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(Article)

Creating the cornerstone of critical and scientific thinking for students of engineering sciences: improves the engineering students' critical and scientific thinking, learned lessons, and the scientific content of the scientific thinking College course

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ABSTRACT

Scientific and critical thinking is a highly important skill for all engineering students. Although scientific and critical thinking are extremely important in qualifying engineering students for the labor market, there is a wide gap between what engineering students need in terms of qualification for sound scientific and critical thinking and what the academic courses offer. This article studies the impact of the scientific and critical thinking course that the authors updated for the Faculty of Engineering (Egyptian Russian University, Badr City, Cairo, Egypt) students and the extent of its feasibility and value in enhancing the scientific thinking of engineering students. The study was carried out on the 1st year students during the academic years 2019–2023, with the total number reaching 1233, according to the faculty database. The article measured the impact of the course contents and teaching methods on students' scientific and critical thinking behavior through interaction during the lectures, students' ability to discuss and express their opinions and refute other opinions, comparing the results of periodic exams, and handing over assignments. Students' behavior showed a significant improvement in the discussion, scientific and critical thinking, and success rates of exams in the late lectures of the semester compared to the first ones.

Finally, the online teaching method, which was resorted to during the Covid-19 pandemic, was discussed, and it proved a complete failure for engineering education students.

1-Introduction

Future engineers must have a sense of scientific and critical thinking in order to enhance creativity and technological development in various aspects of life **[1-3]**. Unfortunately, engineering curricula and teaching methods do not encourage engineering students to open discussion and scientific and critical analysis, which has formed over time the weakness of the analytical mentality that possesses scientific and critical thinking among a portion of engineering students **[4-6]**. Student interaction, discussion, scientific and critical analysis, and various educational tools are the most important elements of students' brainstorming **[7-9]**. Some engineering students graduate with poor abilities in scientific and critical thinking, data collection and analysis, and effective discussions, reflecting on their abilities for emergency/sudden problem-solving. So, the acquired knowledge of these engineering students is thus more superficial than functionally useful **[10-12]**. Therefore, the scientific thinking course is considered one of the most brainstorming courses for engineering students. It enhances and polishes their abilities and skills in interaction, discussion, and scientific and critical thinking **[13-14]**. Scientific thinking is a method for achieving complete knowledge of an issue or topic through collecting information and discussing its details by identifying specific patterns, asking questions, making observations, developing and testing hypotheses, and then drawing conclusions that form a complete picture of the targeted issue/topic **[15-16]**.

On the other hand, critical thinking is defined as reaching conclusions in accordance with goals and knowledge. The general characteristics of critical thinking include reasoning and suspecting, looking at the considered situation/issue from multi-dimensional points of view, openness to changes and innovations (being open-minded), and neutrality, which means looking at ideas without prejudgments, analyzing ideas, and paying attention to all details **[17-18]**. First, urging students of engineering education to develop their skills in reading, collecting and analyzing data, and encouraging them to acquire scientific thinking skills at the beginning of their university studies is considered the basis for building an engineer with a high and effective innovative capacity **[19-21]**. The keenness to teach engineering students the feasibility of scientific thinking qualifies them to collect data, develop hypotheses, and then analyze and interpret the data

accurately, which leads to the benefit of the interpretations in the continuous development of human life **[22-24]**. Raising the efficiency of scientific and critical thinking, brainstorming, and the ability to collect and analyze results is always reflected in the creative level of graduates of engineering education **[22-24]**.

Accordingly, the authors had developed an innovative university course to develop and improve the capabilities of scientific and critical thinking, data collection and analysis, and critical discussion among engineering students. During the study of the course, they used different educational means, giving students a wide space for dialogue and discussion, and preparing exams of an applied nature that help students acquire scientific thinking skills. On the other hand, statistics on students' attendance, commitment to submitting reports and assignments, and success and failure rates in the course were collected over five consecutive years. The authors utilized the inferential statistical method to draw final and accurate conclusions.

2. Methods and Assessment Tools

2.1. Description of the course

Firstly, the previous course content had shortcomings in several aspects, such as the lack of concepts, the main skills of the scientific thinker, and the ethical values in scientific doctrine. The course content did not include examples or case studies, which are the recommended methodology to improve the quality of students' scientific thinking. Therefore, several updates were made to the course contents to overcome the shortcomings. The following main ideas, arranged according to the teaching plan, are the course's basis, to enhance engineering studies students' thinking ability.

- Critical and scientific thinking.
- Structure of scientific thinking and its components.
- Reasoning and intellectual standards.
- The scientific method.
- Elements of scientific thinking.
- Barriers to scientific thinking
- Skills of scientific thinker.
- Ethics of scientists and engineers

Care has been taken to supplement the course with examples and case studies, whether general issues and topics or relevant to the engineering aspects in each of the previous chapters, which are the ideal training for students to develop their scientific and critical thinking skills.

By the end of this course, the student should be able to

- Explain and discuss the aforementioned main ideas in their own words and style.
- Using what they have gained during the course in effective scientific and critical thinking qualifies them to build and support their arguments.
- Use the gained insights to reason, analyze, and judge the quality of the opinions and arguments made by others.
- Improve their ability to collect and analyze data.
- Improve their ability to find effective solutions for emerging problems.
- Work collaboratively in decision-making groups to analyze opinions and arguments to make correct decisions.

2.2.Teaching methods

Interactive lectures, oral discussions, case studies, and applying contemporary scientific activities are the strategies used to teach the course and enable the students to get the most out of it. All the course data were fully uploaded to the university's e-learning platform to be accessible to the students. In 2020, due to the Covid-19 pandemic, the online education method was used, represented in explaining the lectures in videos, uploading them to the university servers, and holding periodic online meetings with students.

2.3.Participating students and assessment methods

The participating students in this study are first-year students of the Faculty of Engineering at Egyptian Russian University during the academic years 2019, 2020, 2021, 2022, and 2023, and their total numbers are 303, 406, 273, 159, and 92, respectively. The study was based on examining the importance of enriching the scientific and critical thinking of students of telecommunications and mechatronics and robotics engineering departments as departments of a technological nature and students of construction and architecture engineering departments as departments of an imaginary, design, and artistic nature. The results of the study were collected during five

consecutive academic years. The study was based on tracking the percentage of students' attendance, the delivery of assignments assigned to the students, the extent of interaction within the lecture, attendance on the exams, pass and fail, and different grades. (Excellent A, Very Good B, Good C, and Fair B).

2.4.Exams design

In the first year of study (2019), the course exams were implemented purely theoretically. While, in the following year (2020), due to the COVID-19 pandemic, we were unable to make any developments in the course exams; on the contrary, due to the transformation of the study during that period to be online, the exams were conducted on e-learning platform. In the following three years (2021, 2022, and 2023), the exams were reinforced by many applied questions that improved the students' scientific and critical thinking in solving dilemmas. 70 % of the exams' scores have been set on the applied questions that test the scientific and critical thinking that the students learned during the semester, while 30% are on the theoretical and written questions.

3-Results and discussion

In the beginning, before discussing the improving rates of the students' scientific and critical thinking, effective discussion and presenting opinions, and solving dilemmas, which were measured using percentage of attendance, discussions during the lectures, the exams' grades (Quizzes, midterm, end of semester), and the handing over of assignments, a post-course survey was conducted to ask the students about the extent to which they benefited from the course and whether the course succeeded in changing their way of thinking scientifically and critically. In the first year of teaching this course, the survey was conducted in exchange for grades in order to motivate the students to do the survey. In the following years, we were keen to avoid this shortcoming, as we urged the students at intervals (1^{st}, 6^{th}, and 12^{th} lectures for 1/4 hour in each lecture) to do the survey scheduled to be done at the end of the semester and to learn the culture of impartial evaluation of what they study**. Figure 1** shows the questions asked to the students,

and Figure 2 shows the percentage of student responses (positive and negative) during the studied years.

Egyptian Russian University
Faculty of Engineering

Course Survey
2022/2023

HM102
Scientific Thinking

	Strongly disagree	Slightly disagree	Neither agree nor	Slightly agree	Strongly agree	Don't know/not applicable
1) Did the course enhance your scientific and critical way of thinking?	○	○	○	○	○	○
2) Are the teaching methods suitable for familiarity with the course?	○	○	○	○	○	○
3) Is the course interesting and useful in engineering applications?	○	○	○	○	○	○
4) Lectures involve student participation and the lecturer encourages students to have open discussions.	○	○	○	○	○	○
5) The lectures included practical applications that enhance your scientific and critical thinking.	○	○	○	○	○	○
6) The course improved your ability to collect and analyze data.	○	○	○	○	○	○
7) The course provided me with many professional skills that are useful in practical life.	○	○	○	○	○	○

Figure 1: A survey of students' opinions in the scientific thinking course.

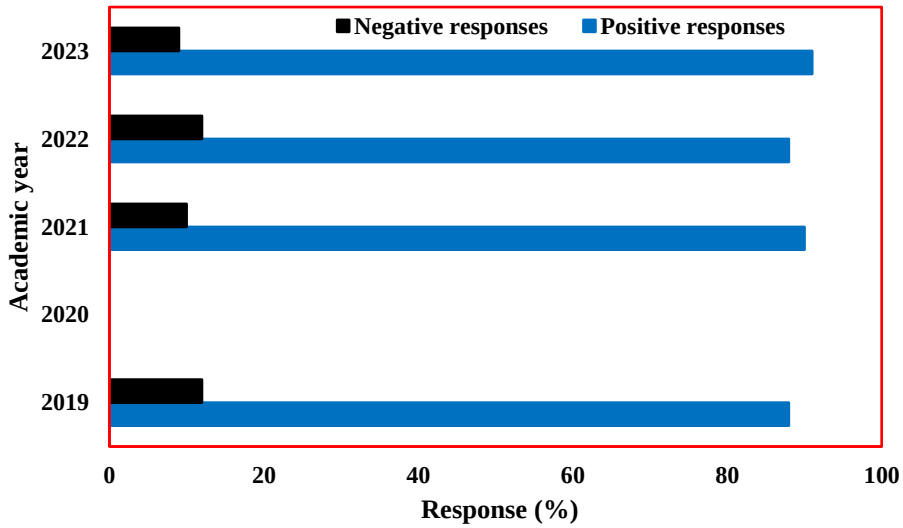


Figure 2: Positive and negative opinions (%) of students in a survey of the importance and feasibility of the course.

The highest values of the positive responses of the students, as shown in **Figure 2**, strongly refer to the extent to which students benefit from the course and reflect on enhancing their ability in scientific and critical thinking, collecting and analyzing data, effective discussions, presenting their opinions and discussing their validity, and refuting the erroneous opinions. Because course

teaching was held online during the year 2020, it was found that there was very great difficulty in the students following up and the extent of their level of progress, so the survey was not conducted during this year, as shown in **Figure 2**. The lecture attendance percentage during the semester for the five studied years is shown in **Figure 3**. For each semester, the attendance percentage was increased for the later lectures compared to the first lectures. The increase in attendance percentages reflects students' interest in benefiting from the course, due to their belief in the role of the course in developing their scientific and critical ways of thinking. Generally, scientific and critical thinking are processes that require the skills of collecting and analyzing information and presenting and discussing evidence, of which the commitment to attendance is an integral part of their implementation. Hence, the methods followed during teaching the course, which involved urging students to collect information on specific topics related to their disciplines and working within groups to present and discuss that information, increased the percentage of students attending the lecture participating in these activities. For example, the groups of students studying the course were usually formed after the fifth or sixth lecture (after finishing the teaching of the course fundamentals) in each semester. They were assigned to collect information about specific topics and then conduct presentations to discuss those topics and refute incorrect data and evidence, if any. Consequently, this is reflected in an increase in student attendance rates, which was observed in **Figure 3** in the last lectures compared to the first.

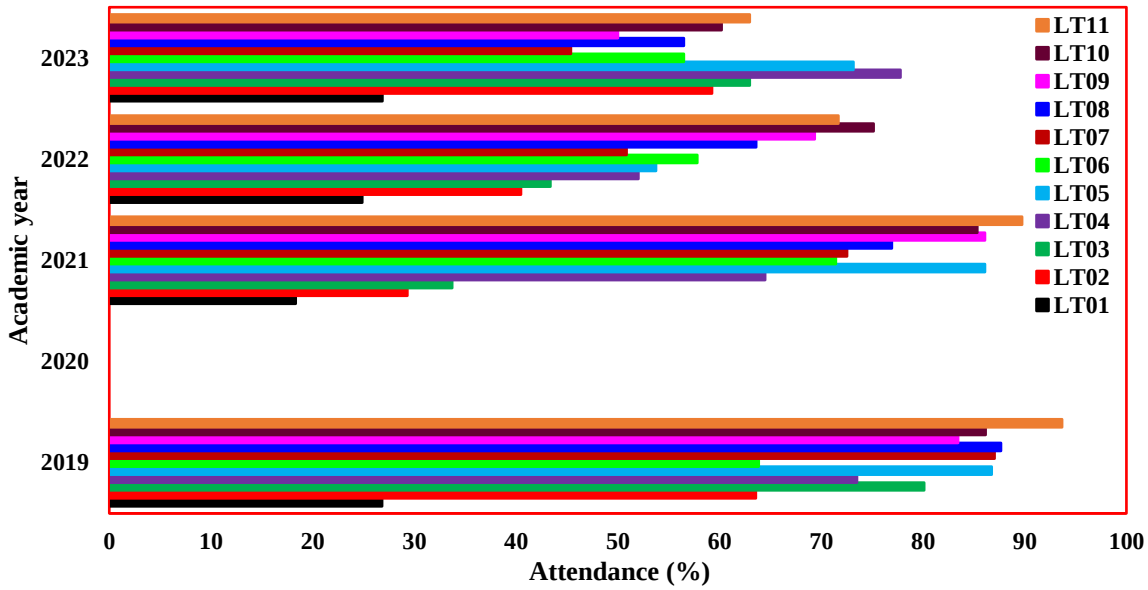
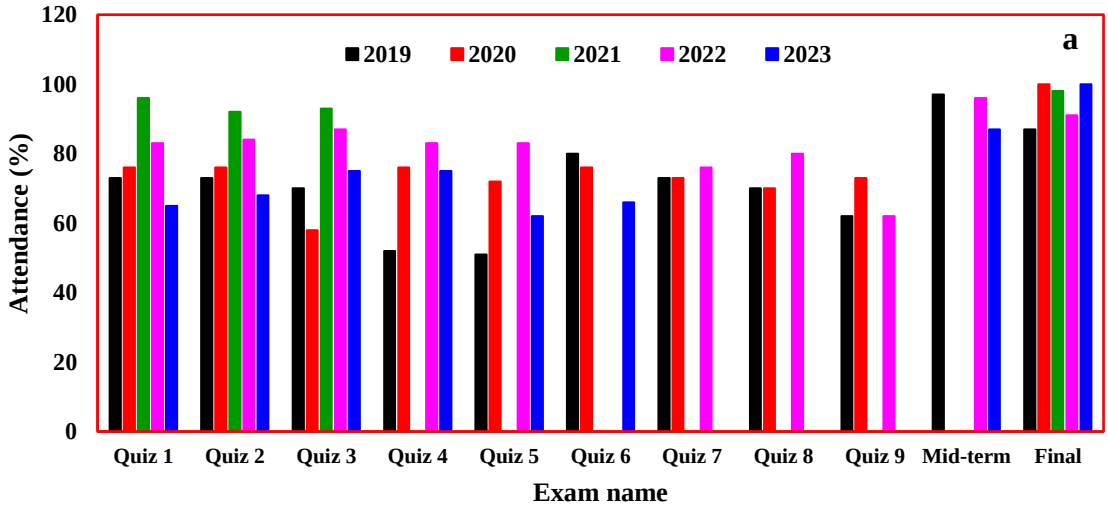


Figure 3: Attendance percentage during each semester of the studied three years.

Finally, the validity and reliability of the results of the questionnaires were tested through the face validation method. Despite the many methods of examining, measuring, and documenting the validity of questionnaire results, this method is relatively the easiest when teaching the course, as random samples of students were selected, and several aspects of the form and nature of the questions contained in the questionnaires were discussed, along with examining their answers to them. Several questions were asked of the students about their understanding of the questions contained in the questionnaire, asking them to clarify their understanding of them, coordinating the style of the questionnaire and the arrangement of its questions, ease of reading, and clarity of the used synonyms. It is worth noting that care was taken to conduct this test randomly and irregularly every time the questionnaire was administered to ensure that students completed the questionnaire in a neutral manner that expresses what is inside them without a tendency to prepare or fear being discussed in their answer.

The percentages of exam attendance, passing, and the students who had full grades for all exams carried out during the five years are shown in **Figure 4**. First, before discussing these percentages, it is necessary to signify that the exams' style during 2019 was based on theoretical and essay questions, which was not an appropriate way to measure the extent of enhancing scientific and critical thinking for the students. Alongside our research for exploring the most proper ways to enhance the feasibility and benefit of this course for students of engineering education, many opinions emerged from among the students objecting to the inappropriateness of the exam for the assigned purpose of the course, which prompted us to make radical changes in the way of the course exams, as was listed in the exam design section previously. The attendance percentage of the exams, as shown in **Figure 4a**, showed an almost constant rate. Generally, a significant improvement was observed, as shown in **Figure 4b**, in the passing rates of the students on the later exams compared to the first ones, which reflects the students' overcoming of the difficulties they faced at the beginning of the course and the improvement of their capabilities to answer questions that require high abilities of scientific and critical thinking. Finally, as shown in **Figure 4c**, it was noticed that an increase in the percentage of students obtaining Full grades in 2, 4, 6, and 7 quizzes, mid-term, and end-of-semester exams. The observed increase in the aforementioned exams reflects the students' comprehension of the studied parts of the course and the improvement in the level of scientific thinking, which enabled them to answer the questions that require scientific and critical thinking. Finally, to measure the extent of improvement in students' scientific and critical thinking, which was measured well through the questions of the various exams, the success rate and

obtaining full grades were compared between the quizzes and each other and between the quizzes and the mid-term and final exams. It was noted in **Figures 4b** and **c** that the success rate and obtaining full grades for the even quizzes (Quiz 2, 4, 6, and 8) are higher than those for the odd quizzes (Quiz 1, 3, 5, and 7). This is because every part of the course content was usually covered well in terms of explaining it, discussing it with the students, and conducting case studies on it throughout two consecutive lectures, while the quiz was being conducted in each lecture, which resulted in low success rates and obtaining full grades in the odd quizzes due to the students' lack of complete familiarity with the content on which the exam is being conducted. Regarding the final exam during the considered years 2019-2023, the success rates in all years were higher compared to the rest of the exams conducted throughout the semester, as shown in **Figure 4b**, due to the ability of the students to fully understand the contents of the course and connect its parts to form a complete picture that enables them to think scientifically and critically in a sound way. On the other hand, although the percentage of students obtaining full grades was not the highest, as shown in **Figure 4c**, these percentages are very good, as 17-21% of students obtained full grades in the final examination paper.



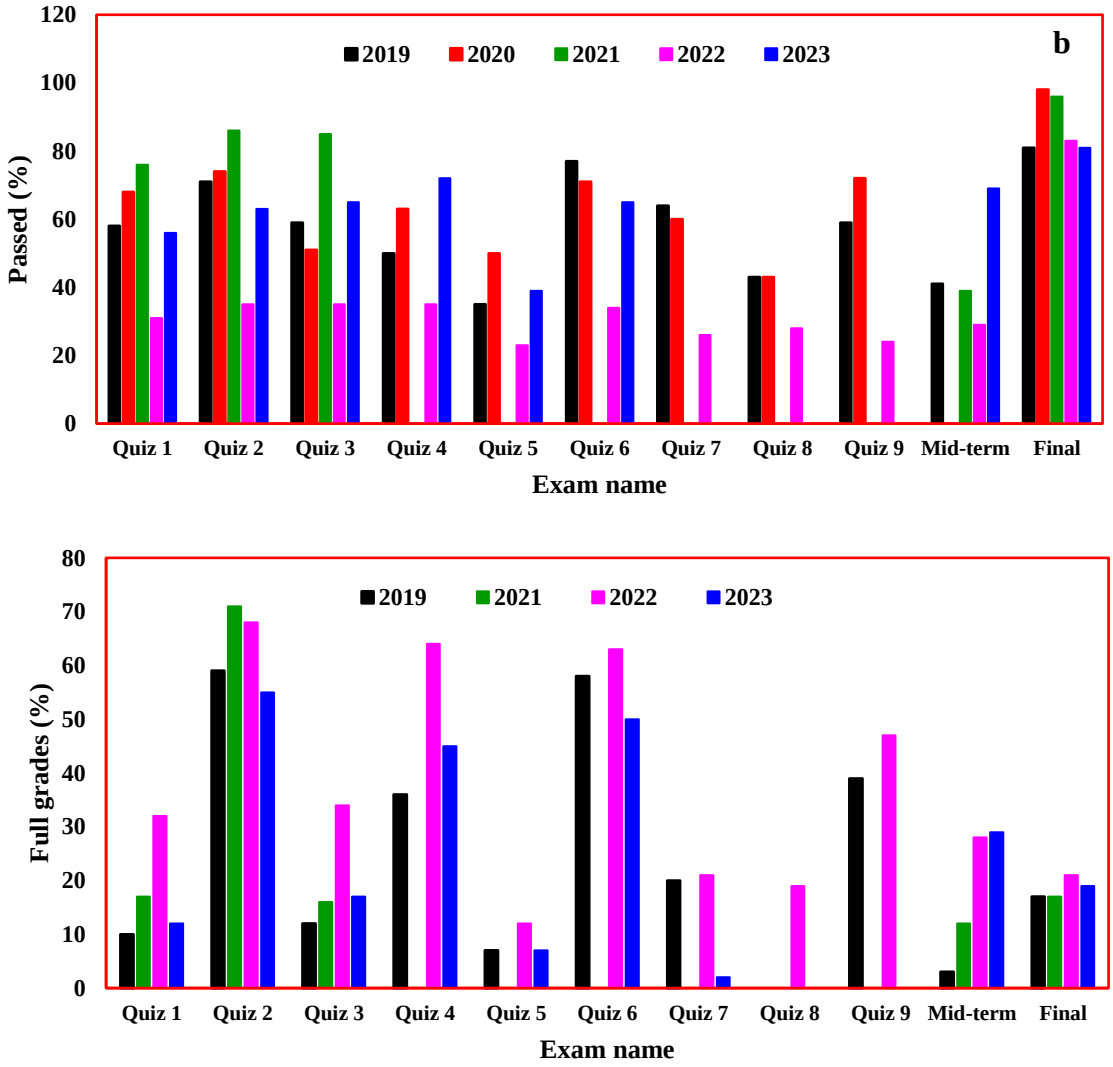


Figure 4: Evaluation of students' improvement through the percentages of a) exam attendance, b) exams passing, and c) students' attainment of final grades in exams.

4. Conclusion

The scientific and critical thinking course, which was taught to the first-year students of the Faculty of Engineering at the Egyptian Russian University, improved the level of scientific and critical thinking among the vast majority of students. The results of student surveys on the feasibility of the course showed a positive response from the majority of students. The attendance statistics of the students and their delivery of the required assignments reflected their interest in the course content and the extent of benefit from it. The percentage of students passing the course and the percentage of students obtaining full grades confirmed the improvement in the level of scientific and critical thinking of students, which made them able to answer exam questions of a thinking nature. Finally, the experience of using online teaching for students, which was resorted

to during the Covid-19 pandemic failed. So, it was seen that the futility of online teaching for engineering education.

Conflict of Interest

This research is totally free from any conflict of interest.

5. References

1.Coil, D., Wenderoth, M. P, Cunningham M., and Dirks, C. Teaching the process of science: faculty perceptions and an effective methodology. CBE—Life Sciences Education 2010; 9: 524-535.

2.Derry, S. J., Levin, J. R., Osana, H. P., Jones, M. S., and P. Michael. Fostering students' statistical and scientific thinking: lessons learned from an innovative college course. American Educational Research Journal 2000; 37(3): 747-773.

3.Moore, J. Ch., and Rubbo, L. J. Scientific reasoning abilities of nonscience majors in physics-based courses. Physical Review Special Topics - Physics Education Research 2012; 8: 010106.

4.Gottesman, A. J. and Hoskins, S. G. Create cornerstone: introduction to scientific thinking, a new course for stem-interested freshmen, demystifies scientific thinking through analysis of scientific literature. CBE—Life Sciences Education 2013; 12: 59-72.

5.Ding, L., Wei, X., Liu, X. Variations in university students' scientific reasoning skills across majors, years, and types of institutions. Research in Science Education 2016; 46: 613-632.

6.Ding, L., Wie, X., Mollohan, K. Does higher education improve student scientific reasoning skills?. International Journal of Science and Mathematics Education volume 2016; 14: 619-634.

7.Jensen, J. L., Neeley, Sh., Hatch, J. B., and Piorczynski, T. Learning. Scientific reasoning skills may be key to retention in science, technology, engineering, and mathematics. Journal of College Student Retention: Research, Theory and Practice 2017; 19(2) 126-144.

8.Caratozzolo, P., Lara-Prieto V., Hosseini S., and Membrillo-Hernández, J. The use of video essays and podcasts to enhance creativity and critical thinking in engineering. International Journal on Interactive Design and Manufacturing (IJIDeM) 2022; 16:1231–1251.

9.Yu, K. Ch., Wu1, P. H., and Fan, S. Ch. Structural relationships among high school students' scientific knowledge, critical thinking, engineering design process, and design product. International Journal of Science and Mathematics Education 2020; 18:1001–1022.

10. Clarisa, L. and Riley, D. Situation critical: critical theory and critical thinking in engineering education. Engineering Studies 2012; 4(2): 101–120.

11. Siregar, Y. E. Y., Rachmadtullah, R., Pohan, N., Rasmitadila, and Zulela, M. S. The impacts of science, technology, engineering, and mathematics (STEM) on critical thinking in elementary school. IOP Conf. Series: Journal of Physics: Conf. Series 2019; 1175: 012156.

12. Hafni, R. N., T Herman, Nurlaelah, E., and Mustikasar, L. The importance of science, technology, engineering, and mathematics (STEM) education to enhance students' critical thinking skill in facing the industry 4.0. Journal of Physics: Conference Series 2020; 1521: 042040.

13. Prasadi, A. H., Wiyanto, W., and Suharini, E. The implementation of student worksheet based on stem (science, technology, engineering, mathematics) and local wisdom to improve of critical thinking ability of fourth grade students. Journal of Primary Education 2020; 9(3): 227–237.

14. Aherna, A., Connor, T. O., Ruairc, G. M., Namara, M. M., and Donnell, D. O. Critical thinking in the university curriculum – the impact on engineering education. European Journal of Engineering Education 2012; 37(2): 125–132.

15. Jirout, J. J., Supporting early scientific thinking through curiosity, Frontiers in Psychology 2020; 11: 1717.

16. M, B. J., Croker, S., Masnick, A. M., and Zimmerman, C., The emergence of scientific reasoning, IntechOpen; 2012.

17. Birgili, B., Creative and critical thinking skills in problem-based learning environments, Journal of Gifted Education and Creativity 2015; 2(2): 71-80.

18. Hyytinen, H., Toom, A. and Shavelson, R. J., Enhancing scientific thinking through the development of critical thinking in higher education, In M. Murtonen & K. Balloo (Eds.), Redefining scientific thinking for higher education 2019; 59–78. Palgrave Macmillan.

19. Caratozzolo, P., Delgado, A. A., and Hosseini, S. Strengthening critical thinking in engineering students. International Journal on Interactive Design and Manufacturing (IJIDeM) 2019; 13: 995–1012.

20. Douglas, E. P. Defining and measuring critical thinking in engineering. Procedia - Social and Behavioral Sciences 2012; 56: 153 – 159.

21. Waks, S., Trotskovsky, E., Sabag, N., and Hazzan, O. Engineering Thinking: The Experts' Perspective. International Journal of Engineering Education 2011; 27(4): 838–851.

22. Smirnov, E. and Bogun, V. Science learning with information technologies as a tool for "scientific thinking" in engineering education. US-China Education Review A 2011; 4: 439-463.

23. Smirnov, E. and Bogun, V. Information and communication technology in science learning as a tool for “scientific thinking” in engineering education. Natural Science 2010; 4(12): 1400-1406.
24. Zimmerman, C. The development of scientifc thinking skills in elementary and middle school. Developmental Review 2007; 27: 172–223.