The Future of Engineering Education
2024 Annual Conference & Exposition
Oregon Convention Center
Portland, OR . June 23 - 26, 2024
Paper ID #41597

Assessing Critical Thinking in Computer and Software Engineering Courses

Dr. Mohammad Shokrolah Shirazi, Marian University
Hung-fu Chang

Assessing Critical Thinking in Computer and Software Engineering Courses

Mohammad Shokrolah Shirazi [a] and Hung-Fu Chang[b]

E. S. Witchger School of Engineering, Marian University, Indianapolis, IN, USA[a] ; [b] R.B. Annis School of Engineering, University of Indianapolis, IN, USA

ABSTRACT

Critical thinking is a crucial component of effective learning, enabling students to comprehend, reflect, and apply their learning toward solving new problems. Although critical thinking could be used toward solving challenging problems, it is sometimes considered as a similar concept of “challenging level” among students and instructors. This study aims to investigate this similarity issue by evaluating students’ opinions based on critical thinking, and challenging level of course assignments in computer and software engineering courses. Students are asked to rank each assignment based on how much each assignment stimulated their critical thinking, and how much it challenged them. Moreover, instructors provide their opinions about critical components of each course assignment for comparison and validation purposes. The t-tests were conducted on collected data from students and analysis results show that 50% of assignments on average are not significantly different from students’ perspectives. The additional collected data on overall satisfaction with each course assignment indicates that students welcome the assignments with a higher degree of critical thinking rather than those that are more challenging.

KEYWORDS

Critical thinking; challenging level; course assignments; t-tests.

1. Introduction

Critical thinking (CT) has been a trending topic of discussion among academia and industries which implies a high proficiency level of students to solve complex problems. While the subject has been incorporated by instructors in the classrooms to increase the chance of students to impress their prospective employers, students may not know its precise definition.

Although the concept and definition of critical thinking is a matter of debate (Ennis, 2018), related studies suggest intellectual discipline with some core elements such as purpose and problem identification, concept clarification, discovery of assumptions, consideration of points of view, detection of consequences, validation of evidence, and reflection (Seibert, 2021).

Applying critical thinking skills is well suited for engineering problems since they often require a thorough process with a suggested model consisting of interpretation, analysis, inference, evaluation, and opinions. Moreover, the Accreditation Board for Engineering and Technology (ABET) stresses the significance of incorporating critical thinking instruction, along with other general engineering expertise (e.g., soft skills) in engineering curriculum through their published student outcomes (Claris and Riley,

Email: mshokrolahshirazi@marian.edu

2012).

Since the connection between CT and problem-solving in engineering is a recurring theme in the literature, teaching and learning critical thinking should equip different levels of problems with varied features that involve appropriate hypotheses, methods for experiments, and structuring open design problems (Ahern, Dominguez, McNally, O'Sullivan, and Pedrosa, 2019).

On the other hand, the challenging level of the problems is another key factor to assist students be engaged during the courses and developing their mindset. In broader terms, the general idea of challenge-based learning (CBL) focuses on learning while solving real-world problems that could be collaborative, and hands-on. Moreover, all participants (e.g., students) are encouraged to identify big ideas, ask good questions, discover and solve challenges, gain in-depth subject area knowledge, develop 21st-century skills, and even share their thoughts with the world (Gallagher and Savage, 2020). Based on the definitions, the challenging level of the problems has quite a different meaning than critical thinking, but they can be easily misunderstood by students and instructors due to a lack of background knowledge.

This research study aims to investigate whether there is a distinction between critical thinking and challenging level of problems from students' perspective. In other words, we are interested to see whether students and instructors confuse the concepts of challenge and critical thinking. The paper investigates how much these concepts (e.g., challenging level of the problems and critical thinking level) are related to each other and how each concept is related to overall student satisfaction. The data are collected from students of the three computer and software engineering courses and statistical analysis methods provide insights for our proposed research questions.

2. Literature Survey

Due to the controversial nature of the critical thinking concept, some studies have provided its meaning and how to implement it in the classrooms. Ennis (Ennis, 2018) provided an actual meaning of critical thinking followed by a comprehensive investigation of a related program that aims to implement critical thinking across the curriculum (CTAC) called "The Alpha Conception of Critical Thinking". Even though critical thinking can be taught as a course, the amounts currently taught are arguably disappointing, so many instructors introduce it within their problem-solving and combine it with subject-matter instruction.

To make appropriate incorporation of CT in teaching, some research studies suggested specific teaching approaches employing a critical thinking model. For instance, the proposed model by Zivkovil (Zivkovil, 2016) designed class activities and mapped them to the CT elements such as interpretation, analysis, inference, evaluation, explanation, and self-regulation. In contrast to "rote memorization" which requires recital and repetition, the proposed model reinforces a more contemporary learning style that is more suitable for solving real-world problems.

Engineers need to develop critical thinking skills to deal with a dynamic world that always gets threatened by automated machines and artificial intelligence. Since their CT will impact the quality of their product design, they need to obtain this skill which is quite different than referring to the memorized materials from lectures and textbooks. As a result of this, Adair and Jaege (Adair and Jaeger, 2016) proposed three methods to cultivate CT within engineering education. The methods include an initial course to make the student familiar with CT and its objectives, a seminar and discussion group for faculty and how they can integrate it into their course modules, and finally open-ended assignments.

Although CT can be utilized within the course curriculum to equip students with this important skill, its learning outcome of the students might be varied. So, Mohaffyza et al. (Mohamad, Jamali, Mukhtar, Sern, and Ahmad, 2017) presented learning styles and investigated their relationship with critical thinking. The index of learning styles was adopted to measure the learning styles of the students, whereas a questionnaire for critical thinking was utilized to identify the critical thinking skills of the students.

Another crucial factor assisting students to be engaged during the learning and improving their skills is a challenging feature of the course assignments. Especially in higher education, challenge-based learning (CBL) has been highlighted and defined as a multidisciplinary teaching and learning approach that encourages students to leverage technology to solve real-world problems. So, it has some common features such as being collaborative and hands-on with peers, teachers, and experts in their communities. Problem-based learning (PBL) is a variation of CBL with less open general problems and students don't need to formulate the challenges they will address (Leijon, Gudmundsson, Staaf, and Christersson, 2022).

Since problem-based learning has been effective in learning and improving CT skills (Ulger, 2018), it is always recommended to be utilized within the projects and assignments of engineering education. Based on these definitions, the challenging feature of problems can impact the student's critical thinking though they are completely different concepts. That is our main motivation to investigate this issue and recommend approaches to distinguish these two terms for instructors and students of computer and software engineering courses. In this paper, we are looking for answering the following research questions (RQ):

- RQ1: Do students know the difference between the two keywords of "critical thinking" and "difficulty level" of the course assignments?
- RQ2: Is there any relationship between "critical thinking" and the "overall satisfaction" of the students?
- RQ3: Is there any relationship between the "difficulty level" of the problems and the "overall satisfaction" of the students?

To answer the research questions, the course assignments are utilized as a data source for assessment and analysis. The main subject of this research study is students since they play a key role in the educational system and they are typically asked for the course evaluation to fill out by the end of the semester. So, our research aims to investigate their opinions and gauge how much students' reflections in course evaluations are valid. Moreover, the instructors provide their opinions about course assignments for comparison and validation purposes. The rest of the paper will explain the methodology such as data collection and analysis in more detail.

3. Methodology

Students evaluate courses and instructors with questions related to the challenging level of the course assignments and the level of critical thinking that has been encouraged throughout the semester. Although these two factors seem fairly distinct, students might not think properly about their differences due to a lack of background knowledge. This might lead to misinterpretation inappropriate data collection and biased evaluations. So, the methodology used in this research study consists of the data collection and statistical analysis of students' data and comparing that with instructor opinions for critical thinking.

3.1. Data Collection

The data collection was performed for three different courses in computer and software engineering courses that were taught by the authors of this paper. The courses were taught in fall semester at the University of Indianapolis and informed consents were collected on the first day of the class from students' participation in the study based on the approved Institutional Review Boards (IRB) guidelines. Students are asked to rank each problem assignment based on its critical thinking and challenging features. They also provide their overall satisfaction rate at the end of each assignment.

There are three questions that students need to answer for each assignment:

- In my opinion, the difficulty of each problem in this homework or lab was:
  1: Extremely low, 2: Low, 3: Medium, 4: High, 5: Extremely high
- In my opinion, the problems of this homework or lab stimulated my critical thinking as follows:
  1: Extremely low, 2: Low, 3: Medium, 4: High, 5: Extremely high
- Overall, this homework or lab assignment was:
  1: Extremely bad, 2: Bad, 3: OK, 4: Good, 5: Very good

To validate and get more insights regarding students' responses, instructors also rank each course assignment based on CT and difficulty levels. For critical thinking (CT), the proposed model by Zivkovil (2016) is used with components presented in Table 1.

Table 1. Critical thinking components for assessing the course assignments

Skills	Sub-skills
(I) Interpretation	(a) Categorization, (b) decoding significance, (c) clarifying meaning
(II) Analysis	(a) Examining ideas, (b) identifying arguments, (c) analyzing arguments
(III) Inference	(a) Querying evidence, (b) conjecturing alternatives, (c) drawing conclusions
(IV) Evaluation	(a) Assessing claims, (b) assessing arguments
(V) Explanation	(a) Stating results, (b) justifying procedures, (c) presenting arguments
(VI) Self-regulation	(a) Self-examination, (b) self-correction

3.1.1. Computer Architecture and Parallel Computing Course (CSCI 230)

The introductory Computer Architecture and Parallel Computing course is aims to make sophomore computer science students familiar with varied computer architecture topics such as digital logic, the classical Von Neumann model, machine-level representation of data, assembly language programming, and parallel computing concepts and methods. Table 2 provides more details about each homework assignment topic and CT skill components enabled by the instructor. The overall score is computed based on the number of CT skill components over a total of six skills presented as rows in Table 1.

Table 2. Critical thinking evaluation of homework assignments by the instructor for CSCI 230 course

Assignment	Topics	CT Skills	Score
HW1	Basic computer architecture concepts, base conversions for numbers, Gnu Debugger (GDB), and its debugging features.	Categorization, identifying arguments, conjecturing alternatives, stating results.	4/6
HW2	Circuits inference, Boolean simplification with Karnaugh maps, sum of products, bit-level manipulation.	Clarifying meaning, analyzing arguments, drawing conclusions, stating results.	4/6
HW3	Write Advanced RISC Machine (ARM) assembly programs for a total run, Fibonacci series, bit-level manipulation, use GDB to verify the correctness.	Clarifying meaning, identifying arguments, conjecturing alternatives, stating results, self-examination.	5/6
HW4	Write ARM assembly programs to work with arrays using the store, and load instructions, utilize GDB for verification of memory contents, cache mapping methods, and measure catch miss rate using Valgrind for alternative matrix computations.	Clarifying meaning, analyzing arguments, assessing arguments, assessing claims, justifying procedures, and self-examination.	6/6
HW5	Compress data using the Huffman method, writing programs using multi-threading and multi-processing techniques.	Decoding significance, analyzing arguments, drawing conclusions, assessing claims, stating results, and self-examination.	6/6
HW6	Parallel processing for vectors and matrices operations using multi-threading and Compute Unified Device Architecture (CUDA).	Clarifying meaning, examining ideas, conjecturing alternatives, stating results, self-examination.	5/6

3.1.2. Operating Systems (SWEN 310)

The course is presented at the junior level for computer/software engineering as well as computer science students. The course covers different topics such as Central Process Unit (CPU) scheduling algorithms, process synchronization, memory management, threads, file systems, I/O systems, privacy and security, and performance evaluation. Tables 3, 4 provide more details about each homework and lab assignment subject, and CT skill components activated by the instructor. Based on the instructor's opinion, the homework assignments have a higher average CT score of 5.4 in comparison with 5.0 for lab assignments.

Table 3. Critical thinking evaluation of homework assignments by the instructor for SWEN 310 course

Assignment	Topics	CT Skills	Score
HW1	Program test and debug, process creation and features (e.g., fork system call, zombie process), process communication with pipe.	Clarifying meaning, identifying arguments, drawing conclusions, assessing arguments, justifying procedures, self-examination.	6/6
HW2	Multi-threading with pthreads, Monte Carlo technique to estimate π number, protect against race condition.	Clarifying meaning, analyzing arguments, drawing conclusions, stating results.	4/6
HW3	CPU scheduling algorithms for regular and real-time operating systems and their evaluation and analysis using Gantt chart.	Categorization, analyzing arguments, conjecturing alternatives, assessing claims, justifying procedures, and self-examination.	6/6
HW4	memory mapping (e.g., logical address, physical address), memory management algorithms (first-fit, best-fit, worst-fit) evaluation, and paging algorithm implementation.	Clarifying meaning, examining ideas, conjecturing alternatives, assessing arguments, self-examination, stating results	6/6
HW5	Work with Linux file system permissions, type of users, implementing Rivest–Shamir–Adleman (RSA) encryption method.	Decoding significance, identifying arguments, drawing conclusions, assessing arguments, stating results.	5/6

Table 4. Critical thinking evaluation of lab assignments by the instructor for SWEN 310 course

Assignment	Topics	CT Skills	Score
Lab1	Setting up Linux-based environment, practicing directory and file-related commands.	Categorization, examining ideas, querying evidence, justifying procedures.	4/6
Lab2	Arrays, pointers, command line arguments in C, execute, run, and debug programs in the command line.	Clarifying meaning, identifying arguments, conjecturing alternatives, stating results, self-examination.	5/6
Lab3	Process creation, listing system process information, implementing a shell, and improving their initial version.	Categorization, identifying arguments, drawing conclusions, assessing arguments, presenting arguments, and self-examination.	6/6
Lab4	Threads creation, and termination, joining with a terminated thread.	Clarifying meaning, identifying arguments, drawing conclusions, stating results.	4/6
Lab5	Protecting shared variables (e.g., mutex), threads signalization, and conditional variables.	clarifying meaning, analyzing arguments, conjecturing alternatives, and justifying procedures.	4/6
Lab6	Semaphore definition, wait and post functions, producer and consumer problem implementation, binary Semaphore.	Decoding significance, analyzing arguments, drawing conclusions, assessing claims, stating results, and self-examination.	6/6
Lab7	CPU scheduling algorithms testing and evaluation, judging alternative scheduling software and methods.	Clarifying meaning, analyzing arguments, conjecturing alternatives, assessing arguments, presenting arguments, drawing conclusions, and self-examination.	6/6
Lab8	Memory management system commands, tracing memory usage, testing and evaluating memory issues (e.g., leakage, usage, etc.) with Valgrind software.	Clarifying meaning, identifying arguments, drawing conclusions, assessing claims, presenting arguments.	5/6
Lab9	File system architecture, directory, file property.	clarifying meaning, analyzing arguments, querying evidence, assessing claims, and justifying procedures.	5/6

3.1.3. Software Project Management (SWEN 400)

The course is presented at the senior level for software engineering and computer science students introducing software development, process, and management. Tools and techniques are learned for project definition, work breakdown, estimating, resource planning, critical path development, scheduling, project monitoring, control, and scope management. Convey the concept of technical baselines and associated risks. Students will use project management software to accomplish these tasks. In addition, the student will become familiar with the responsibilities, skills, and effective leadership styles of a good project manager. Table 5 provides more details about each homework assignment topic, and CT skill components activated by the instructor.

Table 5. Critical thinking evaluation of homework assignments by the instructor for SWEN 400 course

Assignment	Topics	CT Skills	Score
HW1	Basic process concepts in project management. Various software process models. Scrum framework and development time estimation. Basic concepts about various types of software development organizational structures.	Clarifying meaning, analyzing arguments, conjecturing alternatives, stating results.	4/6
HW2	Software development time estimation, software task scheduling, critical path method, Cumulative Flow Diagram (CFD), software project manager's ethics.	Clarifying meaning, analyzing arguments, drawing conclusions, stating results.	4/6

3.2. Statistical Analysis

After conducting the data collection, students' response to each question is mapped to their corresponding number. For example, Extremely low maps to 1, low maps to 2, medium maps to 3, high maps to 4, and extremely high maps to 5. Due to the popularity of the t-test as a statistical method to compare the means of two groups, we utilize it for hypothesis testing. The t-tests with 95% confidence intervals are applied to collected data to identify whether there is a significant difference between the two groups. So, the null hypothesis H_0 states that there is no significant difference between the data of each variable. Three defined variables are critical thinking (CT), challenging feature (Diff) of assignments, and overall satisfaction (OF) of students for the homework/lab assignments. Finally, the calculated p value provides insight into rejecting or accepting the null hypothesis.

4. Experimental Results

4.1. Critical Thinking Versus Challenging Level and Overall Satisfaction

The null hypothesis indicates no significant difference between the mean of the three groups (i.e., difficulty level (Diff), critical thinking (CT), and overall satisfaction (OS)) if the calculated p-value is greater than 0.05. There were a total of eleven students enrolled for the CSCI 230 course and they were asked to fill out six surveys by the end of every homework assignment. Four students on average participated in the research (See the column 'N' of Table 6 for more details on the participation of every assignment). Table 6 presents the estimated p-values for homework assignments of the CSCI 230 course. The p-values less than 0.05 are depicted with the green color indicating significant differences among the groups of the column. The "similar" row shows the frequency of red colors over the total for each column. The experiments on students' response data for each group (Diff, CT, OS) show that HW1, and HW2 are significantly different for the three groups. The difference is also significant for two groups, Diff vs. OS and CT vs. OS of HW05. Based on the average of the similarity row, more than 55% are not rated significantly different from students' perspectives.

Table 6. T-tests p value for homework assignments in CSCI 230 course (N= Number of participated students)

Assignment	Diff vs. CT	Diff vs. OS	CT vs. OS	N
HW1	0.02	0.00	0.02	6
HW2	0.02	0.00	0.00	4
HW3	0.24	0.17	0.14	4
HW4	0.41	0.24	0.28	3
HW5	0.5	0.01	0.01	4
HW6	0.38	0.06	0.12	3
Similarity	66%	50%	50%	–

There were ten total students enrolled for the SWEN 310 course and they were asked to fill out five surveys by the end of every homework assignment, and nine surveys by the end of each lab assignment. Tables 7 and 8 show minimum 5 and 6 students' participation for the homework and lab assignment surveys respectively. They also present the estimated p-values for homework assignments of the SWEN 310 course. HW1 has an average mean difference for both two groups of Diff vs OS and CT vs OS. The difference is observed for Diff vs CT and CT vs OS in HW3, and HW4 respectively. The average of data in the similarity row indicates that more than 73% are not significantly different from students' perspectives.

Table 7. Difference evaluation in homework assignments for SWEN 310 course

Assignment	Diff vs. CT	Diff vs. OS	CT vs. OS	N
HW1	0.33	0.04	0.02	5
HW2	0.36	0.23	0.29	5
HW3	0.04	0.40	0.15	5
HW4	0.12	0.02	0.07	7
HW5	0.36	0.19	0.12	6
Similarity	80%	60%	80%	–

Table 8 presents the t-tests for the lab assignments of the SWEN 310 course. The table depicts more than 55% (i.e., 15/27) similarity in average scores of group comparisons. Interestingly, there are a higher number of significant differences between the group of overall satisfaction with difficulty level and critical thinking (e.g., Diff vs OS, and Diff vs OS). Lab3, Lab4, Lab5, and Lab9 have significant differences in average scores for overall satisfaction in comparison to difficulty level and critical thinking groups. Lab6, Lab7, and Lab8 show no significant difference for all three groups which requires revision if instructors plan to use it in the future.

Table 8. Difference evaluation in lab assignments for SWEN 310 course

Assignment	Diff vs. CT	Diff vs. OS	CT vs. OS	N
Lab1	0.02	0.00	0.02	7
Lab2	0.14	0.04	0.10	7
Lab3	0.06	0.00	0.00	8
Lab4	0.17	0.00	0.00	9
Lab5	0.07	0.00	0.00	8
Lab6	0.06	0.09	0.22	8
Lab7	0.29	0.35	0.41	7
Lab8	0.06	0.07	0.18	8
Lab9	0.44	0.00	0.00	6
Similarity	88%	33%	44%	–

There were three students registered for the SWEN 400 course and all of them participated in this research. Table 9 presents the t-tests for the two homework assignments of the SWEN 400 course. The results for this course show significant difference between all three groups except the challenging feature versus critical thinking in HW1. Figure 4 presents a significant difference in average score for both HW1 and HW2. One possible explanation is that students do not have sufficient software development or project management experience. It might be difficult for them to interpret the situational software process questions in HW1. As a result, this could be homework that might need some improvements.

Table 9. Difference evaluation in homework assignments for SWEN 400 course

Assignment	Diff vs. CT	Diff vs. OS	CT vs. OS	N
HW1	0.06	0.00	0.01	3
HW2	0.01	0.00	0.01	3
Similarity	50%	0%	0%	–

4.2. Mean Comparison

After mapping students' opinion rates (e.g., "extremely low", "low", "medium", "high", "extremely high") to the corresponding values from the set $rate = \{1, 2, 3, 4, 5\}$ regarding each assignment problem, the average for every assignment was calculated regarding the Diff, CT, and OS categories.

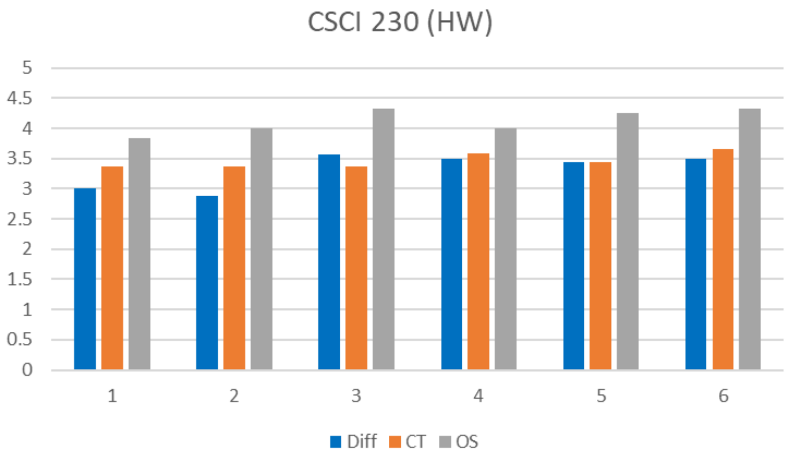

Figure 1. Students' average rate based on challenging feature, critical thinking and overall satisfaction for each homework in CSCI 230 course

Figure 1 shows the average students' rate for homework assignments of the computer architecture course is 3.31, 3.46, and 4.12 for Diff, CT, and OS groups respectively. Based on students' opinions, the two highest challenging homework assignments are HW3 and HW6 with values of 3.6 and 3.5 respectively. The two homework assignments that required a higher degree of CT are HW6 and HW4 with values of 3.66 and 3.58. Interestingly, HW3 and HW6 have the highest OS with a value of 4.33. In summary, overall satisfaction (OS) is significantly higher than CT and Diff and HW6 can be interpreted as a good assignment since it has the highest values for both CT and OS categories.

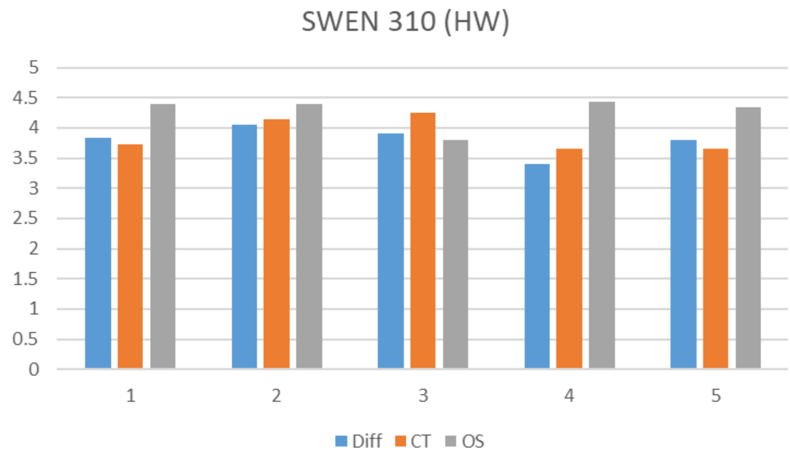

Figure 2. Students' average rate based on Diff, CT and OS for each homework in SWEN 310 course

Figure 2 shows the students' average opinion for homework assignments of the operating system course. The average scores of 5 homework assignments are 3.79, 3.88, and 4.27 for Diff, CT, and OS groups respectively. The figure implies that HW2 and HW3 had the highest difficulty (Diff) with values of 4.05 and 3.9. HW3 and HW2 required more critical thinking (CT) with values of 4.25 and 4.15, and the highest overall satisfaction belongs to HW4 and HW2 with values of 4.42 and 4.4 respectively. Although HW2 was the most difficult one, it was highly appreciated by students as indicated by the high overall satisfaction of 4.4.

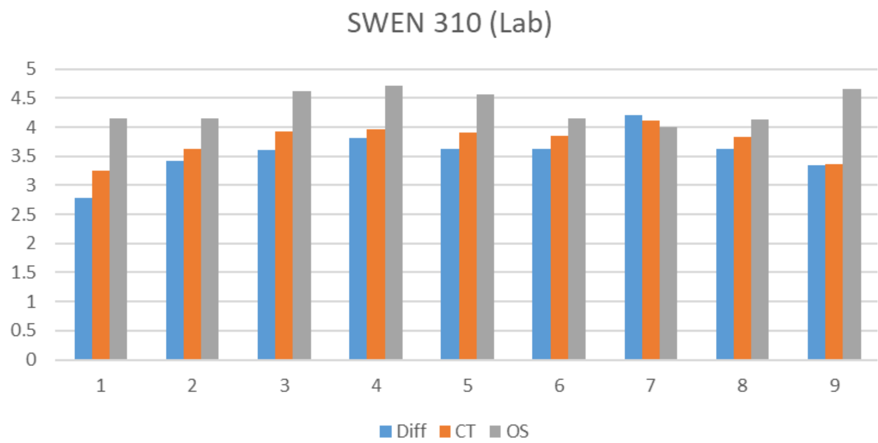

Figure 3. Students' average rate for lab assignment of operating system course (SWEN 310)

In the operating system course (SWEN 310), nine lab assignments have been analyzed as well, and Figure 3 presents the average score for each assignment. The average scores of all nine lab assignments are 3.56, 3.76, and 4.34 for Diff, CT, and OS groups respectively. The most challenging labs are Lab7 (4.2) and Lab4 (3.80), the most critical thinking ones are Lab7 (4.11) and Lab4 (3.97), and Lab4 and Lab9 have the highest satisfaction with average values of 4.71 and 4.66. Similarly, OS has higher values in comparison to CT and Diff. Although Lab7 has the highest CT and Diff values, it has the lowest OS (e.g., 4). Students' overall satisfaction is significantly higher for the lab assignments in comparison with homework for the SWEN310 course.

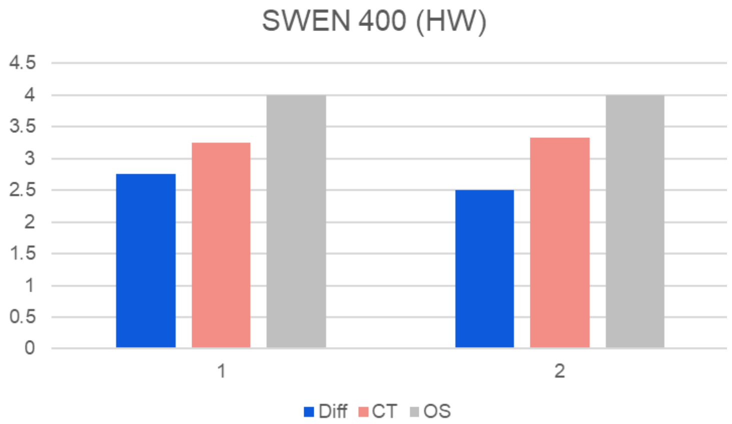

Figure 4. Students' average rate for homework assignment of software project management course (SWEN 400)

There were only two homework assignments for the Software Project Management (SWEN 400) course and Figure 4 shows the higher critical thinking for the course in comparison to the difficulty of assignments. The average value of 2 homework assignments is 2.65, 3.29, and 4 for Diff, CT, and OS respectively. Similar to other evaluated courses, overall satisfaction is higher even though the course has been taught by different instructors.

4.3. Critical Thinking Comparison

Based on collected data from students and course instructors, we can provide more insight about each course presented in Table 10. The results show that students' rate for assignments is lower than the instructor's since they don't use the listed CT components (See Table 1) and are not quite informed about them. As a consequence, they may not be able to identify CT components of the course assignments. While we see a high difference in average for CSCI 230, and SWEN 310 courses, the SWEN 400 opinions are closer (i.e., 0.66 vs 0.65) due to a lower number of participants.

Table 10. Average rate comparison of CT for instructors versus students perspective

Course	Instructor		Students	
CSCI 230 (HW)	5/6	0.83	3.46/5	0.69
SWEN 310 (HW)	5.4/6	0.9	3.88/5	0.77
SWEN 310 (Lab)	5/6	0.83	3.76/5	0.75
SWEN 400 (HW)	4/6	0.66	3.29/5	0.65

5. Discussion & Conclusion

In this paper, we investigated critical thinking (CT), challenging level (Diff), and overall satisfaction (OS) for undergraduate students in three computer and software engineering courses. Instructors of each course also provided their opinions about the critical thinking of the course for comparison with student data. We observed similar patterns and trends for three components of Diff, CT, and OS among all courses. The average rate of overall satisfaction is significantly higher and critical thinking is the second highest one. The lowest average belongs to the difficulty level observed among all course assignments. We are afraid students have provided more conservative opinions to the instructor for the OS group of data. For lab assignments of SWEN 310 course, the overall satisfaction is higher than homework which is reasonable since students complete lab assignments during the lab time. Since they are doing the lab when the instructor observing them, they have a chance to ask questions and get help to finish the lab while for homework they might neglect to do it. Interestingly, the homework assignment had higher critical thinking than labs based on students' opinions for SWEN 310 which is in agreement with the instructor's opinion presented in Table 10. In contrast to labs, homework assignments don't have detailed guidelines and students should complete them outside the classroom which can be a possible reason for this finding.

In response to the research questions, students don't see much difference between the critical thinking versus difficulty level of the course assignments except for the SWEN 400 course (See Tables 9). However, the overall satisfaction category versus critical thinking and difficulty level implies a higher degree of differences from the student's perspective. The reason could be a lack of former knowledge about the critical thinking concept and its difference with difficulty level. Providing education about these concepts and rubrics to students as presented in Table 1 can help to avoid this confusion among students. We can identify good assignments if it is highly rated by students, and instructors based on critical thinking and also are well appreciated by the students based on a high overall satisfaction rate. This was observed for HW6 of the CSCI 230 course. We suggest providing critical thinking components to students and instructors (See Table 1). Students can identify skills during problem solving and instructors should consider these components during designing the course assignments. This can be helpful to promote critical thinking across various courses.

References

Adair, D. and Jaeger, M., 2016. Incorporating critical thinking into an engineering undergraduate learning environment., *International Journal of Higher Education*, 5 (2), 23–39.

Ahern, A., Dominguez, C., McNally, C., O'Sullivan, J.J., and Pedrosa, D., 2019. A literature review of critical thinking in engineering education, *Studies in Higher Education*, 44 (5), 816–828.

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

Ennis, R.H., 2018. Critical thinking across the curriculum: A vision, *Topoi*, 37, 165–184.

Gallagher, S.E. and Savage, T., 2020. Challenge-based learning in higher education: an exploratory literature review, *Teaching in Higher Education*, 1–23.

Leijon, M., Gudmundsson, P., Staaf, P., and Christersson, C., 2022. Challenge based learning in higher education–a systematic literature review, *Innovations in education and teaching international*, 59 (5), 609–618.

Mohamad, M.M., Jamali, A.R., Mukhtar, M.I., Sern, L.C., and Ahmad, A., 2017. Learning styles and critical thinking skills of engineering students, *in: 2017 IEEE 9th International Conference on Engineering Education (ICEED)*, IEEE, 54–58.

Seibert, S.A., 2021. Problem-based learning: A strategy to foster generation z's critical thinking and perseverance, *Teaching and Learning in Nursing*, 16 (1), 85–88.

Ulger, K., 2018. The effect of problem-based learning on the creative thinking and critical thinking disposition of students in visual arts education, *Interdisciplinary Journal of Problem-Based Learning*, 12 (1).

Zivkovil, S., 2016. A model of critical thinking as an important attribute for success in the 21st century, *Procedia - Social and Behavioral Sciences*, 232, 102–108.