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Assessing the Impact of a Project-Based Learning Robotics Course with Integrating of STEM Education Using Content Analysis Method

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ABSTRACT

The National Science Foundation (NSF) proposed in 1996 "Shaping the Future" report that "STEM" (Science, Technology, Engineering, Mathematics) is a set of education methods that focus on learners. The STEM education actively cultivates students' independent thinking and creativity in the learning process. In recent years, the use of STEM education methods in teaching has become a trend in Taiwan's education system. In this study, a content analysis method is used to analyze and observe the knowledge learned and the attitude toward STEM education for a total of 30 junior students, who have no background in robotics-related professional knowledge, after taking a semester of project-based learning (PBL) robotics general course from National Chiayi University, Taiwan. From the study results, it is found that by integrating STEM into the acquisition of robotics, students can use logical thinking, compile different programs, increase their understanding of technical operations, and finally create more methods to complete the project. On the other hand, through PBL, students can stimulate thinking in discussions with their peers, and achieve the effect of problem-solving and stress-less learning. The findings of the study also show that the PBL robotics course provides the learning aids which is beneficial in exercising STEM education learned by learners.

Keywords: project-based learning, robotics, STEM education, content analysis method

INTRODUCTION

For a long time, academia has realized that experimental hands-on education can provide practical meaning for the original abstract knowledge, which provides an excellent motivation for learning new knowledge. Curriculum in robotics has been proven to be one of the best tools for hands-on learning, because it includes not only the machinery and mechanisms of the robot itself, but also the general interdisciplinary of science, technology, engineering, and mathematics, i.e., STEM. Robotics not only is a good learning environment for the application of STEM education (Kim et al., 2015) but it also provides a platform by integrating the STEM education for learners (Barak and Assal, 2018) In the learning theory, project-based learning (PBL) is regarded as an effective means of organization learning. Members participating in project-based learning usually undertake a specific task while focusing on the same goal or product as other project members. As the project develops, participating members must collect, analyze, and synthesize information from various sources to form knowledge, and communicate and share knowledge with team members to produce results through collaboration, and finally display the results or present the final product before the project deadline. Project-based learning not only can involve project members and give them their own tasks and learning responsibilities, but group members can also learn in-depth knowledge most effectively through the project team. This study uses a qualitative content analysis research method to analyze the impacts of project-based learning robotics course for STEM education, and tries to answer the following two questions:

1. How does the application of project-based learning (PBL) for STEM education curriculum help student's learning?
2. How can students benefit from integrating STEM teaching methods into robotics learning classrooms?

LITERATURE REVIEW

Nugent et al. (2010) studied whether teaching robotics in summer camp courses can affect students' STEM learning and found that robotics courses indeed can enhance students' hands-on practice, creativity, and self-learning ability. They also claimed that such STEM-related robotic camp courses provide young learners with an excellent opportunity to get involved in STEM activities and concepts. Through hands-on and inquiry-oriented robotics experimentation and design, such technologies can help youth to translate abstract mathematics and science concepts into concrete real-world applications (Nugent et al., 2010). Karahoca et al. (2011) taught robotics courses to elementary and middle school students aged 10-15 and encouraged them to participate in robotics competitions. The authors found that robotics design courses can enhance the ability of elementary and middle school students in technology and engineering, as well as their self-confidence, and help school children to learn from team design. Since robots and STEM are both interdisciplinary, it is indeed a feasible teaching and learning platform to realize STEM learning using robotics courses. With the rapid development of information technology (IT) and knowledge economy, as well as the rapid development of artificial intelligence and robotics, technology-based universities and colleges are experiencing of information technology paradigm shift from teaching the fundamentals IT knowledge to IT-related industry education (Lenschow, 1998). How to keep up with the development of the IT industry and train students with characteristics related to the information technology industry so that they can adapt to the job market has become one of the most important issues for technical colleges' students. On the other hand, the development of a knowledge society with information technology has also put forward new requirements for higher education, that is, students learn the content of knowledge that he/she is interested in and require professors to provide the required learning resources. Many educators are aware of the urgency of IT education reform to meet the current needs and future trends of the information and artificial intelligence industry and society.

In response to learners' changes in learning paradigms, the academic world has implemented curriculum reforms through work-based learning (WBL) and project-based learning (PBL) in recognizing the field of general learning technology (Gibson, 2003). Different from the traditional classroom teaching/examination method of teaching and student learning, providing industry-related project-based learning courses mean providing students with more industry-related content and self-study opportunities. Therefore, among the curriculum reforms, project-based learning (PBL) has attracted more attention in technology-oriented schools and learning institutions. Rhodes and Garrick (2003) believe that project-based learning is an attempt to integrate learning into project work, so the project results are based on both task and learning. They suggested that the participation of academia and companies in PBL should focus on teamwork, leading practical activities, and promoting reflection in the company's training plans and practical tasks. Therefore, project-based learning seems to be a possible innovative learning strategy to meet the needs of academia and companies in the changing learning paradigm. Project-based learning is also used as an effective means to provide on-the-job training for employees in the industry as well. Keegan and Turner (2001) pointed out that in project-based companies, some influencing factors may hinder project-based learning, such as time pressure, centralization, and delay. Considering that project-based learning has the nature of such influencing factors in the industry, similar influencing factors may also hinder the adoption of project-based learning teaching methods and lesson plans in universities, thus affecting the effectiveness of learning.

METHODOLOGY

In the methods of analyzing and evaluating the results of project implementation and the key factors affecting success, past literature studies have suggested cognitive map representations that can be used to extract and analyze personal mental models (Laukkanen, 1994). Cognitive map, also called cause map, is composed of nodes and arrows linked to each other (Weick and Bougon, 1986). Nodes usually represent "concepts", that is, the phenomenon that the owners subjectively perceive in their domain of knowledge, while the arrows represent their "beliefs" in the relationship that produces effects (causality). Such a cognitive map of interconnected concepts and beliefs can therefore model the causal thinking pattern of individuals or organizations and is often called a mental model. Laukkanen (1994) developed a two-stage information acquisition method and analyzed the acquired data through a series of analysis and linking processes to generate the final cognitive map. Laukkanen (1994) uses cognitive maps to compare management thinking and organizational cognition in real life. Weick and Bougon (1986) link the meaning of the organization with the cognitive map to explain that the consciousness of the organization exists in the thoughts of the participants of the organization, and the existence of the organization is presented in the form of a cognitive map. They suggest that the way of cognition of the organization should start from the participants editing their own organizational experience into a personal knowledge model, and the representation of this knowledge is called a cognitive map, which is composed of the concepts and relationships used by participants to understand the organizational situation. Carley (1997) uses textual analysis technology to extract personal cognitive maps from interview data, locate similarities between maps, and generate team cognitive maps by combining the similarities of various maps. According to her research, each person's cognitive map can be interpreted as the interviewee's mental model. The team mental model can also be generated by combining the similarities of the cognitive maps in the team. The team cognitive map generated by intersecting with individual cognitive maps represents the team cognitive map for effective teamwork. Therefore, this study adopts the qualitative content analysis research method to analyze the key characteristics of a project-based learning educational robotics course for STEM education. Integrating STEM activities and concepts for educational robotics not only help students in solving complex design problem, but it also provides an innovative learning environment in enhancing and building higher order computational thinking skills and programming abilities (Atmatzidou and Demetriadis, 2016). To conduct this research, a "Robotics Computational Thinking and Programming" general course is offered for junior college students with no background in robotics-related professional knowledge from National Chiayi University, Taiwan. Students were invited to answer the following two questions in the final week of the course after accomplishing the course assignments and final contest. And the full text of answers will be analyzed using the content analysis method to construct the cognitive map of each student.

- How does the application of project-based learning (PBL) for STEM education curriculum help student's learning?
- How can students benefit from integrating STEM teaching methods into robotics learning classrooms?

COURSE INFORMATION

A "Robotics Computational Thinking and Programming" general course is offered for junior college students with no background in robotics-related professional knowledge from National Chiayi University, Taiwan in Fall semester, 2020. There were 30 students enrolled in the course, including 9 girl and 21 boy students with ages among 20 to 22 years old. Three students are organized into a team for the "Robotics Computational Thinking and Programming" project-based learning course. After accomplishing all the course assignments and the final contest of S-shape racing track time trial, all students were invited to answer the aforementioned two questions in the final week of the course. Due to the COVID-19 pandemic, the planned interview was replaced with writing answer to the application topics. And there were only 25 students writing the answers and uploading the answering file to our course websites. The educational robotics used for the course is LEGO Mindstorms EV3, the third-generation robotics kit in LEGO's Mindstorms line. It uses a program called LEGO Mindstorms Education EV3-G to write code using software blocks by point-and-click and drag-and-drop instead of lines. (https://en.wikipedia.org/wiki/Lego_Mindstorms_EV3). The example of class assignment by integrating STEM to the EV3 Robotics application is listed in the **Table 1**.

Table 1. Example of class assignment by integrating STEM to the EV3 Robotics application

Assignment #3	To design an EV3 for running 2 meters precisely by using manual operation of EV3.
Allowed time	30 minutes
Principle	The radius of a circle is *r*, the perimeter of the circle is $2\times\pi\times r$
Requirements	Employing STEM and taking steps of computational thinking to accomplish the assignment
Suggested steps	1. Measuring the radius of the wheel of your EV3 robot car, calculating the perimeter of the wheel, and using a rule to make sure the length of the perimeter
	2. Measuring how many rotations wheel runs with 2 seconds and calculating distance the robot car goes
	3. Estimating how many seconds it will takes for the robot car to go for 2 meters, and run it

In teaching the **Table 1** assignment for an example, the teacher first explained the theory of motor for driving the robot car, and the STEM activities and concepts listed in **Table 1** were then introduced. The grading policy was that the first team to accomplish the assignment will obtain the highest grade, the slowest obtain the least

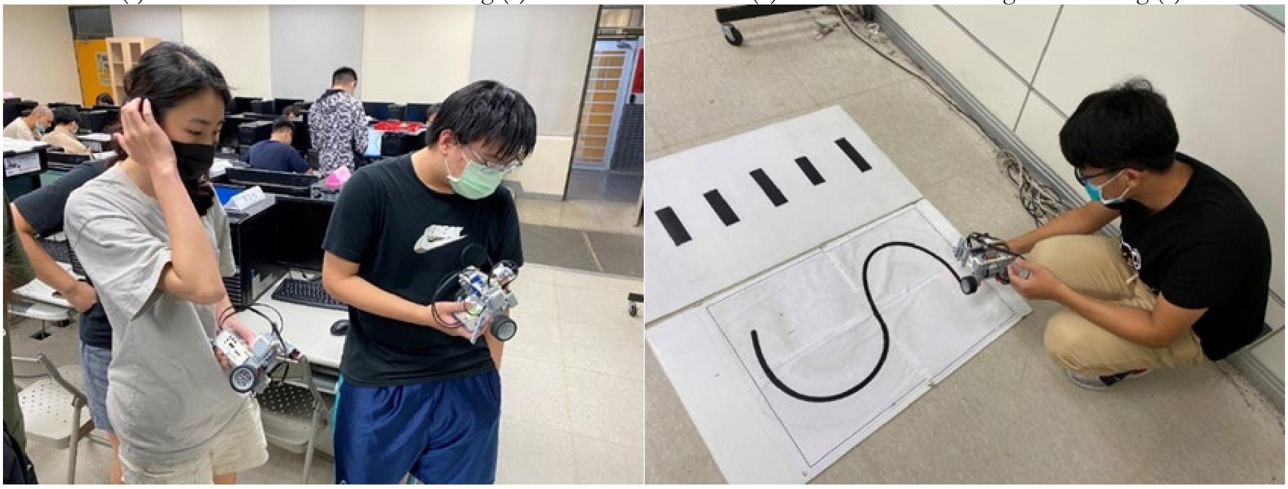
Table 2. Rules for the final contest of S-shape racing track time trial

Dimensionality of the robot car	The robot car should be fitted within an A4 size paper
Playing field	80 cm × 60 cm, width of the black S-shape racing track is 2 cm
Rule 1	Each team has two times for racing by following on the S-shape racing track. The shorter time of accomplishing the time trial will be recorded
Rule 2	Each team has the allowable 3 minutes to make changes to their robot car in the preliminary round
Rule 3	The 4 shortest time trial team will be allowed for running in the final run.
Scoring policy	Preliminary round: 85 for accomplishment S-shape racing track time trial, 80 for these failed teams. Final run: 98, 94, 90, and 88, respectively for the first, second, third, and the fourth shortest time trial team.
Notes	The judge will determines whatsoever not mention in this rule

Table 3. The class photos

(a) Students are in class and learning (1)

(b) Students are in coding and learning (2)



(c) Students are in preparation for testing

(d) Student is under testing the robot S-shape racing track time trial

grade, and so on and so forth. Team of student was hence motivated to cooperate in group discussion in winning the highest grade. Even though the students are not used to group discussions before.

The rules of the final contest of S-shape racing track time trial are listed and explained as in the **Table 2**. Some of the class photos are shown in **Table 3**.

RESULTS AND FINDINGS

The full text answered by the students were collected from the feedback at the end of the semester. By highlighting keywords and the cause-and-effect relevance in the article, a cognitive map with logical thinking can be constructed.

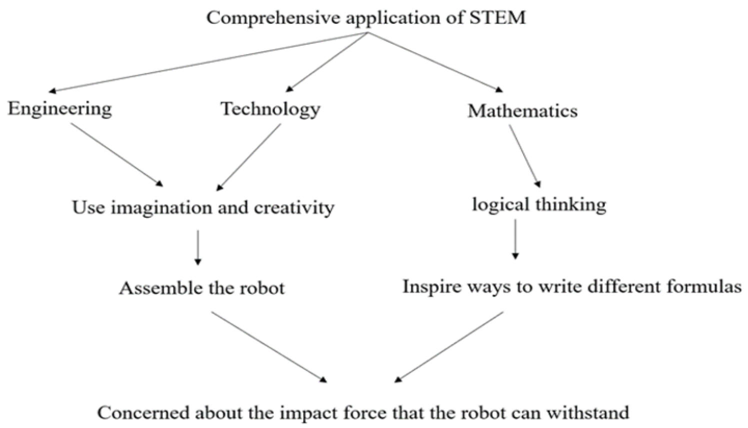


Figure 1. The example cognitive map of student #8

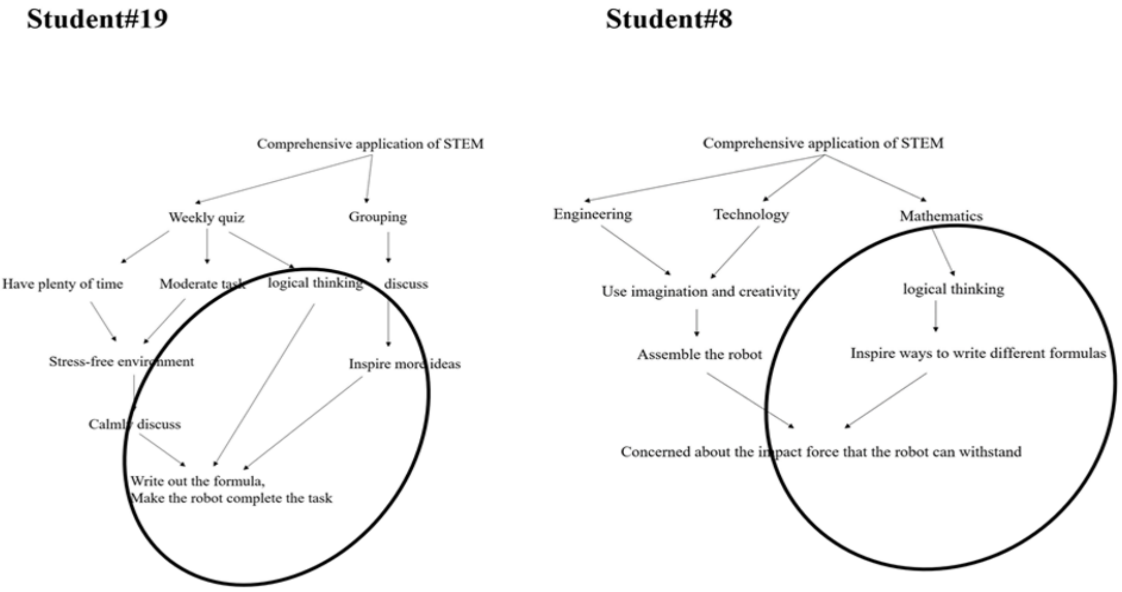


Figure 2. Comparison of cognitive maps of student #19 and student #8

How Does the Application of Project-Based Learning (PBL) For STEM Education Curriculum Help Student's Learning?

Now the issue of "How does the application of project-based learning (PBL) for STEM education curriculum help student's learning?" will be analyzed by examining the individual cognitive map as well as the team cognitive map, and by deciphering the mental model of corresponding cognitive maps. To illustrate how the cognitive map is constructed, the full text and the associated cognitive map of student #8 are listed in the following as an example. The first step in constructing the cognitive map is to extract the concept as the bold words below.

> This course is of great help to **technology**, **engineering**, and **mathematics** in the **comprehensive application of STEM**. Through the formula design, the robot can move forward, backward, rotate, etc. It can be regarded as a kind of **technology**. Assembling robots is part of **engineering**. While **using imagination and creativity**, we also **concerned about the impact force that the robot can withstand**. In addition, the possibility of **inspiring ways to write different formulas** through **logical thinking** is mathematics.

The second step of concept linking is to find out the relevant cause and effect between these keywords and use an arrow to connect the keywords of cause to the keywords of effect, and finally to draw a cognitive map which is shown in Figure 1.

It can be seen from Figure 1 that based on project-based learning, combined with the learning tools of "Engineering", "Technology", and "Mathematics" in STEM, student #8 inspired a variety of different formulas through logical thinking, and was also able to exert imagination and creativity in assembling the robot.

A second and third set of full text data from student #1 and student #19 were analyzed for comparison purpose. Comparison results for the cognitive maps of student #19 and student #8, and for the cognitive maps of students # 19 and student #1are shown in the Figure 2 and Figure 3, respectively.

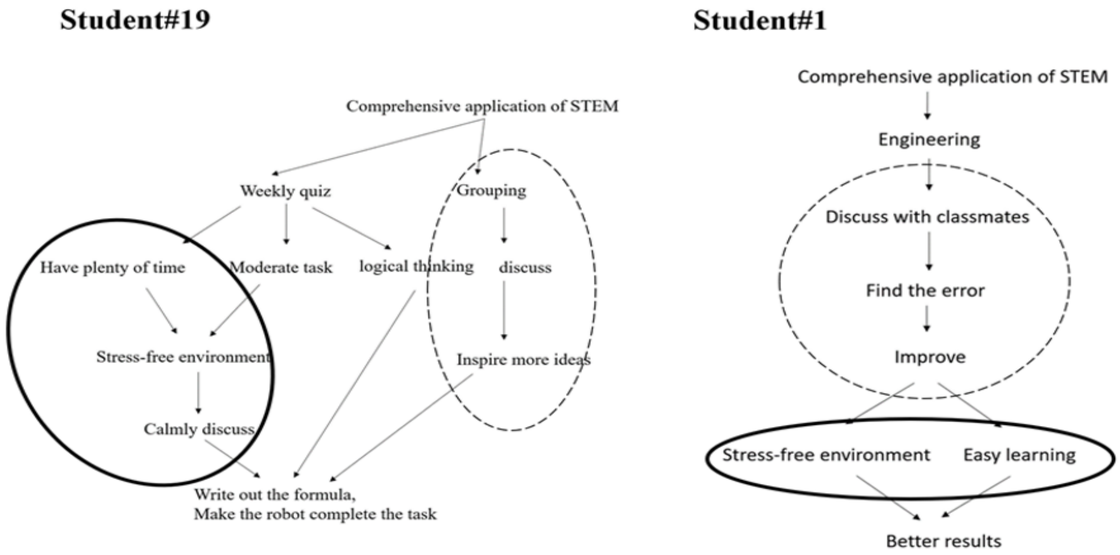


Figure 3. Comparison of cognitive maps of student #19 and student #1

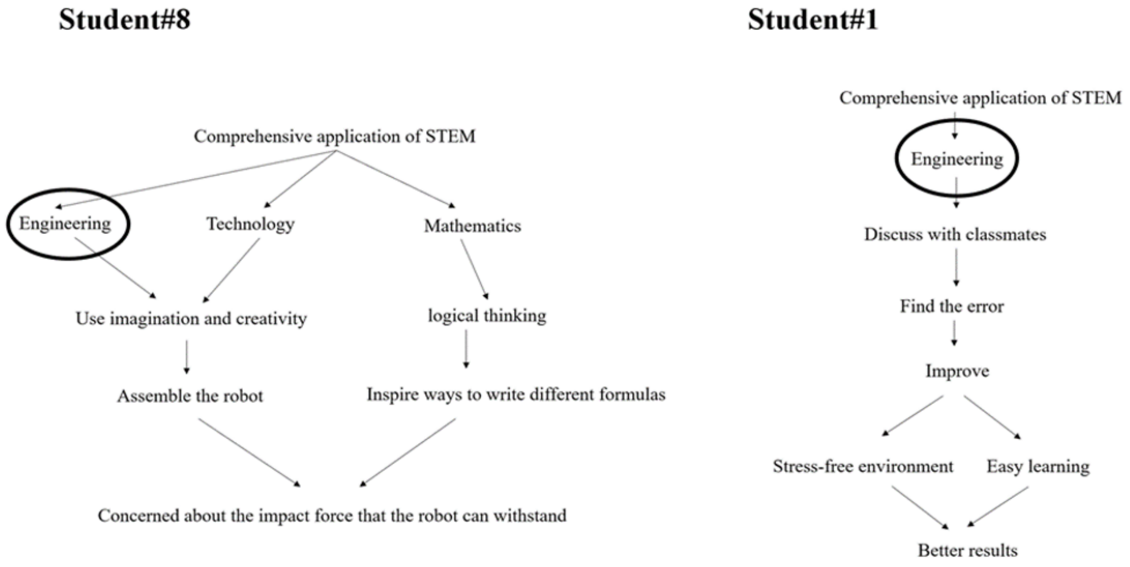


Figure 4. Comparison of the cognitive map of student #8 and student #1

By examining the cognitive map of student #19 as in the left of **Figure 2**, it is found that in one hand through weekly quizzes, student #19 was able to come up with more ideas through group discussions. On the other hand, by appropriate learning tasks and sufficient preparation time to allow students to apply STEM in writing formula and completing robotic task in a stress-free environment. Besides, commonalities can also be found from the dotted line in **Figure 2** for both cognitive maps that through logical thinking the two students have inspired more ideas and created different formulas, and finally completed the robot's task.

By examining the cognitive map of student #1 as in the right of **Figure 3**, it is found that student #1 employed the "engineering" tools in STEM to figure out how to solve the problems and make improvements to show the better robot works by discussing with the teammates in an easy learning and stress-free environment. Commonalities of cognitive maps of student #19 and #1 can be found from the dotted line that both students stimulated more ideas and found mistakes through group discussions. In addition, as indicated by the circles with bold line that given ample discussion time to allow students get better learning results in a relaxed/stress-free environment.

By examining **Figure 4**, it can be seen clearly from the circles with bold line that both students have used engineering in STEM as a tool to complete the assembly of the robot.

The abovementioned comparison results in **Figures 2-4** shown by using the project-based learning method to provide learners with moderate and task-oriented learning, it allows learners to stimulate ideas and solve problems in the process of cooperative learning, and finally complete the comprehensive application of STEM. In other word, the pedagogical method of project-based learning effectively applies the domain knowledge of STEM to the task of designing the robot.

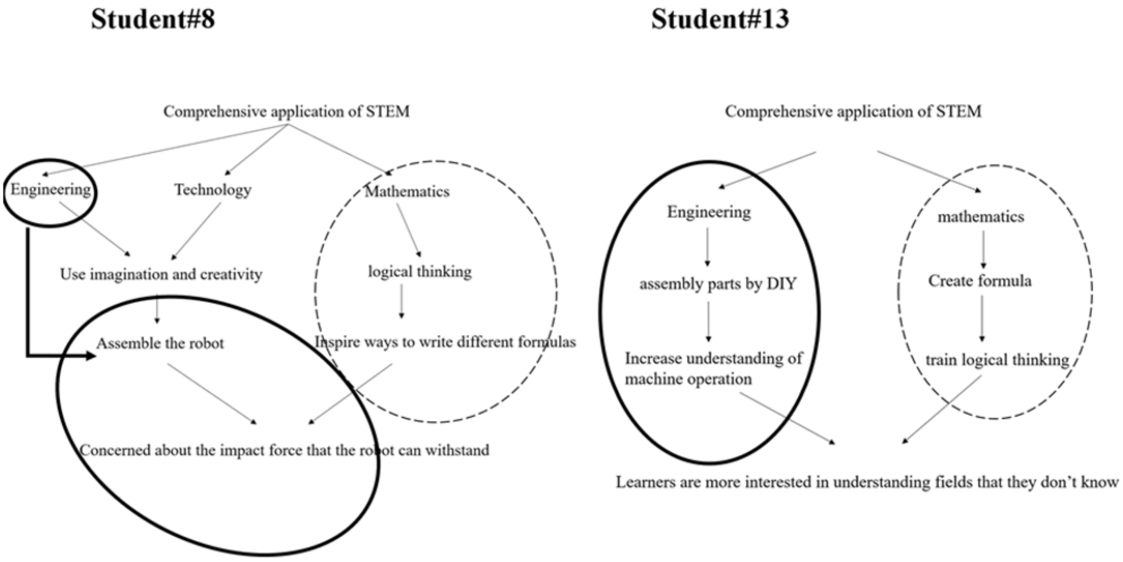


Figure 5. Comparison of cognitive maps of student #8 and student #13

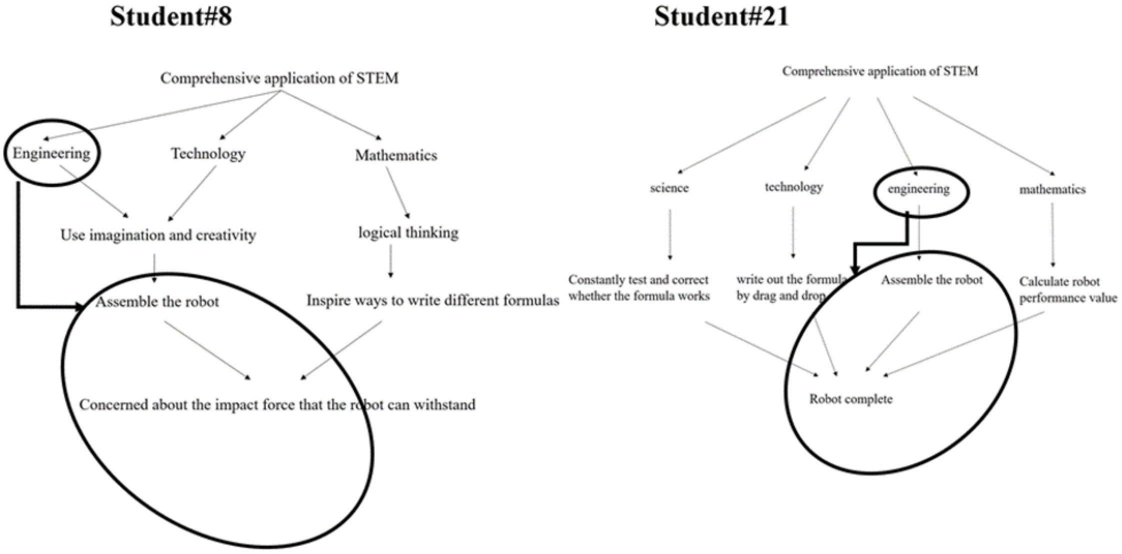


Figure 6. Comparison of cognitive maps of student #8 and student #21

How Can Students Benefit from Integrating Stem Teaching Methods into Robotics Learning Classrooms?

The following figures are comparison of cognitive maps constructed from analyzing the text content answered by three students in the class.

By reading the cognitive map of student #13, as shown in the right of Figure 5, one can found that student #13 learned how to assemble parts by employing the "engineering" tool in STEM, which in consequence increase the learner's understanding of mechanical operation. Through the "mathematics" tool in STEM, student #13 also learned how to write formulas and train the ability of logical thinking. Finally, student #13 was able to complete the assembly of the robot and increase their interest in understanding the robotics fields, which are different fields regarding the expertise of student #13. Commonalities among the cognitive maps of student #8 and student #13 can be found from the circles with bold line and dotted line in Figure 5 that both students have used the tools of "engineering" and "mathematics" in STEM to accomplish the task of robot assembly. On one hand, both learners increased their own understanding of mechanical operation by assembling robot parts, and finally completed the product under consideration of the impact force that the robot can withstand. On the other hand, the arrangement of different formulas is stimulated to complete the robot by both students through logical thinking as shown in the dotted line.

By examining the cognitive map of student #21, as shown in the right of Figure 6, one can found that student #21 used the four tools of "science", "technology", "engineering" and "mathematics" in STEM to test whether the formula can work in solving various robotics tasks. Through correcting the formula and assembling the robot

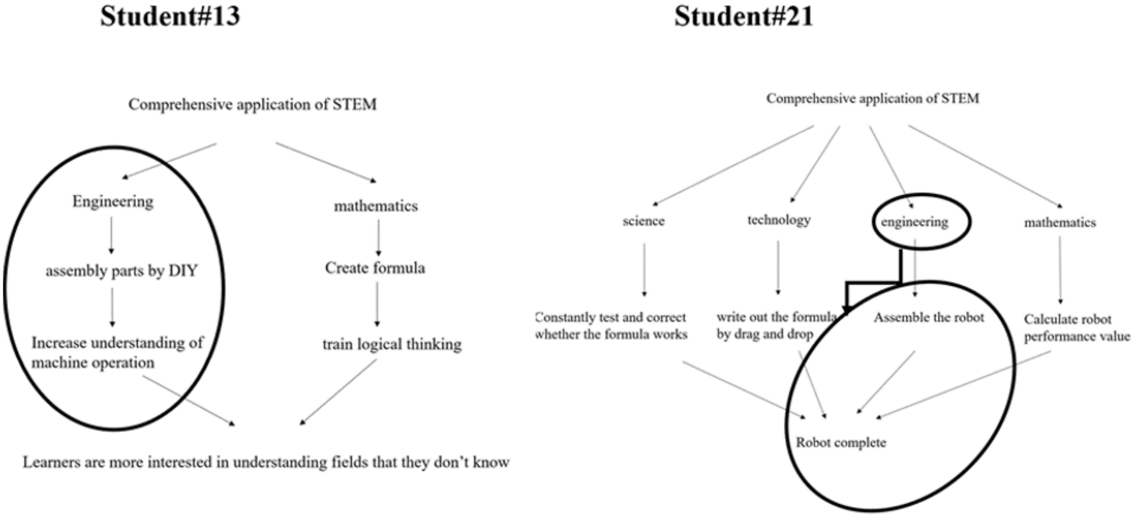


Figure 7. Comparison of the cognitive map of student #13 and student #21

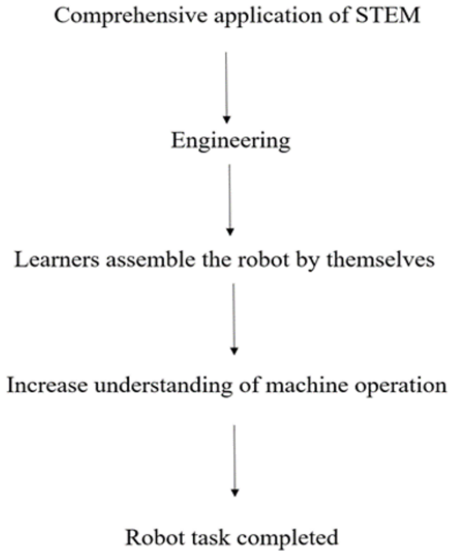


Figure 8. The collective cognitive map of student#8, student#13, and student#21

as well as calculating the robot's performance value, student #21 finally successfully completed the robot task. Besides, common feature can be seen from **Figure 6** that both students use the "engineering" tool in STEM to assemble the robot such that the requirements of the robot can be met.

By reading the cognitive map of student #13 and student #21 in **Figure 7**, one can find that both students used "engineering" tool in STEM to assemble the parts of the robot to increase the learner's understanding of the mechanical operation and to complete the robot works.

Besides, it can be expected that the commonalities can also be found by comparing and examining the pair cognitive maps in **Figure 5** to **Figure 7** among the three learners. As a result, we showed the team cognitive map as in the following **Figure 8**.

It can be clearly observed from **Figure 8** that through "engineering" tool in STEM, students learn how to assemble robots by themselves to increase their knowledge of mechanical operations and finally complete robot tasks.

CONCLUSION AND IMPLICATION

A content analysis technique for extracting and comparing abstractions of individual mental models and generating shared mental model for students from a project-based learning robotics course with integrating STEM education was presented in this study. It can be clearly seen that the application of project-based learning (PBL) robotics in the classroom with STEM as the curriculum framework has significant benefits for learners. Students benefit not only from employing STEM concepts and knowledge in fast and precisely completing various robotics tasks, but students also encourage their team creativity through exercising the PBL robotics. Through the project-based learning, a relaxed environment for learners to do cooperative learning was created for moderately accomplishing educational robotics tasks. By providing sufficient time for group discussions with STEM as the core concept, learners stimulate more ideas by reflecting on themselves and learning from their mistakes in obtaining the knowledge and competency of accomplishing robotics, w course assignment and contest which is also the core value of project-based learning. In addition, the results from the second issue also shows that the integration of STEM teaching methods into the classroom of robotics acquisition has obvious benefits for learners. On the one hand, by using the tools in STEM, learners learn how to develop computational thinking to stimulate more ideas, also know how to apply what they have learned in STEM in accomplishing the robotics tasks. On the other hand, learners not only can learn mistakes from experiments by themselves, but they also assemble robots and complete the tasks, finally inspire their own interest in different fields, which is also the core value of STEM education. Yet this research also has limitation that only a few students' response carried rich information for creating meaningful cognitive map due to the answering of application topics, instead of face-to-face interview. 25 students out of the 30 registered students responded with texted answer, but only about half of the responses bear valuable content for textual analysis. Hence, the larger the volume of students' responses with quality are collected for analysis, the better personal and team cognitive maps can be created for analysis in providing qualitative result with precision.

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