Arduino for Chemical Engineering Students via Game-based Learning

Article history
Received
3 April 2020
Received in revised form
28 April 2020
Accepted
30 April 2020
Published online
2 June 2020

Muhd Nazrul Hisham Zainal Alam
School of Chemical and Energy Engineering, Faculty of Engineering,
Universiti Teknologi Malaysia, Malaysia.
Email: nazrulhisham@utm.my

Abstract

This paper presents author experience in teaching Arduino for chemical engineering students using the game-based learning teaching methodology. Learning outcomes associated to the work included attainment of necessary technical skills related to Arduino and development of essential attributes especially team-working, communication and problem-solving through the proposed game-based learning method. The mechanic of the game proposed is based on the snake-and-ladder board game where students need to complete series of tasks using a customized Arduino learning kits to complete the game. Rubrics were formed to evaluate student's competency and achievements on the tasks given. Compared to the teacher-centered method, an increased in student performance by at least 40-50% was achieved. The learning structure of the game were formulated to achieve different level of cognitive skills namely comprehension, apply and analysis and therefore, allowed them to meet the learning outcomes. Majority of the students agreed that the game-based learning method conducted has successfully created an enjoyable learning environment and excite their interest on Arduino where nearly 70% of the respondents believed that the game had made them acquired the lifelong learning and team-working skills.

Keywords: Arduino, chemical engineering, active learning, game-based learning, programming

Introduction

Arduino is an open-source data acquisition device based on easy-to-use hardware and software (Husain et al., 2016). It is inexpensive (Arduino UNO board cost merely 10-15 USD per unit), can operates on Windows interface and it is very straight forward to use for beginners (non-computer specialties). Moreover, it has the capacity to read direct-current (DC) voltage inputs (both analog and digital signals) from a variety physical sensors and execute commands (send out output signals) to actuators for realization of a simple automated control system. Most importantly, data attained will be in real time (Husain et al., 2016; Yasin et al., 2018). Such tools would open the opportunities to create a variety of hands-on and data driven projects that could easily benefit chemical engineering students.

Elmer and Krout (2018) proposed a teaching module for the training of chemical engineering student on design and fabrication of a mini scale spectrophotometer platform using Arduino. Circuit for the operation of the spectrophotometer were made using low cost electrical components such as light-emitting-diode (LED), photo-resistor, etc. and Arduino as programmed to control the light transmission for the optical measurement. This is quite an advance module and was implemented as a design course for the duration of six weeks. Barcia-Quimí et al. (2017) used an Arduino MEGA board for the automation of lab scale distillation column as a low-cost solution for automated chemical processes. Their work demonstrated on how Arduino can be utilized as part of a lab work exercise for chemical engineering student. Furthermore, Arduino has also been applied as a teaching aid to support the teaching and learning activities of core chemical engineering subjects (Omar, 2018, Pereira Filho et al., 2014). The content of the lectures were modified to include experimental part using Arduino board to validate the theoretical concepts taught during the lecture. Omar (2018) applied numerical solution using Arduino to evaluate the chemical reaction kinetics in a batch reactor whereby Pereira Filho et al. (2014) utilized Arduino in chemical engineering process control course where students were given the chance to build their own Proportional-Integral-Derivative (PID) controller.

Clearly, Arduino could not only be a beneficial teaching tools in the field of chemical engineering but it is also a useful skill set for the student. Anyone who master such a skill would have the capacity to design and/or fabricate their own prototypes and therefore, eliminating the need to rely too much on commercial equipment or devices which are usually expensive. Despite the obvious advantage, Arduino is never included in the syllabus of chemical engineering degree program. It cannot be directly introduced as a new course because the curriculum of chemical engineering major is already compacted with courses related to thermodynamics, transport phenomena, reactor design, etc. Moreover, not all of the faculty member is an expert in using Arduino. One of the logical option would be to include the topic about Arduino as part of the lecture content in any of the chemical engineering courses.

In this paper, author experience in conducting lectures about Arduino for the chemical engineering student is presented. Topic about Arduino was introduced as part of the lecture in the "Introduction to Programming" course. The work emphasis on educating the student about the basic functionality of Arduino which included serial communication with

Arduino, read and build an electronic circuit and obtainment of analog/digital inputs from various sensors using Arduino. Teaching chemical engineering majors about programming and application of Arduino is not the same as teaching them about mass transfer or transport phenomena. This is simply because programming and basic electronic hands-on work are not their main forte. In the first attempt, the end results were rather disappointing. The students were keen to learn about Arduino but fail to translate knowledge gained in their final examinations where overall student performance were below average. Two main issues were recognized. First, tasks associated to Arduino were assigned to individual and many were unable to explore the device on their own. Secondly, teaching and learning activities were not properly designed to develop student cognitive skills for the topic.

To address this issue, the classroom requirements and teaching activities for learning Arduino are carefully reviewed. Lectures cannot be totally eliminated but must be limited only to brief the student about Arduino. Practical exercises are necessary as the student need to learn about how to initiate the communication with Arduino, build the electronic circuit and know how to write program to run the Arduino. Hands-on work is essential but should not be as extensive as a laboratory session. Extra attention should be given to team-working and critical thinking as these values are needed during the learning processes. Methodology used must take into account the use of specific tools (in this case Arduino board) and availability of laptop or computer. Knowledge gained should be shared and assessed during/after the learning session. These circumstances has led to the selection of the game-based learning teaching methodology. In a game-based learning method, instructor create a competitive exercise so that students would compete against one another to accomplish the same learning outcome (Qian and Clark, 2016; Youngkyun, 2006).

Apart from the experience sharing, the aim of the study was to comprehend students' learning motivation, learning process and achievements on learning Arduino through game-based learning method. The study was conducted with the use of a customized board game and Arduino learning kits. The board game used imitates the classical "Snake and Ladder" board game where students were required to complete series of tasks and assignments to complete the game. Assessments on the performance of the students were made on three main aspects; learning process, learning motivation and learning achievements. The latter was done through quiz, assignments and examinations. Output from this activity – including results of survey analysis were discussed to evaluate the following research questions:

- What is the perception of the students on the game-based activities towards learning Arduino?
- Does the game-based learning method improve student performance and develop necessary cognitive skills?

Game-Based Learning: General Perception

Game-based learning refers to a type of active learning methodology that uses games to support the teaching and learning activities (Carenys and Moya, 2016). The content of the lecture is incorporated into games in order to motivate the learners and to develop/practice a wide range of skills (Gee, 2008). Positive outcomes are often the results in game-based learning when learning theories is associated to the game. One of the advantage of game –based learning over other types of active learning technique is that it drives the student towards the development of the essential 21st century skills. The 21st century skill sets included critical thinking, creativity, collaboration and communication (Binkley et al., 2014). Another important point is that game-based learning is a platform typically used by many educators to educate the student about something that is incomprehensible through a normal lecture (Sousa and Rocha, 2019). This means that the subject of interest requires both deep understanding and active involvement of student (Abbot 2019). Studies also show that game-based learning is much suited to current millennial generation since social networking platforms (Facebook, WhatsApp, etc.) and computer games has becoming their informal learning environment (Jain and Dutta, 2018).

The idea of creating games to encourage student towards achieving a specific goal has been widely applied. Azizan et al. (2018) developed a board game to teach third-year chemical engineering students about reaction kinetics and reactor design. The board game was embedded with various technical questions and values attained (creativity, deep learning and team-working) were evaluated using questionnaire and survey analysis. Miller et al. (2019) invented a strategy card game called the 'Green Machine' as a mean to educate student about recycling processes and green chemistry. Learning gain from the endeavor was evaluated using pre- and post-test questions. Cardino and Fairfield (2019) created an astronomy board game and utilized it as a teaching tools in physics education. Their methods not only improve student social skills but also has broaden student's view on physics and its applications.

It is obvious that the game-based learning method has many positive values. Nevertheless, if such learning technique is not properly executed, it would easily ended as an activity merely to provide students with a game to play. Students will be motivated but without any (or with very little) knowledge acquisition (Qian and Clark, 2016). Game-based learning is also rather demanding as the game design and play will not only require the players to be critical thinkers but also demands those involved to be familiar with media and technology (Sousa and Rocha, 2019; Qian and Clark,

2016). Moreover, in order to design a game for a specific educational purposes, one needs to acquire a deep understanding on the game plan/structure, knowledge of the subject, time frame and also a s (Qian and Clark, 2016; Azizan et al., 2018). The size of the classroom is also crucial and small sizes class often results in increased of participation, devotion and would improve the communisolid understanding about teaching-learning theoriecation between the instructor and the students (Murdoch, and Guy, 2002).

Application Design

Teaching overview and participants

Topic about Arduino was included as part of the lecture content in the "Introduction to Programming" course. The course is offered to the second-year chemical (bioprocess) engineering program in School of Chemical and Energy Engineering, Universiti Teknologi Malaysia and the content of the course is mainly about application of basic engineering based software and compiled languages. The nature of the course suited well as a platform to teach chemical engineering student about the fundamental of Arduino. Every year, approximately 40 to 50 students registered for this course where enrolled students are divided into two sections and thus, giving maximum number of students per section to about 25 students.

The course was held in a computer lab and the lecture time available for teaching and learning activity was approximately 3 hours. In order to integrate Arduino into the course, the course content was divided into three parts. First, series of lectures about C programming language. Secondly, training on how to use Microsoft Excel and Microsoft Visio software for chemical engineering application. In the last phase of the course, the lectures on Arduino will be given where topic discussed included general definition about Arduino and benefits of Arduino to chemical (and biochemical) engineers. Lecture time (plus implementation of the pause procedure activity) was limited only for 20 minutes. Shortly after the lecture, the game-based learning was initiated. For this purpose, several groups were formed. Each group consisted no more than five students. Heterogeneity of each group was ensured by forming the group consisting of students with grade-point-average (GPA) greater than 3.0/4.0 and students with GPA lower than 3.0/4.0.

Learning outcomes

The following learning outcomes were identified in our implementation of the game-based learning for teaching the student about Arduino:

a) In the end of the exercise, the student would gain technical skills in applying Arduino microcontroller platform for a simple automated measurement system.
b) Essential attributes such as team-working, communication and problem-solving skills will also be developed in the exercise.

Before initiating the game-based learning activity, each group were asked to install the Arduino programming language into their computers or laptop. The software was downloaded from an open-source (*www.arduino.cc*).

Game mechanics

A game board similar to the mechanics of the classical "Snake and Ladder" board game was utilized for the game-based learning activity. The game board contained of a starting grid, a path and the finish line (Figure 1).

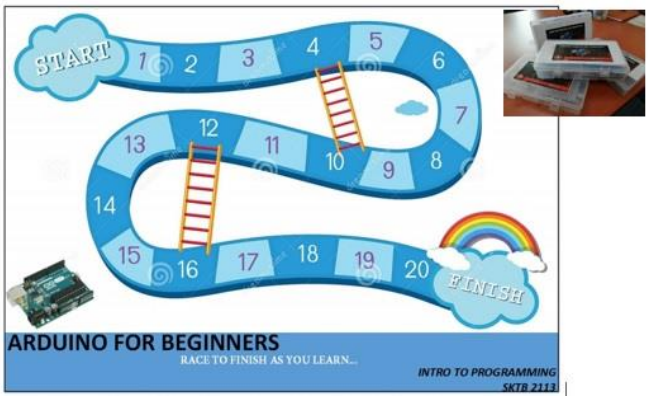

Figure 1. The customized board game imitating the classical "Snake and Ladder" game that was used for teaching students about Arduino. Inset is the image of the customized Arduino learning kit used in this activity.

Players (i.e. each group) may only move their token along the path after completing series of tasks using a customized Arduino learning kit. Tasks given were designed specifically for the development of student cognitive skills and attainment of essential attributes. Each tasks need to be completed sequentially. Moreover, in order to create enjoyable learning environment, the group that completed the task within or faster than the given time frame may exert penalties to other groups and therefore, increases their chance of winning the game ahead of other teams. Details of each tasks for the game-based learning activity are as follows:

Task 1: Introductory Focused Discussion Pairs – Quiz about the features of Arduino

The first task was the "Introductory Focused Discussion Pairs" activity where each group needed to complete a short quiz about technical aspects of Arduino board.

Quiz	Rubrics
1) Voltage limit for analog input pin of Arduino? 2) How many analog input pin for Arduino Uno? 3) How many digital pin does Arduino Uno has?	1) Each group must answer all questions correctly 2) No time limit but those who finished first will be rewarded 3) Answers: Q1 – 0-5V; Q2 – 6 inputs; Q3 – 14 pins

Upon completing this task, students were given the Arduino learning kit and allowed to proceed with the board game. The customized Arduino learning kit contained the Arduino Uno board and several basic electronic components such as light-emitting-diode (LED), jumper wires, push-buttons and resistors.

Task 2: Positive interdependence and face-to-face interaction – presentation of working schedule

In this step, students were given a survey card to identify individual skills/resources. They were required to discuss with one another and decide on the group working plan/schedule for the upcoming hands-on tasks. Card used for this task is presented below:-

Group Assignment	Rubrics
Plan your work for your upcoming tasks. Who would do what? 1) Read/sketch circuit diagram 2) Write and upload coding into Arduino 3) Present work to instructor & state group reflection	1) Each member must participated 2) Each member must involve in at least two of the group assignments 3) No time limit. 4) Must return survey card back to instructor to proceed.

Each group must return the card to the course instructor in order to claim the next reward i.e. allowed to move *2 steps forward*.

Task 3: Learning by doing activity I – Arduino to read analog voltage

This was the first practical exercise for the students. Each group were required to build a circuit and Arduino programming to read analog voltage of a battery using materials from the Arduino kit. Rubrics for this task is as follows:

Group Assignment	Rubrics
Read voltage of batteries using Arduino	1) Must build a circuit for measurement of two batteries 2) Must write a program for automated measurement of analog voltage 3) Must demonstrate the workability of the system to instructor. 4) No time limit but there will be awards for those who completed it under 15 minutes.

Completion of this task will allow the team to move *4 steps forward*. If task completed under 10 minutes, the team may use a ladder or exert 3 minutes halt to other teams. If task completed less within 10-15 minutes, the team will gain 1 extra step.

Task 4: Learning by doing activity II – LED blinking exercise

In this step, students had to read a circuit diagram and uploaded the **Arduino programming for 'LED blinking'** according to the following schematic (Figure 2).

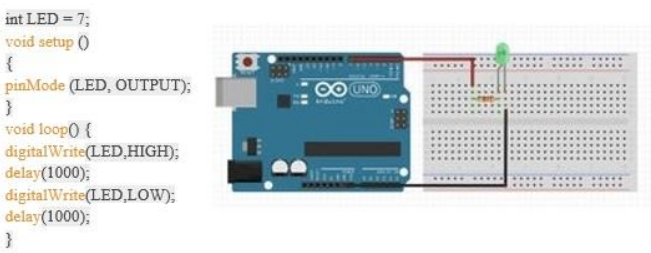

Figure 2. Schematic and coding for the LED blinking exercise.

Rubrics for this task is as follows:

Group Assignment	Rubrics
Circuit diagram and program for making LED blinking is given. Each group is required to realize it.	1) Each group is required to build the circuit and write the program according to the information given. 2) System is considered working when LED is continuously blinking. 3) Must demonstrate the workability of the system to instructor. 4) No time limit but there will be awards for those who completed it under 15 minutes.

Completion of this task will allow the team to move *4 steps forward.* If task completed under 10 minutes – the team will gain 2 extra steps or exert 3 minutes halt to other teams. If task completed within 10-15 minutes, the team will gain 1 extra step. Additionally, students who somewhat sort out a way to modify the timer for the LED blinking period will be given *1 bonus step* upon completion.

Task 5: Learning by doing activity III – Solving the 'Push button' issue

In this task, students had to read a circuit diagram and uploaded the Arduino programming for 'Push-button' task according to the following schematic. There is however a hidden problem associated to the task and each group need to identify it and solve it whilst completing the task. (Figure 3).

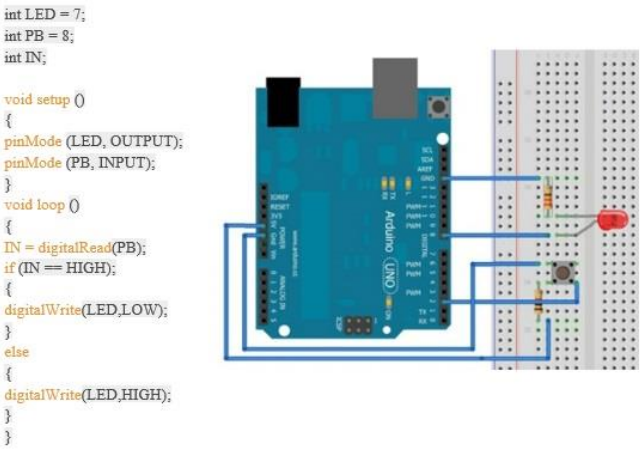

Figure 3. Schematic and coding for the 'push button' exercise.

Rubrics for this task is as follows:

Group Assignment	Rubrics
Circuit diagram and program for making operating a push button function is given. Each group is required to solve hidden issue associated to the task and make it operational.	1) Each group is required to build the circuit and write the program according to the information given. 2) Each group needs to identify and solve hidden problem associated to the task. 2) System is considered working when push button can be used to control lighting of LED. 3) Must demonstrate the workability of the system to instructor. 4) No time limit but there will be awards for those who completed it under 15 minutes.

Completion of this task will allow the team to move *4 steps forward.* If task completed under 10 minutes, the team will gain 2 extra steps or exert 3 minutes halt to other teams. If task completed within 10-15 minutes, the team will gain 1 extra step.

Task 6: Student reflection on activity

The final step is the '*Students reflection*' task. Competing teams may only cross or go straight to the finish line after they had showed a proof that the team had given their reflection (and pictures) on the activity and uploaded it into the faculty e-portfolio page. This step is essential as the student could reflect on what they have learnt and the course instructor would receive immediate feedback on the effectiveness of the activity.

The game-based learning activity was designed such that it can be completed in less than 2.5 hours. Table 1 presents the mapping of each tasks of the proposed game to the attainment of relevant skills/attributes and knowledge.

Data collection and assessment

In this study, both qualitative and quantitative methods were utilized for collecting and analyzing of data (mixed methods). For evaluation on the achievement of the learning outcomes, assessments were done by (1) classroom observation and evaluation of student output of each task, (2) peer-rating evaluations where each team member evaluates the contributions of his/her teammates and (3) post-examinations. The latter is a form of summative assessment in order to measure to what extent the students have met the learning outcomes. Examinations were carried out a week after the activity where questions were focused on Arduino technicalities, wiring schematics and troubleshoot of Arduino programs. Peer rating evaluation form used is presented in Table 2.

Additionally, a questionnaire survey using multiple choices questions was given to the student in order to assess student perception on how the game had affected their critical thinking. Students were also required to give feedback about applicability of game-based technique as a learning tool for topics associated to Arduino (i.e. final task of the game). Thematic analysis was performed on the feedbacks received in which repetitive (or similar) text/comments were first identified before grouping them into themes that are related to the research questions imposed for the activity. In this case, essential individual attributes and acquisition of technical skills.

Results and Discussion

Learning motivation and learning process

A game-based learning method was implemented as a mean to teach chemical engineering students about Arduino. It was carried out as part of the course learning activity in the 'Introduction to Programming' course. The activity was successfully implemented and it took nearly 2 hours to complete. Evident of student participation in this activity is shown in Figure 4.

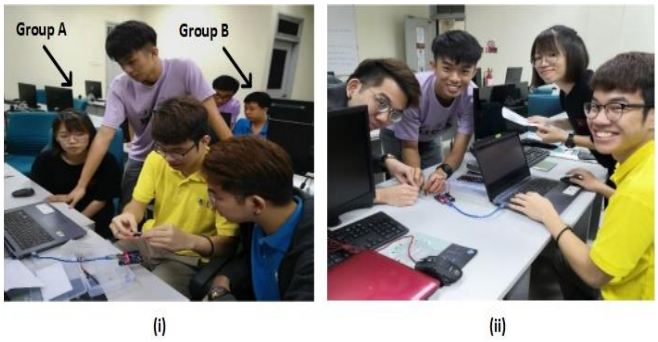

Figure 4. (i) Picture of two different group of students working closely with their team members to complete one of the tasks required. (ii) Picture of students enjoying their assignment on Arduino.

A quick lecturing session (~20 minutes) before starting the gamification session was essential in order to channel the students into the right mood towards learning Arduino via the game-based learning method. Surprisingly, once the session began, it was found that the student were not at all felt awkward or reluctant to participate in such gamification session. In fact, they jumped right in and eager to find out more about the learning activity. Based on our random interviews with the student, three main factors could have contributed to this response. First, it is due to the fact that Arduino is highly relevant to the field of chemical engineering and somewhat became the driving force that made them wanted to learn more about the topic. Secondly, are their attraction and curiosity towards gamification of any sorts particularly the ones that they could benefited upon. The third factor could probably because of their previous experiences in active learning methods. Students enrolled in this course is already in their second year of their study. They have been exposed and/or experience different active learning techniques on various subjects in their first

year of study (Sadikin et al., 2019). These experiences could have motivated them to join any sorts of active learning activities.

The lecturing session was meant to train the student about the fundamentals of Arduino. On this basis, the game was structured such that the learning curve (i.e. both knowledge acquisition and cognitive development) of the student could steadily progresses in stages. It started with cognitive level of 'knowledge' where student need to first recognize what is Arduino in general and the information was acquired from the lectures prior to initiation of the game-based learning activity. Next, student began to interpret the knowledge gained by answering some basic questions about Arduino (cognitive level – comprehension). This particular session was designed to develop student lifelong learning skills in performing literature search. Each group needs to learn how to look for relevant information on their own rather than to ask instructors for answers. In the subsequent session, students started filling the task division survey card. The intention simply to encourage the student to start cooperating and engage with one another about each other responsibilities (positive interdependence nature). This is important before proceeding to the practical part in order to prevent anyone from dominating all the work.

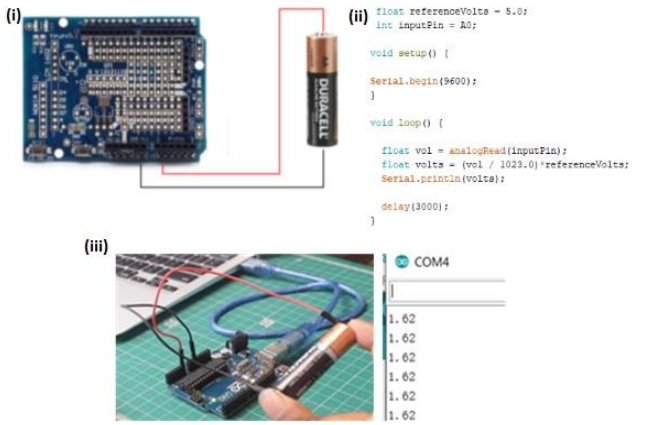

Figure 5. (i) Wiring schematic for reading analog voltage of a battery. (ii) Coding required for the reading analog voltage using Arduino. (iii) Circuit built by the students and the results attained from their online measurements task.

Figure 5 shows the results produced by one of the competing groups on the reading analog voltage of a battery task (*step 3 of the game*). Neither guidance nor lecture notes were provided to the students prior to completion of the task. Schematic diagram of the wiring connection (Figure 5(i)) and coding for Arduino program (Figure 3(ii)) needed for the task were obtained by their own efforts i.e. through seeking the required information from the internet. Based on the data attained, students built the circuit and demonstrated its functionality (Figure 5(iii)). Our team already anticipated the outcome of the first task. We were certain that the students were able to complete it without much difficulty. This is because Arduino microcontroller platform itself is a very easy-to-use data acquisition device and there are abundance of information about Arduino in the internet that can be accessible by anyone. During presenting their work, students did address some technical questions. These included (1) inquiry about the build-in analog-to-digital converter (ADC) that reads the voltage values as a number between 0 and 1023 which technically proportional to the amount of voltage being applied to the designated analog input pin, and (2) the reason about the need to convert it to actual voltage values before print it out to the serial monitor of the Arduino software. Apart from this, we noticed that several groups did face some trouble establishing a serial communication with the Arduino board. But before the instructor had the chance to provide help, the students somehow sorted it out on their own after exploring the Arduino software and some reading. The gamification factor had pushed them to a point where failure is not an option. Progress made by the students at this stage were very satisfying. Clearly, the student had reached the 'application' stage. Besides actively interacting with their peers and the course instructor, students were very determined to complete any given task and proceeded to the next stage of this Arduino game-based learning activity.

The last two hands-on assignments (*step 4 and 5 of the game*) were designed to train the students on how to read an electronic schematic. Students were required to first read the given schematic and analyze it before realizing a functional Arduino program (cognitive level – analyze). A majority of the students found this rather challenging. This is probably because reading, building and troubleshoot of an electronic circuit is more of a basic skill for electronic engineers. Nevertheless, after several attempts, students did manage to complete the tasks. This session was found to be the most time consuming compared to the other tasks during this game-based learning activity. Although the entire activity had consumed nearly two hours, students remained highly motivated. Not a single student was complaining or showed any sign of boredom. Towards the end of the activity, as the work gotten a little intense, the students were still very enthusiastic to complete the tasks at hand. In fact, the sound of joyful cheering were heard across the lecture room. This was truly unexpected. It was believed that i.e. throughout the activity, positive learning environment was successfully created. In brief, a positive classroom environment is a sort of learning environment that made students feel a sense of belonging, trusting one another and feeling encouraged and motivated to tackle any challenges (Felder and Brent, 2007; Yang, 2015). That is exactly the kind of situation the students were in during the implementation of the Arduino game-based learning session. Despite the fact that they were literally competing with one another, those who had finished early decided to help out their colleagues. Such situation could also be regarded as a type of collaborative learning initiative where students shared

their findings and encourage each other to complete tasks given (Laal, and Ghodsi, 2012).

Student Perception

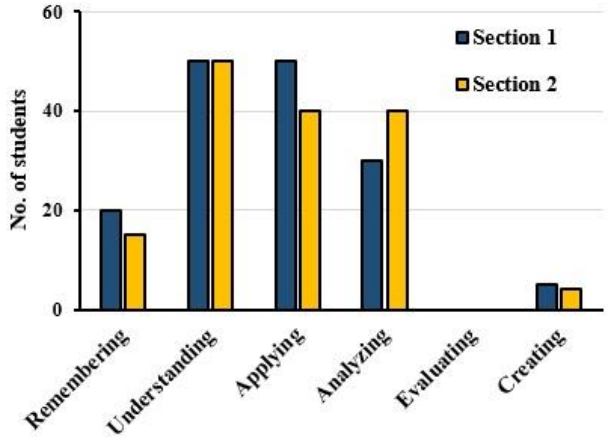

Figure 6. Results of a general survey performed on the students participated in the course from two different sections.

Figure 6 presents the results of a general survey performed on the students participated in the course from two different sections. In the survey, students were asked about the level of critical thinking attained from the Arduino game-based learning activity. Majority of the students were certain that the game-based learning method applied has helped them to understand the topic better. The structure of the exercise enabled them to explain the concept of Arduino and understood about the significance of Arduino in the field of chemical engineering. They also believed that the learning activity is not about remembering and/or recalling of information about Arduino (Figure 6). In fact, it has helped them to move beyond that and deeper into application and assessing the subject from various perspectives (level 3 and level 4 of Bloom's Taxonomy for higher order thinking in learning). This was benefited directly from the tasks associated to sketch, read and build of an electronic circuit. Data search for seeking of relevant information whilst carrying out those tasks furthermore strengthen the students understanding about Arduino. A small number of students were convinced that team working have sparked their creativity and acquired the highest level of thinking in the Bloom's Taxonomy (i.e. creating). They are confident that they could put all the necessary elements together to get the Arduino to work for a basic real-time monitoring task. This is indeed a critical skill for chemical engineers and/or those who interested to venture upon the field of process automation and control. In current curriculum, hands-on use of sensors and actuators for process automation is only taught to the senior students (third year and final year students) in unit operations and process control laboratories. Through this Arduino game-based learning activity, junior year students will now have the opportunity to learn and acquire fundamental knowledge about process automation and control system.

Before finishing up the activity, the students were required to give some reflections of what they had learnt throughout the activity. Randomly selected reflections from the student are summarized in Table 3. Based on the info in Table 3, student did express their satisfaction with the learning experience by playing the game. They collectively agreed that the active learning elements promoted in the game was entertaining. Some of them claimed that the activities were challenging at first but the nature of the game somewhat motivated them to be creative and therefore, gaining new set of skills. Analysis based on the student feedbacks indicated that nearly 70% of the respondents believed that the game had a more significant impact on individual attributes compared to acquisition of technical skills particularly lifelong learning and communication skills. Indeed, because in the game, student were encouraged to interact with others while attempted problems given in various conditions. Most of the students enrolled in the course are group of students in millennial generation where gamification and gadgets are not something out of norm. We took advantage of this to gain their interest and taught them about a new technology that is highly relevant in their line of work. Results from the study are in agreement with findings by various researchers that also practiced the game-based learning in engineering field (Azizan et al., 2018; Cardinot and Fairfield, 2019).

Learning achievements

In order to evaluate the effectiveness of the Arduino-game based learning method, examinations were organized to assess the student on three different aspects; technicalities about Arduino, wiring schematics about online measurements using Arduino and troubleshooting of errors in coding for Arduino operation. Test scores are indeed a direct measurement to assess student knowledge acquisition about Arduino.

Figure 7(a) and 7(b) depicts the performance of two different batches of students taking similar exams in 2018/2019-I semester and 2019/2020-I semester, respectively. In 2018/2019-I, there were nearly 60 students enrolled in the course (*Introduction to programming*) with two faculty members teaching the topic about Arduino. The teaching style was mostly teacher centered with not much of practical work involved. However, in 2019/2020-I, a total of 52 students registered for the course and the course was handle by one faculty member where Arduino was taught using the game-based learning technique. As shown in figure, there was a significant improvement on the student performance i.e. at least by 40-50% increase for all type of questions. Results attained were also compared using the two level independent-means t-test to determine the p-value and statistically, there is indeed a significant difference between the two groups (p-value = 0.000138; $p < 0.05$). Clearly, the exercise in the game-based learning activity has proven to be beneficial for the students.

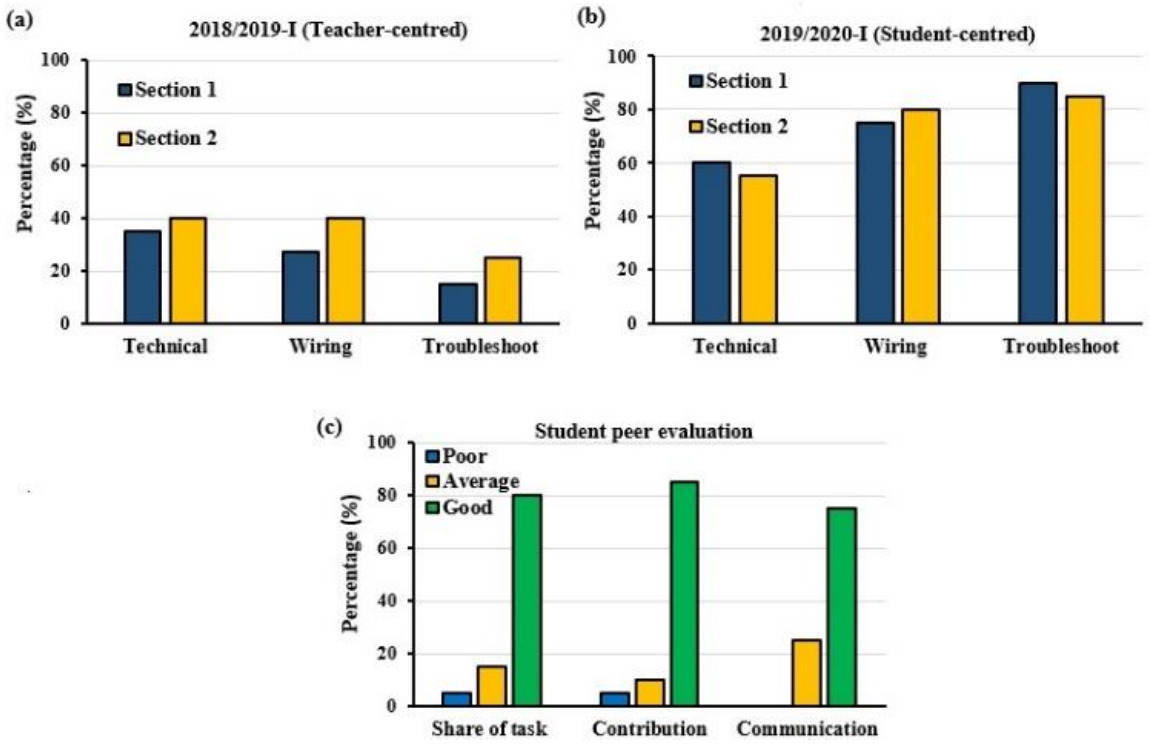

Figure 7. Performance of two different batches of students taking similar exams in (a) 2018/2019-I semester and in (b) 2019/2020-I semester, respectively. (c) Results of student peer evaluation on task sharing, contribution and effectiveness of communication.

In 2018/2019-I, Arduino UNO board was given to each individuals for them to explore but in 2019/2020-I, student were trained to use Arduino in a group – a form of collaborative learning environment (Laal, and Ghodsi, 2012). Group formation ensured that the knowledge gained was shared by all and not dominated by few good students. This maybe one of the reasons why the overall exam scores is higher in 2019/2020-I session. Another important point is that in 2018/2019-I, there was no clear learning structure for the student. On the contrary, in the proposed game-based learning activity, the learning process is aligned with Bloom's taxonomy that encouraged student to seek new information and directly applied it in different levels (comprehension, apply and analysis) and hence, enabled the student to achieve the learning outcomes of the game.

Despite a solid improvement, achievements of the learning outcomes to the certain extent are still far from perfect. The data (Figure 7b) shows that in 2019/2020-I session, whilst 75% of the student in managed to answer the part about wiring schematics and troubleshooting correctly, the results on questions about Arduino technicalities were less convincing – merely 60% of the students answered it correctly. One clear explanation about the results attained is that the students did not seem to remember much about the technical aspect of Arduino. It was suspected that maybe student are much eager to get involved in the practical aspect of the game and less time were spent on technology literacy of Arduino. In fact, maybe only few who truly spent time on it where majority of them would prefer to get their hands on Arduino and solve real case problems. Obviously, not everyone participated in the activity were able to sustain the knowledge gained. A slight worrying fact and perhaps it would be better if a proper (and simple) learning module should be provided as well for this sort of gamification learning activity. This way knowledge gained and essential discussion points can be recorded for future preferences.

The students were also asked to assess their group members on task sharing, contribution and effectiveness of communication amongst them. Based on the input from the students, it shows that majority of the student (> 75%) believed that their peers have done a fair share of work and significantly contributed to the work given during the activity. Only a minority of them thought that their peers could have done more. Communication between the group member were not an issue at all with nearly 80% of the student agreed that they had appropriately interact with one another. This is an interesting statistics and signified that the learning environment created in the game prevented anyone from becoming a dominant figure that would take charge of all the work. Sometimes, teamwork does not naturally take place when a group of student sits together to work on something specific. Consequently, weak students simply setback and became passive learners. This is however not the case for the proposed game-based learning activity. By introducing the task division assignment (*step 2 of the game*), everyone shared the load of each tasks. They had to plan, communicate and learnt on how to cooperate with one

another. It was seen that one student was exploring the learning kit whilst the rest of the group members focused on other tasks at hand such as programming of Arduino, wiring and even seeking information from the internet. Such scenario was consistent in all of the competing groups. Clearly, satisfactorily amount of communication was displayed and the game had successfully promoted team working skills amongst the student.

Conclusion

A game-based learning method was successfully implemented for teaching chemical engineering majors about Arduino and its basic operation. The learning activity was carried out for a second year student using a customized board game that imitated a classical snake-and-ladder board game. An Arduino learning kit was customized and use as a teaching tool in this game-based learning activity. Since students have already gained fundamental knowledge about C programming language, students did not show much of a difficulty when working with Arduino programming interface. By taking the students through a step by step introduction to various basic components of Arduino, it helped the students to understand the subject better. Practical work through series of tasks allowed the students to learn Arduino through 'seeing' the concept and somewhat made the students to think out of the box. Moreover, apart from knowledge about basic electronics and the application of Arduino, other skills gained through the activity included team working, communication and problem solving skills. Indeed, learning Arduino do benefit chemical engineering majors and now; a skill that is normally seen amongst electrical engineering majors can be instilled into chemical engineering students.

Application of Arduino should be further exploited in other chemical engineering courses. In this course, student only gained basic skills about Arduino. However, if they were given the chance to use Arduino in actual chemical engineering practice, it would made them an expert user and enabled them to develop their creative thinking skills. Arduino can be used to control pumps and this is useful in many chemical engineering course such as fluid mechanics, process control, etc. A project-based assignment can for example be formulated with the use of Arduino. Cost incurred in each project is not really a major concern because additional electrical parts such as power supply, flow sensor, and other electronics components are available online or it can even be purchased from any local electronic store inexpensively. Lack of experience or expertise amongst the faculty member should not be used as an excuse as well. This is because there are abundant of programs (coding) for control of various sensors and actuators for Arduino in the internet that can be used as references.

Acknowledgement

Our team would like to express our gratitude to the second year students of chemical-bioprocess engineering program of academic session 2019/2020-I for their participation in the activity. The work is partially funded by Universiti Teknologi Malaysia Prototype Research Grant (#00L49).

References

Abbott, D., 2019. Game-based learning for postgraduates: an empirical study of an educational game to teach research skills. Higher Education Pedagogies, 4:1, 80-104, DOI: 10.1080/23752696.2019.1629825.

Azizan, M. T., Mellon N., Ramli, R.M., Yusup, S., 2018. Improving teamwork skills and enhancing deep learning via development of board game using cooperative learning method in Reaction Engineering course. Education for Chemical Engineers. 22, 1-13.

Barcia-Quimí, A. F., León-Munizaga, N. C., Aguirre-Munizaga, M., Hernandez-Mendoza, L., Vergara, V.,2017. Automation of a Distillation Column of Packed Bed for an Alcohol Solution using Arduino. Revista internacional de investigación y docencia, ISSN 2445-1711.

Binkley, M., Erstad, O., Herman, J., Raizen, S., Ripley, M., Runmble, M. 2014. Partnership for 21st century skills. Retrieved from http://www.p21.org/.

Cardinot, A., Fairfield, J. A., 2019. Game-based learning to engage students with physics and astronomy using a board game. International Journal of Game-Based Learning (IJGBL). 9(1), 42-57. doi: 10.4018/IJGBL.2019010104.

Carenys, J., Moya, S. 2016. Digital game-based learning in accounting and business education. Accounting Education. 25(6), 598–651.

Elmer, J. J., Krout, D. A., 2018. 3-D printing and Arduino in the chemical engineering classroom: Protein structures, heat exchangers, and flow cells. ASEE Annual Conference & Exposition. Salt Lake City, Utah. https://peer.asee.org/29653.

Felder, R.M., Brent, R., 2007. Cooperative learning. ActiveLearning: Models from the Analytical Sciences, vol. 970. ACS Symposium Series. 34–53.

Gee, J. P., 2008. Game-like learning: an example of situated learning and implications for opportunity to learn. In Assessment, equity, and opportunity to learn. 200-221.

Husain, A. R., Hadad, Y., M. N. H. Z. Alam., 2016. Development of low-cost microcontroller-based interface for data acquisition and control of microbioreactor operation. Journal of Laboratory Automation. 21, 660-670.

Jain, A., Dutta, D. 2018. Millennials and gamification: Guerilla tactics for making learning fun. South Asian Journal of Human Resources Management. 1-16. DOI: 10.1177/2322093718796303.

Laal, M., Ghodsi, S. M., 2012. Benefits of collaborative learning. Procedia – Social and Behavioral Sciences. 31: 486-490.

Miller, J. L., Wentzel, M. T., Clark, J. H., Hurst, G.A., 2019. Green machine: A card game introducing students to systems thinking in green chemistry by strategizing the creation of a recycling plant. Journal of Chemical Education. 96: 3006-3013.

Murdoch, B., Guy, P. W., 2002. Active learning in small and large classes. Journal of Accouting Education. 11(3): 271-282.

Omar, H. M., 2017. Enhancing automatic control learning through Arduino-based projects. European Journal of Engineering Education. 43(5), 1-12.

Pereira Filho, R. D., Furlong, V., Vieira Costa, J. A., 2014. Dynamic simulation of chemical Kinetics in Microcontroller. International Journal of Engineering Research and Applications. 4 (12), 34-38.

Qian, M., Clark, K. R., 2016. Game-based Learning and 21st century skills: A review of recent research. Computers in Human Behavior. 63, 50-58.

Sadikin, A. N., Mohd-Yusof, K., Phang F. A., Abdul Aziz, A., 2019. The introduction to engineering course: A case study from

Universiti Teknologi Malaysia. Education for Chemical Engineers. 28, 45-53.

Sousa, M. J., Rocha, A., 2019. Leadership styles and skills developed through game-based learning. Journal of Business Research. 94, 360-366.

Yang, Y. T. C., 2015. Virtual CEOs: A blended approach to digital gaming for enhancing higher order thinking and academic achievement among vocational high school students. Computers & Education. 81, 281–295.

Yasin, A. I., Prima, E. C., Sholihin H., 2018. Learning electricity using Arduino-Android based game to improve STEM literacy. Journal of Science Learning. 1(3), 77-94.

Youngkyun, B., 2006. Understanding and application of game-based learning. Educational Science Press, Seoul.

Appendix

Table 1. Mapping of tasks to the attainment of skills/attributes and knowledge gained.

Activity	Skills/Attributes	Knowledge gain	Award/penalties
Task 1 Complete a short quiz given by course instructor	Literature search (lifelong learning) Sharing of info (information management and communication)	Basic features of Arduino	First to answer all questions correctly get *2 minutes head start*. Move two steps forward and collect Arduino kit
Task 2 Discussion and presentation of working schedule	Face-to-face interaction (communication)	Task division/scheduling	Move two steps forward.
Task 3 Read voltage of batteries using Arduino	Literature search (lifelong learning) Team working Face-to-face interaction (communication)	Build a simple electronic circuit Programming to read analog voltage	Move 4 steps forward. If completed < 10 mins -may use ladder or exert 3 mins penalty If completed within 10-15 mins, gain 1 extra step.
Task 4 Realize the program for making LED to blink.	Team working Face-to-face interaction (communication)	Read and build a simple electronic circuit Programming to manipulate system output.	Move 4 steps forward. If completed < 10 mins -gain 2 extra steps or exert 3 mins penalty If completed within 10-15 mins, gain 1 extra step. 1 bonus step if manage to modify timer for LED blinking.
Task 5 Solving and realizing the 'Push button' issue to control lighting to LED.	Critical thinking Problem solving Team working Face-to-face interaction (communication)	Solve and build a simple electronic circuit Programming to manipulate digital output to actuator.	Move 4 steps forward. If completed < 10 mins -gain 2 extra steps or exert 3 mins penalty If completed within 10-15 mins, gain 1 extra step. 1 bonus step if manage to modify timer for LED blinking.

Table 2. Peer rating evaluation form used to qualitatively assess student team-working and contribution during the activity

Criteria/Rating	Poor	Average	Good
Share of Task	Did little, almost no work or did not do any work at all.	Did average amount of work and could have done more.	Did fair share of work.
Contribution & Quality of Work	Made little contribution to team discussions and decision. Quality of work was very poor.	Made valuable contribution to team discussion and decision. Quality of work was average and could have done more.	Contributed far beyond average in team discussion and decision. Quality of work was excellent.
Communication	Never listen and at times argue/speak appropriately with team members.	Sometimes listen and speaks appropriately. Sometimes argues inappropriately with team members.	Always listen and speaks appropriately. Never argues inappropriately with team members.

Table 3. Selected reflections from the students about the Arduino game-based learning activity.

Gender/ethnic	Reflection
Female/Chinese	Active learning offers different ways of learning including small group discussion, own learning through website and others. Everyone has different types of learning and I am a slow learner so it is quite hard let me to catch up. However, with the help of the lecturer and my course mates I finally get some skills about MsExcel, C and Arduino. **Keywords: Communication, Lifelong learning, Challenging, New skill sets.**
Female/Chinese	I found active learning very interesting but also quite challenging when it comes to using software that are very new to me . I am quite confused at first for those commands/functions that are new to me but throughout the whole learning process I manage to find out whatever confused me and learnt something new. **Keywords: Fun, Challenging, Lifelong learning.**

Male/Chinese	I really appreciate the active learning activities given by lecturer. It took some time for me to complete the assignment, but the knowledge I gained really worth the time. I found that for this subject, self-learning is more important than attending lecture. To master this subject required many try and error, and learn from mistake we made. **Keywords: Fun, Challenging, Lifelong learning, New skill sets.**
Male/Malay	The lecturer's approach is very intuitive. The tips and tricks given during active learning helps a lot in understanding the concepts and ideas that are to be analysed. **Keywords: Fun.**
Female/Malay	For me, active learning help me learn this programming skill better. I can understand and retain the information better. I can also discover new things by myself and widen my view on certain things. Furthermore, I can think more creatively instead of think inside the box. **Keywords: New skill sets, Lifelong learning, Creative thinking.**
Male/Indian	I'm glad that this subject is carried out in an active learning manner! I have always wanted to learn programming and my first choice before entering this degree program was cyber security. I realized that the way the lecturer conducted the class through active learning is great, though it takes up more time for me personally to understand the idea and the language of C++ and Arduino, it provides more insight and self -satisfaction. **Keywords: Fun, Challenging, Lifelong learning, New skill sets.**
Male/Chinese	The active learning has a bit of challenging for me as I need more time to understanding the content. But, this is also making fun for me as I can enjoy myself in try and error. **Keywords: Challenging, Fun.**
Female/Malay	For me, active learning help me learn this programming skill better. I can understand and retain the information better. I can also discover new things by myself and widen my view on certain things. Furthermore, I can think more creatively instead of think inside the box. **Keywords: Lifelong learning, Creative thinking.**

Website link from which the comments were taken from:
https://eportfolio.utm.my/artefact/artefact.php?artefact=655102&view=152995