Factors influencing the critical and creative thinking skills of college students in computational physics courses

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Abstract. Computational thinking that is an essential skill which everyone should learn, especially in Computational Physics courses. Problems in learning Computational Physics courses in the Department of Physics was the ability of students in analyzing problems and designing algorithms for programming is weak, especially since the last 5 years. Therefore, the indication of this condition is the learning outcomes of students in the Computational Physics course that do not reach the mastery learning standard. The capability required to analyze problems and programming design algorithms is the ability to think critically and computationally. This paper will explain the circumstances that influence Critical and Creative Thinking Skills of students in Computational Physics courses. Next, based on the above, we have conducted research that aims to describe the factors that affect students in critical and creative thinking on the subject of Computational Physics. The data were collected using a Likert-scale questionnaire that have 60 statement items. This questionnaire was distributed to 100 college students who have been and are taking a course in Computational Physics. So, the results showed the factors that influence the critical and creative thinking of college students such as the ability to read the book, the time to learn and do the exercises given, learning resources used, students' understanding of the goals of Computational Physics lectures, student interest in Physics courses Computing, the curiosity of the students being taught, the student's enjoyment of the Computational Physics course.

1. Introduction

Lifelong learning is an important activity for a professional to preserve and update his knowledge according to their existence in his profession. The rapidly evolutionary of computer science that have brought about thoughtful effects in economic and social life due to lifelong learning becomes even more important. Based on the reasons above, equipping students with critical and creative thinking skills can help them learn effectively. However, nowadays, almost everyone, without considering age, is expected to have some basic computing skills along with the developments that are present in technology[1]. Critical and creative thinking skills are important skills for students, so these two skills should be included in the substance of various lecture materials such as Computational Physics or Computer Programming Techniques. Teaching critical skills along with lecture material can establish
Critical and creative thinking skills are important in Computational Physics. Computing has made a tremendous leap from the novelty and creativity of researchers because computation facilitates us in trying to solve complex problems and expand our understanding of ourselves as physics and our relationship with the world around us. This condition is enough to help students not take a long time to introduce new concepts. All student activities today in living life will be greatly influenced by computing, where many fields of work will be associated or guided by computing. To improve the quality of thinking students must be given highest preference in the education system as good thinking. This is needed in the involvement of challenges in living in a rapidly changing and technology-oriented world such as computational physics [2]. Research on thinking is convincing that skilled thinking processes can be embedded in students if thinking skills are taught explicitly and integrated into teaching content. Thus, the process of increasing students' exposure to computational thinking requires systemic change, teacher involvement, and significant advancement of resources.

There are five main skills related to computational thinking, namely abstraction, algorithmic thinking, problem solving, pattern recognition and design-based thinking related to various types of other thoughts such as algorithmic thinking, technical thinking, and mathematical thinking[3]. Computational thinking requires more than computer skills; it includes a basic mode of reasoning about rendering physical or social systems in ways that allow computational experiments to complement physics [4]. We believe that computational thinking is more than just computer programming skills, but is more like thinking in stages and sequences. Thinking like this involves understanding how to model large-scale systems using the right level of abstraction and modularity, it uses descriptions of mechanical inferences to analyze complex data, and it provides computational supplements for physics experiments on natural problems. However, it is difficult to articulate computational thinking concepts that lack facilities in different and unambiguous languages to describe them [5]. Moreover, this requires the use of computer programming languages as a basis for exploring computational concepts.

Creative thinking refers to looking at something in a new approach and affords investigating events from disparate contexts, recommending many alternative solutions to the problems [6]. In this case, creative thinking has four dimensions such as: fluency (creating a large number of ideas), flexibility (creating ideas on the disparate categories or approaches), novelty (creating unusual or rare ideas) and elaboration (creating ideas in specific form). The most important approaches that students use their creative thinking abilities such as : (1) going on alternative procedures; (2) fantasizing, empathizing, imagining inexperienced functions; (3) looking for alternative and unusual solutions to problems; and (4) advancing with common objects in the environment and using it for something other than the other scheme [7]. Therefore, creativity in this case requires what is called as lateral thinking, or the competence to recognize designs that are evident. Some students are customarily more creative than others, but creative thinking can be encouraged to practice. Someone can use, creative thinking throughout solving problems, being conscious of his assumptions, and through play. Therefore, creative people have the ability to devise new procedures to carry out tasks, solve problems, and meet challenges.

Critical thinking is competent to analyze information, to determine the relevance of information collected and then interpret it in solving problems [8]. In this concept critical thinking requires high-level thinking; requires a process of analysis, evaluation, providing argumentation and reflection [9],[11]. Critical thinking can be described as a scientific method applied by ordinary students in the ordinary world, because critical thinking is a duplication of well-known scientific methods, such as identified questions, formulated hypotheses, relevant data sought and collected, hypotheses that are logically tested and evaluated, and reliable conclusions. taken from the results. Therefore, the process of thinking students describes is focused on the context of learning and teaching. Students are involved with the learning process through repetitive activities, memorizing, understanding and reflecting. All of these processes require them to think to achieve effective learning outcomes and thus improve
problem solving skills. Critical thinking will be the goal, the decision on self-assessment as a result of interpretation, analysis, evaluation, and inference, as well as an explanation of the consideration of evidence, conceptual, methodological, contextual which is the basis of the assessment [11]. Critical thinking is very important as a tool of inquiry. Thus, critical thinking has a great introductory power in education and strong resources in personal and community life. The reflection phase in solving problems requires more critical thinking than recalling what has been memorized. There are several factors that can influence students' thinking processes. These factors are teacher-student relations, collective learning or collaborative, in-depth approaches and transformational learning. Lecturers in this context play a major role in giving clear instructions and engaging in interesting activities in the classroom because of their influence on students' thinking processes. Lecturers must struggle to give students' attention by investigating tasks that require them to think critically, as an alternative to focus on learning from memory without thinking [7]. Taking the reasons mentioned above, this study intends to investigate students' perceptions of their critical and creative thinking problem solving skills.

Computer Algorithm and Programming, and Computational Physics courses in the Physics Department are supporting subjects so students think computationally. Both of these courses are the main subjects in the Department of Physics. Lecturer in Computational Physics subject in order to achieve the goal of learning Computational Physics and the challenges above have prepared lecture devices in accordance with the Indonesian National Qualifications Framework (KKNI) 2013 through several improvements, but the efforts that have been made have not yet had a significant impact on improving field student competencies cognitive, psychomotor and affective there is even a tendency to get worse in the Computational Physics course. Student’s learning outcomes since five years ago as Figure 1:

![Figure 1](image-url)

**Figure 1.** Graph of learning outcome score of students since 5 years ago

Figure 1, show that the average student learning outcomes test score in the computational physics course shows a downward trend. On the other hand, the number of the student's experiencing misconceptions has increased. The student’s technical computing skills and Computational Physics skills are used to build their basic knowledge [12]. Another problem is that students' reading skills are lacking, so they have difficulty in determining the variables related to the problem solving [13]. The students have difficulty constructing their knowledge through scientific procedures caused by generative thinking ability of underdeveloped students. Conversely, determining the variables related to the problem needs critical thinking. Therefore, research to find out what are the circumstances that cause this condition to occur was undertaken.

Based on observations of students who attended the Computational Physics course, since 5 years ago, shown that the students' ability to think critically and creatively decrease, especially in solving the problem and making design of computer programs [14]. A lot of students have misconception [13].
The explanation above, research that aims to identify circumstances that influence students' critical thinking skills in the Computational Physics course in the Department of Physics is conducted. To achieve the above objectives, three guiding research questions were proposed to achieve the objectives of this study. First, what are circumstances students' cognitive abilities influence the advancement of critical and creative thinking skills? Second, what are pedagogical circumstances influence the advancement of critical and creative thinking skills of undergraduate students in Computing Physics courses? Furthermore, what are learning process circumstances influence the critical and creative thinking skills of undergraduate students in a Computational Physics course?

2. Research Design.
This research uses qualitative and quantitative designs. The qualitative design is used for the purpose that to describe, to interpret, and to explain data collecting. This can be used to get new awareness into problems about existing information, obtain new perspectives that can be difficult to express through quantitative methods. This study seeks to broaden the knowledge of developing students' critical thinking skills through capturing their perspectives on the circumstances that influence the development of students' thinking skills as candidates for the bachelor in Computational Physics. This method can be used to find new awareness, get new perspectives, or obtain additional information about the phenomena stored in the information found, but it is difficult to express through quantitative methods. This study aims to broaden the knowledge of developing students' critical thinking skills through capturing their perspectives on the circumstances that influence the development of students' thinking skills as candidates for scholars in Computational Physics. The quantitative research is to describe the circumstances that diffuse into the advancement of critical and creative thinking skills in computational Physics courses. The research instruments were questionnaires and observation sheets. Accordingly, the data collection techniques used are filling out questionnaires by responses, interviews, observations and diaries. In addition, this study also used the documentation method. Questionnaire for this research is in the form of closed questions, where the answer options come from the answer instructions. The techniques of collecting data are measured, interview and direct observation of the object being studied. Questionnaire that asked students out about their learning in computational physics are developed an offline.

The research sample was 50 students from the Department of Physics. Mostly, the sample consists of students taking an ongoing Computational Physics class and students who have completed the Computational Physics class more than or equal to the year. The quality of questionnaire answers was developed on a Likert scale (1,2,4,5). While, scale 3 is omitted to avoid respondents who are hesitant in making choices. The data are analyzed in percentage and then plot bar graph. In this research are to test the relationships between the creativity and critical thinking constructs was used Structural Equation Modeling (SEM). Some circumstances that influence was estimated by the path diagram of the Maximum Likelihood method. The models were tested using the Maximum Likelihood method with Lisrel851 software. The Maximum Likelihood estimation method has desired asymptotic means, such as minimum variance and multivariate normality of the observed variables. To understand how students make meaning of a phenomenon are using the basic interpretive and descriptive study.

3. Results and Discussion
The data analysis show that the significant finding in kindred to each of the research questions. First, what are the cognitive ability circumstances that influence the advancement of critical and creative thinking skills?, Second, What pedagogical circumstances that influence the development of critical and creative thinking skills of undergraduate students in Computational Physics course? Next, What are the learning process circumstances that influence critical and creative thinking skills of undergraduate students in Computational Physics course?

3.1. What are the cognitive ability circumstances that influence the advancement of Critical and Creative Thinking skills?
Students as participants in the study were identified as students who important for improving critical thinking skills compared to students who as critical thinkers found in the literature. The study found that students who are affiliated with critical thinking are the same as those classified in the literature as someone who has the character of critical thinking. We study two correlating factors, namely, creative thinking and critical thinking which are broken down into nine variables. Critical thinking is symbolized by deductive reasoning, inductive reasoning, practical reasoning, decision making, and problem solving [15]. While creativity is symbolized by fluency, elaboration, originality, and flexibility. Individuals related to indicators, such as Figure 2.

![Critical Thinking vs Creativity Diagram](image)

**Figure 2.** Model diagram with parameters estimated by the maximum likelihood method.

Data are analyzed to get the parameter estimation by using the maximum Likelihood method. In this study, all variants observed had an index that was in accordance with the assumptions used, the highest kurtosis index was 3.63 for the fluency variable, and the highest asymmetry index was 1.32 for the flexibility variable. Modification of the index is used to obtain a value greater than the value specified for the purpose of getting a better adjustment index on the model. Therefore, if the repetition of the analysis is carried out, modification of the covariance between the errors identified by the modification index as the free parameter is done so that the difference decreases. The results of data analysis are presented in Figure 2. Furthermore, the results of the modified models indicate that the most contributing components to explaining cognitive abilities is the cognitive ability variable of critical thinking, such as problem solving, with a regression coefficient of 0.81, practical reasons, with a coefficient of 0.93, and decision making, with a coefficient of 0.70. Furthermore, the results of the modified model show that creativity and critical thinking factors correlate 0.28, and that flexibility variables contribute to explaining both factors with a regression coefficient of 0.24 for creativity and 0.34 for critical thinking. In addition, inductive reasoning variables contribute to explaining both factors with a regression coefficient of 0.17 for creativity and 0.47 for critical thinking. Then, the most contributing variables to explain critical thinking factors are practical reasons with a regression coefficient of 0.91, problem solving with a regression coefficient of 0.76, and decision making, with a coefficient of 0.70. Finally, with regard to creativity, the most important variables are fluency, with a regression coefficient of 0.86, and originality, with a regression coefficient of 0.61. Finally, the regression coefficients for each observed variable indicate that there is the strongest predictor for developing critical thinking and smooth creative thinking that explains the 80% variant, problem solving that explains the 63.6% variant, and practical reasoning which explains the variance 61%.

### 3.2. Pedagogical circumstances that influence the advancement of critical and creative thinking skills of undergraduate students in Computational Physics course?

The results of data analysis showed that there were significant findings related to each research question. There are two main pedagogical factors that influence the development of critical thinking for students participating in Computational Physics courses. The first, the main factor which is
curriculum design, is explained further in obtaining basic concepts, developing from simple to complex, and applying learning methods of critical and creative thinking in Computing Physics courses. The second main factor is integrated learning activities between practicum and theory. In general, this study found that pedagogical factors that influence the development of critical thinking skills are student learning activities. Integrative learning activities include tests, case studies, simulations, and making algorithms, practicing computer code programming. The remarkable finding in this study is that all students participating in the Computing Physics study said the learning methods provided were factors that could improve their critical thinking skills. Other factors identified were curiosity, confidence, and perseverance, and their desire to read and trace references.

Figure 3. Student’s response to the computational physics syllabus
Figure 4. Student’s response to practicum Computational Physics material

Figure 3, show that students believed that the Computational Physics would be easy to learn (average 68% of student agree that Computational Physics easy to learn base on the syllabus that give to the student. It is mean, there is no problem with the curriculum Computational Physics. The argument is a curriculum of Computational Physics course material close to the real life and technology (58% agree); and the Computational Physics subject matter is important for the development of physics and technology (66% agree); after reading the syllabus of Computational Physics courses, the students knew what I had to learn from computational physics courses (86%). such as Table 1. The student response above shows that the understanding of the student to the topics that will be discussed in the Computational Physics course is very necessary. So, the understanding of students to the curriculum of the Computational Physics is needed before and during the learning process.

In contrast, student who has a GPA less than 3.0 said that getting good grades is more important than mastering Computational Physics material itself (22 % agree and 4% strong agree) and Computational physics practicum only waste my time (2% agree). Next, The student does not need a practicum to understand the material of computational physics (24% agree). Furthermore, the student who difficult to take important ideas that contain in Computational physics teaching materials and distinguish them. Therefore, the student who do not understand with the goal of the course will be getting low grades. Next, Tabel 1 show that The computational physics course material is very suitable for my interests (72% agree); to study Computational Physics courses requires a good understanding of the subjects of Computer Algorithms and Programming (64%).

The students who have a good understanding of Computational Physics and Computer Algorithms and Programming materials, in general they can make analogies of something good. Analogical thinking is a key process in problem solving and scientific discovery, such as designing problem solving by algorithms [13]. If students think critically and creatively in explaining a process, then through analogical thinking brings them creative and changes in knowledge. Analogical thinking is the axis of many theories of creativity [16]. The associative theory of discovery is an example that shows that creativity requires a certain kind of response, bringing together ideas that seem irrelevant or distant. In this term distinguished inflexible thinking is fixed on one area of creative thinking that operates in more than one field.
Table 1 Response of undergraduate students to pedagogical factors influence the development of critical and creative thinking skills in Computational Physics course

| Statement                                                                 | % Respondent's answer |
|--------------------------------------------------------------------------|-----------------------|
| After reading the syllabus of computational physics courses, I knew what I had to learn from computational physics courses | Strongly disagree: 0  Disagree: 10  Agree: 86  Strongly agree: 4 |
| Computational physics subject matter is clearly related to real life and technology | Strongly disagree: 0  Disagree: 18  Agree: 58  Strongly agree: 24 |
| Computational Physics subject matter is important for the development of physics and technology | Strongly disagree: 0  Disagree: 2  Agree: 66  Strongly agree: 32 |
| For me, completing computational physics courses and getting good grades is very important | Strongly disagree: 0  Disagree: 4  Agree: 48  Strongly agree: 48 |
| The computational physics course material is very suitable for my interests | Strongly disagree: 6  Disagree: 72  Agree: 22  Strongly agree: 0 |
| To study Computational Physics courses requires a good understanding of the subjects of Computer Algorithms and Programming | Strongly disagree: 0  Disagree: 2  Agree: 64  Strongly agree: 34 |
| To study Computational Physics subjects, it is necessary to master both the General Physics and Basic Physics courses | Strongly disagree: 0  Disagree: 2  Agree: 56  Strongly agree: 42 |
| Computer programming and programming courses strongly support Computational Physics courses | Strongly disagree: 0  Disagree: 4  Agree: 76  Strongly agree: 20 |
| Getting good grades is more important than mastering Computational Physics material itself | Strongly disagree: 12  Disagree: 62  Agree: 22  Strongly agree: 4 |
| Computational physics practicum only waste my time | Strongly disagree: 34  Disagree: 64  Agree: 2  Strongly agree: 0 |
| I don't need a practicum to understand the material of computational physics | Strongly disagree: 34  Disagree: 42  Agree: 24  Strongly agree: 0 |

3.3. The learning process circumstances that influence critical and creative thinking skills of undergraduate students in Computational Physics course

The learning process circumstances that influence the critical and creative thinking skills of undergraduate students in Computational Physics courses as in Table 2. Critical thinking is the assessment as a result of interpretation based on analysis and evaluation, and inference, and explanation with consideration of evidence, conceptual, contextual became the basis of assessment based on learning Computational Physics. Nevertheless, students who take Computational Physics courses spend less than 8 hours a week (72%). Students complete their own structuring tasks by copying their friend's assignments without understanding the contents (42%). In addition, students like to cheat on exams to get good grades (14%), such as Table 2.

Table 2 Response of undergraduate students to the learning process in Computational Physics course

| Statement                                                                 | % Respondent's answer |
|--------------------------------------------------------------------------|-----------------------|
| I study computational physics less than 8 hours a week, apart from hours of face-to-face theory and practicum lectures in the classroom | Strongly disagree: 0  Disagree: 28  Agree: 72  Strongly agree: 0 |
I completed the task of structuring my own computational physics course by copying my friend assignments without understanding the contents.

| Task                                                                 | Percentage |
|----------------------------------------------------------------------|------------|
| I like cheating on the exam to get good grades                      | 28%        |
| I have difficulty translating the problem into the appropriate formulation | 0%        |
| I have difficulty in setting independent variables and dependent variables on physical phenomena | 2%        |
| I have difficulty in making problem solving algorithms from the physical phenomena found | 2%        |
| I have difficulty in making problem solving flowcharts from physical phenomena based on existing algorithms | 2%        |
| I have difficulty in making a program based on an algorithm or flow chart from an existing numerical formula | 2%        |
| I am not critical of the formulation of algorithms or existing flow charts | 2%        |
| Program (pseudocode) that is made when I take practicum on the internet, without understanding it first | 24%       |

The ideal critical thinker has a habit of more curiosity, broad thinking and open minded evaluation to get better information and knowledge. Critical thinkers are willing to reconsider orderly in complex matters to find information that is relevant to focus on the investigation, and persistent in finding the right results such as the subject and the circumstances of the investigation permit. These data indicate that originality and general creative indices are the best predictors of quality and quantity of creative achievement [17], [18]. Therefore, it is important to help students develop their critical thinking skills, as well as the characteristics they identify as indicated by critical thinkers. The Table 2, show that students difficulty in setting independent variables and dependent variables on physical phenomena (78%); The student has difficulty in problem making solving algorithms from the physical phenomena found (62%); and students have difficulty in problem making solving flowcharts from physical phenomena based on existing algorithms (56%); Next, the student has difficulty in making a program based on an algorithm or flow chart from an existing numerical formula (52%). This data give us information that students have problem in computational thinking. Accordingly, the computational thinking must be supported by critical thinking and creative thinking.

4. Conclusions and Recommendations

The factors in college students that influence the advancement of critical and creative thinking skills are the personal characteristics of students in demonstrate understanding of advanced critical and creative in solve the problems. In addition, pedagogical circumstances influence the advancement of critical and creative thinking skills for undergraduate students in Computational Physics courses, such as curriculum design and textbooks and references used by students; and students' understanding of semester credit systems, homework functions, and initial assignments are a determining factor to bring the students can demonstrate the ability of critical and creative thinking. Another factor that influences the development of critical and creative thinking skills is that what they learn makes sense and is important, according to their values and perspectives, motivations arise. Another personal characteristic identified by participants in my research as helping them develop critical thinking skills is self-confidence. The other is student participation in learning (for example, time to study, how doing it in comparative thinking, etc.). Therefore, we recommend that we conduct learning that can support students to develop critical and creative thinking.
Reference

[1] Rodzalan, S. A., & Saat, M. M. (2015). The perception of critical thinking and problem solving skill among Malaysian undergraduate students. Procedia-Social and Behavioral Sciences, 172, 725-732.

[2] Ayars, E. (2013). Computational Physics With Python.

[3] Kazimoglu, C., Kiernan, M., Bacon, L., & MacKinnon, L. (2012). Learning programming at the computational thinking level via digital game-play. Procedia Computer Science, 9, 522-531.

[4] Barr, V., & Stephenson, C. (2011). Bringing computational thinking to K-12: what is Involved and what is the role of the computer science education community?. Acm Inroads, 2(1), 48-54.

[5] Román-González, M., Pérez-González, J. C., & Jiménez-Fernández, C. (2017). Which cognitive abilities underlie computational thinking? Criterion validity of the Computational Thinking Test. Computers in Human Behavior, 72, 678-691.

[6] Yoon, C. H. (2017). A validation study of the Torrance Tests of Creative Thinking with a sample of Korean elementary school students. Thinking Skills and Creativity, 26, 38-50

[7] Arslan, R., Gulveren, H., & Aydin, E. (2014). A Research on Critical Thinking Tendencies and Factors that Affect Critical Thinking of Higher Education Students. International Journal of Business and Management, 9(5), 43.

[8] Gagné, R. M. (1988). Some reflections on thinking skills. Instructional Science, 17(4), 387-390.

[9] Tian, Z. F. (2017). Teaching and enhancement of critical thinking skills for undergraduate students in a computational fluid dynamics course. International Journal of Mechanical Engineering Education, 45(1), 76-88.

[10] Lockwood, J., & Mooney, A. (2017). Computational thinking in education: Where does it fit. A systematic literary review. arXiv preprint.

[11] Kao, C. Y. (2014). Exploring the relationships between analogical, analytical, and creative thinking. Thinking Skills and Creativity, 13, 80-88.

[12] Behringer, E., & Engelhardt, L. (2017). Guest Editorial: AAPT Recommendations for computational physics in the undergraduate physics curriculum, and the Partnership for Integrating Computation into Undergraduate Physics.

[13] Akmam, A., Anshari, R., Amir, H., Jalinus, N., & Amran, A. (2018, April). Influence of Learning Strategy of Cognitive Conflict on Student Misconception in Computational Physics Course. In IOP Conference Series: Materials Science and Engineering (Vol. 335, No. 1, p. 012074). IOP Publishing.

[14] Hürsen, Ç., Kaplan, A., & Özdal, H. (2014). Assessment of creative thinking studies in terms of content analysis. Procedia-Social and Behavioral Sciences, 143, 1177-1185.

[15] Chen, A., Dong, L., Liu, W., Li, X., Sao, T., & Zhang, J. (2015). Study on the mechanism of improving creative thinking capability based on Extenics. Procedia Computer Science, 55, 119-125.

[16] Gentner, D. & Maravilla, F. (2018). Analogical reasoning. L. J. Ball & V. A. Thompson (eds.) International Handbook of Thinking & Reasoning (pp. 186-203). NY, NY: Psychology Press.)

[17] Yoon, C. H. (2017). A validation study of the Torrance Tests of Creative Thinking with a sample of Korean elementary school students. Thinking Skills and Creativity, 26, 38-50.

[18] Simsek, C. L., & Kıyıcı, F. B. (2010). How much science and technology lesson student studying books support creative thinking?. Procedia-Social and Behavioral Sciences, 2(2), 2105-2110.