# An Examination of Online Discussion Quality of STEM-based Instruction

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## Abstract

This study used STEM as a pedagogical framework to support students' production of four-rotor aircraft and then discuss it online after school. Quantitative content analysis and lag sequential analyses were used to investigate whether, after receiving STEM education, students showed significant increase in discussion quality. This study used the 6E (Engage, Explore, Explain, Engineer, Enrich and Evaluate) teaching model to develop STEM teaching activities as put forward by Barry (2014). Experimental results showed that 80% of the content of the experimental group's discussion focused on the topic, whereas that of the control group was only 51%. In addition, as can be seen in the two figures of the behavioral transition diagram for all students in control and experimental groups, the experimental group showed significant improvement and better knowledge in all dimensions of 6E, whereas the changes from within the control group were less significant.

**Keywords:** STEM based instruction, 6E model, Four-rotor aircraft

## 1 Introduction

Four-rotor aircrafts have recently become highly popular technology. Their design principles involve relevant knowledge and concepts of science (fluid mechanics), technological elements (microprocessor systems, program design, electronic circuits, and automatic controls), engineering principles (engineering design program, mechanism), and mathematics (calculus, measurements, angles, geometry, calculations). They are therefore an ideal tool for the use of the STEM (science, technology, engineering, and mathematics) teaching design [1-2]. However, many four-rotor aircraft production courses lack theoretical support, whilst holding the claim that they allow students to learn through production, which, at best, may merely be the production of a toy; the actual knowledge that students acquire could be superficial and fragmented. Therefore, this research adopts the STEM-6E teaching model to design a teaching method specifically for learning the production process of a four-rotor aircraft, guiding students through the learning process in a systematic and multi-faceted way. Through online discussion, this research also seeks to understand students' behavioral patterns of knowledge construction. The aim is to bring together related courses in various subjects to combine theory with practice and improve students' interest in STEM study [3-4]. In STEM courses, mathematics serves as a language bridging science and technology, and the most advanced scientific discoveries and technologies integrate engineering principles in designing products needed by society [5-6]. Through the integrated application of science, technology, engineering, mathematics, and other disciplines, students can learn how to use tools and appropriate skills to solve real-world problems through hands-on or thematic learning [7]. According to Becker and Park (2011), compared with other methods, in which classes are conducted according to an individual discipline structure (such as mathematics or physics), the STEM teaching method, which integrates various disciplines, results in enhanced student interest in learning. In addition, Keefe (2010) and Bybee (2010) also pointed out that, as American primary and middle school students do not generally perform well in mathematics and science, the study of science and engineering must be expanded to improve national competitiveness [9-10]. Lindberg, Pinelli, and Batterson (2008) showed that STEM teaching can enhance students' abilities, such as problem solving and critical thinking [11].

Life science courses cover science, technology, engineering, and mathematics, with the goal of enabling students to construct knowledge through co-operative learning, exploratory learning, and multiple assessment methods, as well as applying technological tools and engineering design procedures to solve problems and enhance innovative thinking. STEM, as an interdisciplinary teaching mode, not only integrates science, technology, engineering, and mathematics, but

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also allows for a re-testing stage. The re-resting stage is different from traditional activities involving technology, as it puts into practice optimized engineering design procedures. In the 1980s, the American Biological Sciences Curriculum Study (BSCS) developed the BSCS 5E Instruction Model for instruction. It included Engage, Explore, Explain, Elaborate, and Evaluate (E5). The instruction model has been widely discussed and applied [12-13]. In the field of science and technology and engineering education, Barry [14] proposed the 6E instruction mode (description below). In this study, the 6E instruction model was used as the four-rotor aircraft STEM instructional reference design. Explaining 6E as follow:

(1) Engage: Student curiosity, interest, and investment are stimulated. By questioning the students, the teachers connect the student prior experiences and knowledge to the key points of the unit. The questions hint to the design process and the overview of operating techniques. Questions also help to assess the ability of students and decide on instructional strategies. Students' first outline the main concepts of the unit, confirming the content, setting learning objectives, main points, materials, and equipment.

(2) Explore: Provide opportunities for students to construct a learning experience. Teachers begin modeling, a concept introduced as COPA (Constraints, Optimization, Predictive and Analysis), and designing a review process to guide students' use of interrogative thinking and encouraging students to participate in discussions and group work. Students join the group discussions, with modeling and predictive analysis (based on group information, project criteria, and restrictions).

(3) Explain: Students explain what they have learned, and what can be improved. Teachers explain the system concept, design a review process, and through a cross-examination they guide students to more in-depth analysis. They guide the discussion to clarify the concept of loss and error. They make sure that students learn concepts within a broader context. Students apply concepts related to the system, test principles and theories, model human values and system, develop programs, use design programs to explain the formation, and apply a variety of information and communication technologies.

(4) Engineer: Students learn about nature, as applied to the artificial world. In order to obtain a deeper understanding, they apply the concepts, techniques, and attitudes to a main issue. The teacher introduces the concept of interactive design, suggests programs to guide students through inquiry-based learning, provides the necessary resources for students to apply engineering solutions, and facilitates quality control. Students apply design concepts, principles, and theories, and use resources by making decisions. The students use design, modeling, human values, and systems development programs in accordance with programs they co-designed to make tests, as well as improvements and control of quality.

(5) Enrich: Enable students to do more in-depth and applied study on more complex issues. Teachers provide resources for students to design concepts for new applications. Through questions, the students broaden their views and possible applications. Students learn the design process, and apply it to new situations. They then expand beyond project concepts to new situations and new applications, conduct research, keep an inventors' log, and improve upon the original design.

(6) Evaluate: Students and teachers understand the effects of learning. Teachers measure students' knowledge needs and gaps. They confirm if students were learning in accordance with the curriculum standards using formative assessment at each stage. Ratings and grades and evaluations provide students feedback. The use of assessment tools raises the effectiveness of these programs. Engineering students must understand the concepts of design, modeling, and system resources to solve a problem. Complete assessments (formative and summative) confirm whether learning objectives were reached.

Moreover, engineering design processes in STEM instructional activities can be divided into nine steps: (1) Identifying and defining problems, (2) Researching the needs or problems, (3) Developing possible solutions, (4) Selecting the best possible solution(s), (5) Constructing a prototype, (6) Testing and evaluating the solution(s), (7) Communicating the solution, (8) Redesigning the prototype, and finally, (9) Completing the design [15].

## 2 Methods

It is important to utilize e-learning platforms for knowledge sharing and learning [16-17]; the STEM teaching method does just that by using group discussions to improve learning outcomes and to understand students' knowledge connections. In order to gain a deeper understanding of whether the use of STEM teaching is helpful in enhancing students' discussion quality, this study analyzed the messages sent online by students during online discussions. QCA and LSA were then used to analyze such discussion quality [18-20]. The research process is described below.

### 2.1 Participants

A total of 48 students from the seventh to ninth grade participated in the study experiment. Students were divided equally according to their grade levels into the experimental group and control group. Each group included students of both high and low grade averages; both groups were enrolled in the four-rotor aircraft course, and completed a total of 40 class hours over five days. Each group was divided into three sub-groups composed of eight people. The experimental group applied principles of STEM 6E, and the control group was taught with general practice teaching methods. Each student in both groups was required to complete the four-rotor aircraft alone.

## 2.2 Research design and procedures

The teachers of the experimental group applied the STEM 6E teaching method (Table 1). Regarding the teaching design, the two groups established group chat on Facebook, for each group; the teachers were then able to raise questions in the chat rooms for students to discuss and answer after class each day.

**Table 1.** STEM Teaching Activities and Processes for Four-Rotor Aircraft Building

| 6E | Engineering Design Process | Teaching Activities |
|---|---|---|
| Engage | 1. Define the problem. | 1. The heterogeneity of the groups was defined, and group results were published.<br>2. A film related to four-rotor aircraft was shown, and functions explained.<br>3. Students' prior learning experience and knowledge were identified and linked through a series of questions.<br>4. Design procedures and operating techniques were defined.<br>5. Materials required for the four-rotor aircraft was distributed to the students in each group. |
| Explore | 2. Find information. | 1. The principles of four-rotor aircraft were introduced.<br>2. With the teachers' guidance, the students searched online for the use, function, specifications, prices, and other information related to the parts.<br>3. With the teachers' guidance, the students explored questions and information related to four-rotor aircraft.<br>4. The students were encouraged to participate in discussions and cooperate with other members of the group. |
| Explain | 3. Develop the program.<br>4. Select the best program. | 1. Assessments were made according to mathematical and standard scientific theories and technological assessment practices, and students were guided to engage cognitively.<br>2. The functions and cost of the hardware of the four-rotor aircraft were assessed.<br>3. Several software control interfaces were analyzed.<br>4. The students discussed the combination of hardware and software systems in their group. |
| Engineer | 5. Make the prototype.<br>6. Test and evaluate the prototype.<br>7. Communicate the program. | 1. The students were instructed how to purchase the required system materials.<br>2. With the teachers' guidance, the students learned to combine materials based on the designed system to complete prototype production.<br>3. The students were instructed on the method for writing necessary programs.<br>4. The students were taught methods to match the hardware and software, and shown how to test and adjust functions.<br>5. The students were instructed to reduce problems through group discussion.<br>6. System tests, modifications, and retests were performed until problems were resolved.<br>7. Students were instructed to optimize the system. |
| Enrich | 8. Redesign the prototype. | 1. To test extent of student learning, each group was asked to produce a ramp, to control their self-made four-rotor aircrafts, and to land them safely.<br>2. Each group competitively published their results. |
| Evaluation | 9. Finish | 1. The results were published, as well as the competition results and awards.<br>2. The possible fields the principles can be extended and applied to were discussed.<br>3. Each group shared their experience and summarized their report. |

## 2.3 Coding scheme and analysis

This study applied 6E as the quantitative content analysis (QCA) code (Table 2). In addition, as students' discussions may have involved content not related to the same theme, an "else phase" (Code: E7) was added to the table. The kappa value was 0.67, which reached significance at $p < 0.001$ [21].

Figure 1 and Figure 2 show the online discussion information of the 24 students from both the control and experimental groups during the 40 class hours over five days, after being classified by the QCA tool. A total of 1,265 pieces of discussion from the control group and 1,564 from the experimental group were collected. As shown in Figure 1, a large proportion of the discussion of the control group was coded as E7 (Else) (624, 49%), followed by E4 (Engineer) (305, 24%); the largest proportion of the discussion of the

**Table 2.** The coding scheme for the content analysis of discussions quality

| Code | Phase | Description | Examples |
|---|---|---|---|
| E1 | Engage | • Identify and define problem. | • Who can answer the teacher's question? |
| E2 | Explore | • Research the need or problem.<br>• Development possible solutions. | • You can go to Wikipedia to find out the answer.<br>• You can do a quick Google. |
| E3 | Explain | • Select the best possible solution. | • People can get an electric shock due to the current that goes through the body into the ground to form a loop. |
| E4 | Engineer | • Construct a Prototype.<br>• Test and evaluation the solution. | • The propeller and counter-propeller of a four-rotor aircraft are to be mounted in such a manner.<br>• How do you save or upload the code to the IC ?<br>• Why was my four-rotor aircraft unstable during flight ? |
| E5 | Enrich | • Redesign | • The parking ground of the aircraft has been completed, but how can its style be made more creative ? |
| E6 | Evaluation | • Completion | • Who will you designate to participate in the flying game tomorrow ? |
| E7 | Else | • Messages irrelevant to the discussion task. | • Today's box of rice is delicious. |

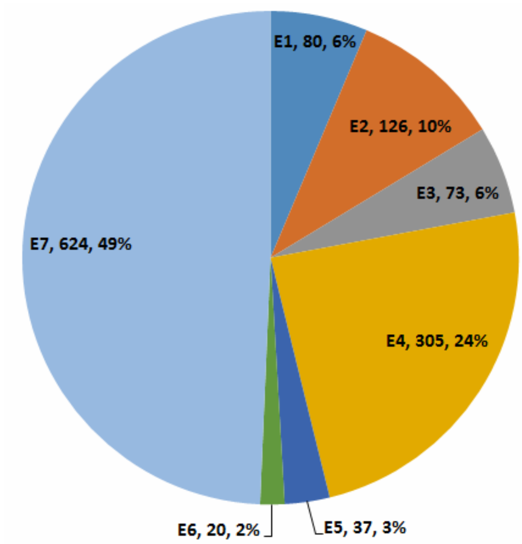


**Figure 1.** Distribution of the codes for quantitative content analysis for all the students of control group

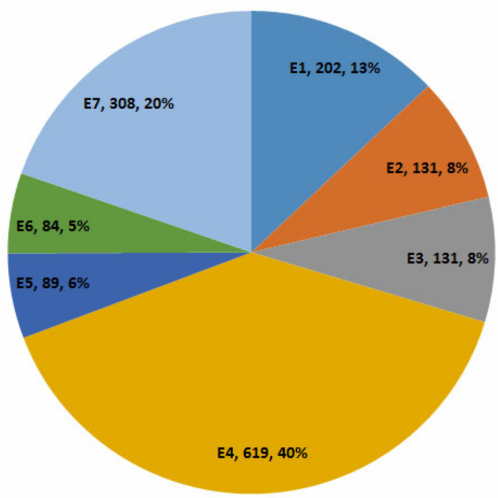


**Figure 2.** Distribution of the codes for quantitative content analysis for all the students of experiment group

experimental group was coded E4 (Engineer) (619, 40%), followed by E7 (Else) (308, 20%). These findings show that approximately half of the discussion content of the control group, which received a general education, was not theme related. Although the second largest code type was E4 (Engineer), which accounted for 24% of the total discussion contents, discussion that involved other phases was limited. However, Figure 2 reveals that a large proportion of the discussion contents of the experimental group, which received E6 education, fell under E4 (Engineer), which accounted for 40% of the total discussion content. Although the proportion of non-theme-related contents was not low (20%), it was assumed that students engaged in casual conversations during the discussion. Moreover, contents related to other phases were relatively higher as compared with the control group.

## 3 Results and Discussions

Figure 3 to Figure 5 are behavioral transition diagrams for the three sub-groups of the control group that participated in group discussions. Figure 3 shows the diagram for the first control sub-group. E1, E2, E4, E5, and E7 codes were related to the topic, in which the E7 Z-score (13.52) accounted for 47.4% of all discussion content of the sub-groups. The behavioral transition of E5 and E6 was higher compared with other behavioral transitions, indicating that the group was keen on the discussion between Enrich and Evaluate. It is worth noting that the discussion of this sub-group on E3 (Explain) was not related to the topic nor correlated to other codes. This result is consistent with the fact that students in sub-groups raised their hands less; teacher–student interaction was thus low. It can be clearly seen from Figure 3 that the discussion from such groups was not at ideal levels. Figure 4 displays the discussion data from the second control sub-group. The discussion of each code was the highest out of all three groups; however, the Z-score of E7, which was irrelevant to the topic, was 21.38, accounting for 52.8% of all discussion and the highest of the three groups. The behavioral transition between E1 and E2 was higher compared with other behavioral transitions, showing that this group was keen on discussing topics related to Engage and Explore. Further, the discussion from this group was the most topic-related out of all the three groups. Figure 5 represents the discussion data from the third control sub-group. The discussion was similar to that from the first sub-group, except that the behavioral transition between E3 and E4 was higher compared with others, showing that the group was more interested in discussion related to Explain and Engineer. The Z-score of E7 (12.73) accounted for 43.8% of all discussion. It is worth noting that the discussion of this group on E6 (Evaluation) was not relevant to the topic and was not linked to other codes. This result is consistent with the fact that the students did not complete the four-rotor aircraft before the end of the project.

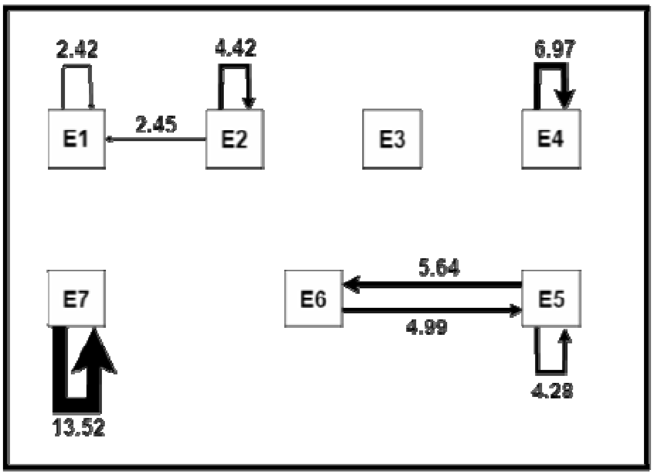


**Figure 3.** The behavioral transition diagram of group 1 of control group

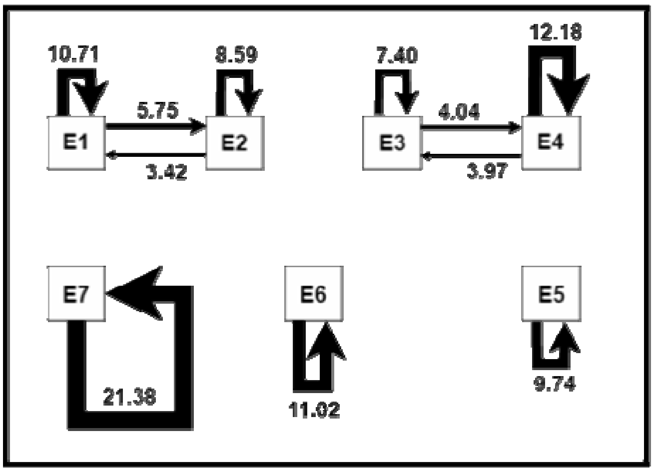


**Figure 4.** The behavioral transition diagram of group 2 of control group

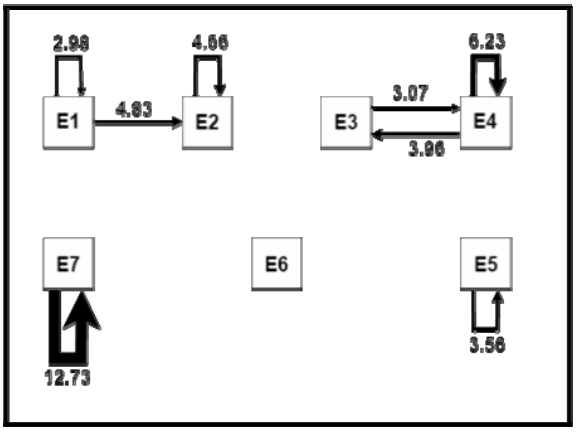


**Figure 5.** The behavioral transition diagram of group 3 of control group

Combining the content discussed by the three sub-groups of the control group, we used MEPA computer software to conduct sequential analysis and obtain the adjusted residuals table (Z-scores). As shown in Table 3, a Z-score greater than 1.98 means that the sequence of a row and column is statistically significant ($p < 0.05$) [21]. The 13 significant sequences were then compiled to form the behavioral transition diagram in Figure 6. It can be seen from Figure 6 that, although all codes reached a significant level, no apparent changes were observed in the conversion between the codes, such as {E1, E2} (Engage, Explore), {E3, E4} (Explain, Engineer), and {E5, E6} (Enrich, Evaluation). Thus, the overall discussion content of the control group was not significantly connected to knowledge of each code, and the proportion of the content discussed by the students irrelevant to the topic (E7) was as high as 49.3%. Moreover, the Z-score of {E3, E4} was the highest, obviously showing that the control group discussed the most content between Explain and Engineer (except E7). For the behavioral transition between each code, the Z-score of E1→E2 was the highest at 6.06 ("→" indicates a unidirectional sequence), which means that the students had the strongest link from knowledge of Engage to that of Explore, but that the opposite direction was worse. The Z-score of E3→E4 was 4.99, and that of E4→E3, 5.46. The behavioral transition between two codes was close, indicating that the students of the control group could equally establish a knowledge link between Explain and Engineer.

**Table 3.** The results of the sequential analysis of behaviors demonstrated by control group students

| Z | E1 | E2 | E3 | E4 | E5 | E6 | E7 |
|---|---|---|---|---|---|---|---|
| E1 | 9.55* | 6.06* | -0.80 | 0.17 | -1.63 | -0.25 | -5.52 |
| E2 | 3.61* | 10.48* | 1.94 | 0.32 | -0.40 | -0.78 | -6.65 |
| E3 | -0.75 | -0.07 | 5.64* | 4.99* | 1.38 | 1.85 | -5.79 |
| E4 | 0.28 | -0.10 | 5.46* | 15.12* | 0.47 | 0.10 | -12.63 |
| E5 | 1.14 | -1.98 | -0.10 | 0.37 | 11.80* | 4.60* | -3.44 |
| E6 | 0.68 | -1.43 | -0.15 | 0.54 | 3.21* | 8.46* | -2.22 |
| E7 | -9.80 | -10.82 | -10.21 | -19.73 | -6.59 | -5.58 | 28.24* |

*$p < 0.05$

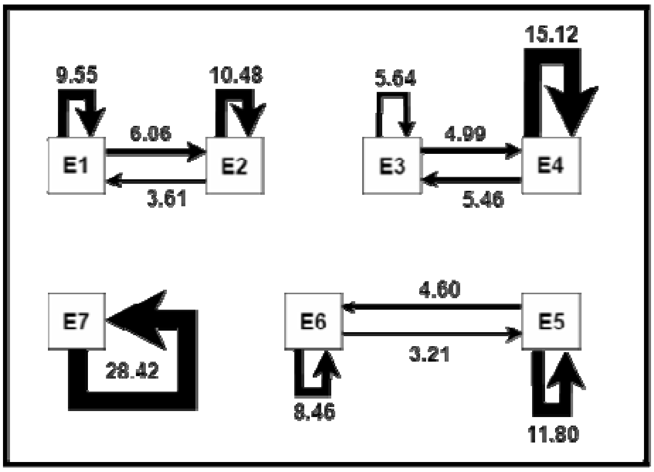


**Figure 6.** The behavioral transition diagram of all the students of control group

Figure 7 to Figure 9 are behavioral transition diagrams for the three experimental sub-groups in the group discussion. Figure 7 shows the diagram for the first experimental sub-group. Apart from E3, all codes were discussed, and five links between the codes were found to be significant (E1→E2, E1→E3, E3→E4, E5→E6, and E6→E5). The total Z-score was not high, reaching 17.43; however, the number of topics discussed was up to 531, of which the proportion irrelevant to the topic was 23.7%, showing a significantly better outcome than the control sub-groups. Moreover, E1 (Engage)→E3 (Explain) was significantly identified in the discussion, with a Z-score of 4.56, indicating that the link between knowledge does not respect a normal pattern. Figure 8 represents the second experimental sub-group. There were six links between the codes, including E1→E2, E1→E3, E3→E1, E2→E3, E3→E2, and E5→E6, and the total Z-score reached 23.44. In this group, the E1→E2→E3→E1 link was significantly identified in the discussion, and Z-score reached 9.78. The closed loop of the three codes indicated good overall knowledge connection and discussion by this group for Engage→Explore→Explain. Figure 9 shows the diagram for the third experimental sub-group. For this group, there were five links between codes (E2→E1, E3→E2, E1→E3, E3→E1, and E5→E6), and the total Z-scores reached 17.10. For this group, the E3→E2→E1→E3 link was significant (Z-score = 8.41). A closed loop connected by three codes was formed, which was the same as in Figure 8. However, the order of such group for connecting knowledge was Explain→Explore→Engage, as the group was composed of students who were equipped with more in-depth knowledge and were often first to present results to other students, as well as guide others into discussion.

Combining the content discussed by the three experimental sub-groups, we used the MEPA computer software to conduct a sequential analysis and generate the adjusted residual table (Z-scores). As shown in

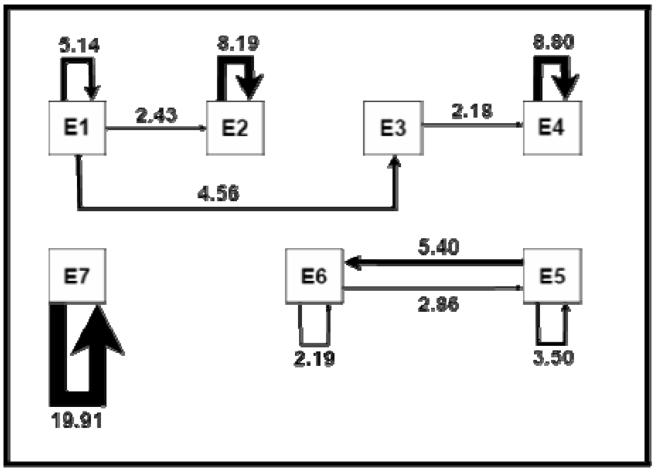


**Figure 7.** The behavioral transition diagram of group 1 of experiment group

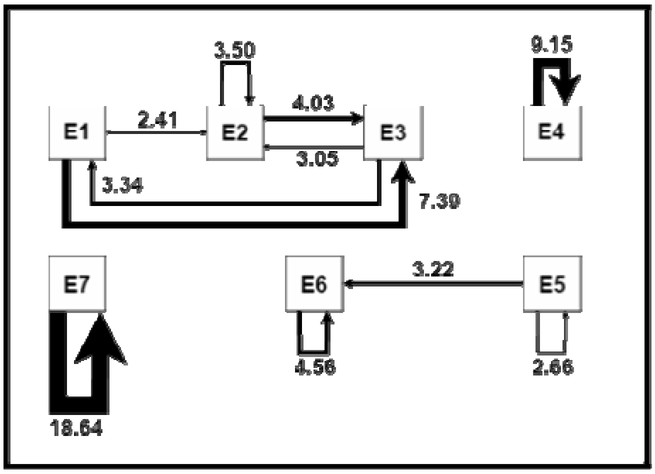


**Figure 8.** The behavioral transition diagram of group 2 of experiment group

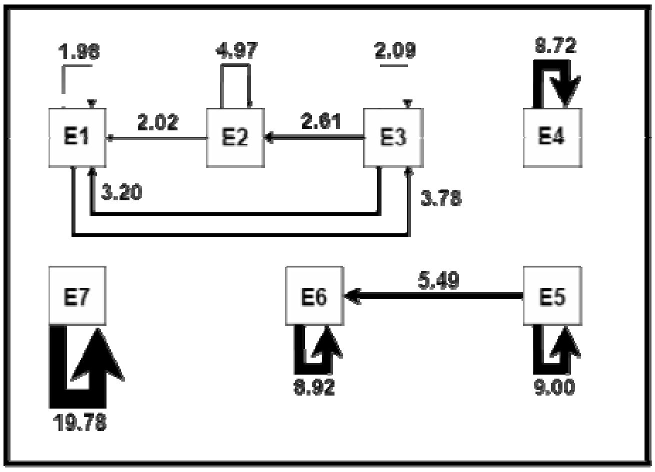


**Figure 9.** The behavioral transition diagram of group 3 of experiment group

Table 4, a Z-score greater than 1.98 indicates that the sequence of a row and column was statistically significant ($p$ < 0.05). [13] The 14 significant sequences were then compiled to form the behavioral transition diagram in Figure 10. Each code (except E3) was significantly identified in the discussion. In particular, a closed double loop was formed between E1→E2→E3 (the sum of the Z-scores was 10.36) and E3→E2→E1 (the sum of the Z-scores was 14.68), showing good knowledge connection and discussion by the experimental group on Engage, Explore, and Explain. Links E5→E6 (Z-score = 8.35) and E6→E5 (Z-score = 2.56) were significantly present in the discussion, indicating a significant connection was made by the experimental group between Enrich and Evaluation.

**Table 4.** The results of the sequential analysis of behaviors demonstrated by experiment group students.

| Z | E1 | E2 | E3 | E4 | E5 | E6 | E7 |
|---|---|---|---|---|---|---|---|
| E1 | 3.84* | 3.09* | 8.95* | -2.70 | -0.51 | -1.69 | -5.97 |
| E2 | 2.43* | 9.56* | 2.97* | -1.95 | -1.38 | -2.90 | -5.12 |
| E3 | 4.30* | 3.30* | 1.32 | 0.02 | -2.18 | -0.02 | -5.33 |
| E4 | 0.07 | -3.42 | -3.19 | 15.42* | -0.35 | -3.52 | -15.59 |
| E5 | -3.59 | -2.12 | -2.12 | -0.22 | 9.86* | 8.35* | -3.68 |
| E6 | 0.11 | -1.58 | -1.58 | -0.90 | 2.56* | 9.27* | -2.97 |
| E7 | -6.25 | -6.33 | -5.35 | -11.95 | -4.32 | -3.54 | 33.78* |

$*p < 0.05$

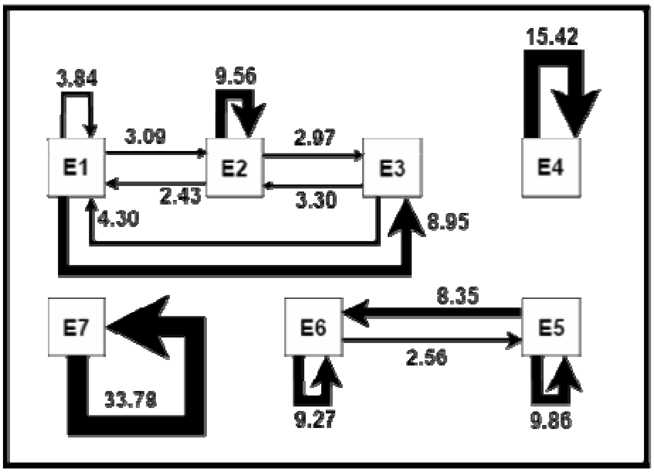


**Figure 10.** The behavioral transition diagram of all the students of experiment group

In summary, there are three observations that could be made when comparing Figure 6 and Figure 10: (1) there were a higher number of linkages in the experimental group than in the control group. This finding indicates that students in the experimental group had a more significant understanding of the knowledge acquired than the control group, potentially proving that students developed a wider range of knowledge. (2) As seen in Figure 10, the connection structures between the codes of the experimental group were stronger, while the control group connections were more scattered. This means that when the experimental group participated in discussion, students had more horizontal knowledge connections, whilst the control group focused mainly on a single direction. (3) Throughout the seven codes, the control group had four codes that were more substantial than the experimental group. This means that although the control group had poorer knowledge linkages, in relation to horizontal knowledge, the discussion quality in the single direction was good. Although the STEM teaching method was not applied to the control group, so long as students discussed the topic properly, they acquired positive gains.

## 4 Conclusions

This study found that the experimental group using the 6E teaching method had significant results in discussion quality and knowledge connection. From the online discussion of the students, it was found that the experimental group was more focused on the topic than the control group, and the phase included all levels of 6E, between which there were many links. The students also successfully completed the four-rotor aircraft production by the end of the course. On the contrary, the discussion of the control group, which did not apply the 6E teaching method, had as high as 49% content irrelevant to the topic, indicating that a large proportion of the discussion was social conversation; moreover, the phases of discussion involved were limited. The discussion of the sub-groups in the control group barely covered important phases, such as Explain and Evaluation, and the connections of knowledge between phases was not as sufficient as that of the experimental group, resulting in several students in each group failing to complete the production of the four-rotor aircraft. It is therefore suggested that teachers, or their assistants, participate in the discussion if online discussions are implemented in the future, so that they can facilitate the discussion at appropriate times, guiding it as necessary [22-23]. This researcher believes that such actions would greatly help the quality of discussion. Further, regarding research limitations, since most students were from metropolitan schools, the results are only applicable to students of metropolitan schools; it may not be appropriate to infer the results onto non-metropolitan schools. Nevertheless, the findings still provide a reference for relevant teaching activities and research.

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