shattuck, Design-based research: A decade of progress in education research? *Educational Researcher*, **41**(1), pp. 16–25, 2012.
39. American Society for Engineering Education, *Best practices and strategies for retaining engineering, engineering technology and computing students*, Washington, D.C., 2012.
40. American Society for Engineering Education, *Engineering by the numbers: ASEE retention and time-to-graduation benchmarks for undergraduate engineering schools*, Departments and Programs. Washington, DC: Brian L. Yoder, 2016.
41. B. B. Geisinger and D. R. Raman, Why they leave: Understanding student attrition from engineering majors, *International Journal of Engineering Education*, **29**(4), pp. 914–925, 2013.
42. R. E. Nisbett, *The Geography of thought: How Asians and Westerners think differently . . . and why*. New York, NY: Free Press, 2004.
43. E. Machi, *Improving U.S. competitiveness with K–12 STEM education and training*, A Report on the STEM Education and National Security Conference. Heritage Special Report, SR-57, 2009.
44. R. Collins and R. Leathley, Psychological Predispositions to Errors in Safety, Reliability and Failure Analysis, *Journal of Safety and Reliability*, **14**(3), pp. 6–42, 1995.
45. P. Mosley, G. Ardito and L. Scollins, Robotic cooperative learning promotes student STEM interest, *American Journal of Engineering Education*, **7**(2), pp. 117–128, 2016.
46. G. M. Jacobs, *Ten strengths of how teachers do cooperative learning*. Online Submission. Accessed on Aug. 1, 2019 from http://files.eric.ed.gov/fulltext/ED573761.pdf, 2016.
47. A. Jansen, Developing productive dispositions during small-group work in two sixth-grade mathematics classrooms: Teachers' facilitation efforts and students' self-reported benefits, *Middle Grades Research Journal*, **7**(1), pp. 37–56, 2012.

Do-Yong Park is an Associate Professor in the College of Education at Illinois State University, USA. Dr. Park is the recipient of a 2018 Core Fulbright US Scholar award. His research interests lie in STEM Education, particularly engineering education. He earned his bachelor's degree in science education from Seoul National University of Education, Republic of Korea in 1987, a master's degree from West Chester University, USA in 1996, and Ph.D. degree in science education from The University of Iowa, USA in 2001. Currently, his research focuses on engineering education; engineering knowledge and design; Makerspace and Internet of Things in science education.

Dae Hwan Bae is a Professor at the Department of Telecommunication and Electronic Engineering at The Royal University of Phnom Penh, Cambodia. He is a Faculty Fellow and the recipient of a 2015 award from Hunsen, the Prime Minister of Cambodia for aiding the development of education. Dr. Bae is also an Advisor to the Vocational Orientation Department at the Ministry of Education and Youth, Sports in Cambodia. His research focuses on teacher training, analysis of EMI/EMC environment and engineering education. He received a BS in Automatic Control of Engineering at Bukyeung National University in Korea in 1995 and MS and PhD degree in Radio and Telecommunication Engineering from Korea Maritime University in The Republic of Korea in 2001.

Appendix 1

Electrical Characteristics of L7805 IC

Symbol	Testing Condition	Min [V]	Type [V]	Max [V]
VO	TJ = 25 °C	4.9	5	5.1
VO	IO = 5 mA to 1A, VI = 7.5 to 18V	4.8	5	5.2
VO	IO = 1A, VI = 18 to 20V, TJ = 25°C	4.8	5	5.2

Note: VO = Voltage Optimization, TJ = Operating Junction Temperature, IO = Current (I) Optimization, VI = Voltage Current.

Appendix 2

Calculation for Efficiency Loss

Efficiency Loss	Calculation
No Efficiency Loss	MTFC = ((BC/CRC) × 11)/10 or MTFC = ((BC/CRP) × 11)/10
10% Efficiency Loss	MTFC = ((BC/CRC) × 11)/10 or MTFC = ((BC/CRP) × 11)/10
20% Efficiency Loss	MTFC = ((BC/CRC) × 12)/10 or MTFC = ((BC/CRP) × 12)/10
30% Efficiency Loss	MTFC = ((BC/CRC) × 13)/10 or MTFC = ((BC/CRP) × 13)/10

Note: MTFC = Maximum Time to Full Charge (h); BC = Battery Capacity (mAh); CRC = Charge Rate Current (mA); BP = Battery Power (Wh); CRP = Charge Rate Power (W).