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Improving critical thinking skills of preservice chemistry teachers through integrated biochemistry course

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Abstract

Many studies have reported various interventions to increase critical thinking, but very few studies have examined the impact of learning in classrooms and laboratories. This study aimed to find a learning pattern (practice to theory or theory to practice) in improving students' critical thinking skills (CTs). Pre and posttest nonequivalent group design was employed in this study. Eighty preservice chemistry teachers divided 40 students in experimental class 1 and 40 in experimental class 2. A test of enzyme-CTs was developed to measure student CTs before and after the intervention. The result showed that integrated biochemistry courses could improve students' CTs. An independent sample *t*-test was employed, and the result showed a significant difference N-gain students' CTs between experimental classes 1 and 2 ($p = 0.018$). It indicates that the pattern of developing CTs from practice to theory is better than theory to practice. The research result can be taken into consideration for placing biochemistry theory and biochemistry practicum in the same semester for the chemistry or chemistry education curriculum. Students can find concepts independently in practical activities and develop them in theoretical activities. Further research should analyze the discriminant factors that differentiate between students in experimental classes 1 and 2.

KEYWORDS

critical thinking skills, integrated biochemistry course, practice, theory

1 | INTRODUCTION

One of the challenges facing higher education in Indonesia is the lack of development of students' ability to connect theory and practice.[1] Graduates of the future from higher education will need to solve unknown problems that are not currently found.[2] Higher-order thinking skills (HOTS) are crucial skills for preparing qualified human resources to be ready to compete globally. Critical thinking is an important part of HOTS, and some countries include it in part of the curriculum. Two things concern developing and demonstrating critical thinking, including abilities and dispositions.[3] Critical thinking as the abilities (critical thinking skills/CTs) is intellectual aspects for critical thinking.[4] In contrast, critical thinking as the dispositions (critical thinking dispositions/CTd) tends towards patterns of intellectual aspects for critical thinking.[5] A critical thinker will be able to make interpretations and considerations as well as objective and logical conclusions based on information or observation.[6] CTs are needed to deal with world-class competition and make it possible to overcome future problems.

In science education, CTs are an essential dimension.[7–10] Cause the importance of CTs, CTs become one of the thinking skills that must be possessed by preservice teachers in the teaching of 21st-century skills.[11]

Teachers must be taught to conduct quality learning and provide debriefing to improve CTs.[12] Through CTs, the teacher is expected to be able to prepare quality human resources. CTs does not develop without effort explicitly embedded in their development. One way to develop CTs can be done through continuous learning.[13]

Several studies improve CTs through learning activities in the laboratory,[10,14–18] whereas other studies increase CTs through classroom activities.[7,8,19–26] Other studies have developed CTs by using problem as the initial learning unit.[27,28] The problem can motivate students to identify and look concepts or principles in discussing problem that have been given.[27] Students will identify problem by conducting investigations through practical activities and examining them in the classroom.[29] This allows students to establish connections between theory and practice. Using problem as an initial learning unit aligns with the characteristics of biochemistry that are often related to social contexts.[30] For example, blood sugar explained carbohydrate metabolism,[31] influenza and HIV explained DNA replication, and herpes explained membrane transfer.[32] The enzyme is biochemistry core because it is important for understanding other topics such as metabolic pathways, transcription, and translation.[33] Browning reaction is a social context and related to the topic of the enzyme. Polyphenol oxidase (PPO) catalyzes browning reactions by forming complex brown polymers (melanin) with two different reactions.[34] The first step is an enzymatic reaction, monophenol is converted into o-diphenol, and o-diphenol is changed to o-quinone. The second step is a nonenzymatic reaction. o-quinone undergoes nonenzymatic oxidative condensation into melanin.

Previous research found that biochemistry courses and biochemistry laboratory were not carried out in an integrated manner, even though they were placed in the same semester.[1] Wrenn and Wrenn[35] believe that experience is the best teacher; therefore, experiential learning activities are made in a learning environment that integrates theory and practice activities without partitioning. However, no research has become empirical evidence about integrating theory and practice, especially, in improving CTs. Laboratory activities are carried out after students take a theory test. Students are divided into several groups and practice with different topics. The findings of this study will find patterns of integration in biochemistry, especially, in the topic of enzymes. Learning will be developed with two models, the model of practice to theory (P → T) and the model of theory to practice (T → P).

The research focus is to compare the improvement of CTs between the pattern of integration of practice to theory (P → T) and theory to practice (T → P). Both patterns use problem-based learning as the initial unit of learning. This is because, the biochemistry content is closely related to contextual problem. The main objective of this research is to find the most effective integration pattern in improving CTs in biochemistry courses. This objective operationally follows the following research questions.

1. How is the improvement of students' CTs with the integration of theory into practice (T → P) in biochemistry courses?
2. How is the improvement of students' CTs with the pattern of integration of practice into theory (P → T) in biochemistry courses?
3. Which is the most effective pattern to improve students' CTs?

2 | METHOD

2.1 | Research design

This research method is an experimental method with a quasi-experiment pre and posttest nonequivalent group design. Group was divided into experimental class 1 and experimental class 2. Experimental class 1 starts with practical to theoretical activities (P → T), while experimental class 2 starts from theoretical to practical activities (T → P). Learning in experimental classes 1 and 2 was conducted for five face-to-face meetings that consisted of two laboratory activities (LA) and three classroom activities (CA) (Table 1).

Table 1 illustrates two different learning activities, yet still using the same context: browning reaction on potatoes. Learning stage of P → T consist of five stages: (1) problem discovery; (2) problem and issue analysis; (3) investigation and report findings; (4) presentation of problem-solving results and reflection; (5) conclusions, integration, and evaluation. In the problem discovery phase, students are tasked with recognizing the symptoms of browning reactions on potatoes, indicating quality and marketability issues. Through discourse and probing questions, they explore the impact of these reactions, laying the groundwork for subsequent problem-solving endeavors. By identifying areas needing attention and improvement, students initiate their problem-solving journey. Moving to problem and issue analysis, students delve deeper into the root causes and implications of browning reactions. Through systematic examination and critical thinking, they analyze the mechanisms behind the oxidation reaction of PPO enzymes, which lead to melanin formation. This phase involves developing an investigation plan to analyze factors influencing

TABLE 1 Learning activities in experimental class 1 and 2.

Experimental class 1		Experimental class 2	
Meeting	**Learning activities**	**Learning activities**	**Meeting**
Meeting 1	Pretraining experiment • For CTs performance Stage 1. problem discovery • Browning reaction on potatoes Stage 2. problem analysis • Analyze the causes and effects of browning reactions on potatoes		Meeting 1
Meeting 2 Meeting 3	Stage 3. investigation and report findings • Isolation and qualitative analysis of PPO on potatoes (LA) • Quantitative analysis of PPO (LA)	Stage 3. receiving verbal material • A verbal explanation of enzymes (CA)	Meeting 2
Meeting 4	Stage 4. presentation of problem-solving results and reflection • Presentation from laboratory activities (CA)	Stage 4. elaboration through investigation • Isolation and qualitative analysis of PPO on potatoes (LA) • Quantitative analysis of PPO (LA)	Meeting 3 Meeting 4
Meeting 5	Stage 5. conclusions, integration, and evaluation • Synthesize their findings • Identify factors affecting PPO enzyme action • Propose follow-up actions to inhibit browning reactions Posttraining experiment • For CTs performance		Meeting 5

Abbreviations: CA, classroom activities; CTs, critical thinking skills; LA, laboratory activities; PPO, polyphenol oxidase.

enzyme action on the subsequent investigative stage. In investigation and report findings, students engage in practical experiments to isolate and characterize PPO enzyme activity in potatoes. They conduct tests with various substrates, determine optimal pH and temperature conditions, and identify effective inhibitors. All findings are compiled into a practicum report, showcasing students' hands-on exploration and analytical skills. Transitioning to presentation of problem-solving results and reflection, students communicate their findings to stakeholders through presentations. They link their results to learning indicators, such as enzyme classification and the effects of substrate concentration, temperature, and pH. This phase also encourages reflection on the problem-solving journey, facilitating continuous learning and skill refinement. Conclusions, integration, and evaluation mark the final stage of the learning process. Here, students synthesize their findings, identify factors affecting PPO enzyme action, and propose follow-up actions to inhibit browning reactions. The lesson concludes with an evaluation, utilizing enzyme-CTs to gauge the impact of interventions on students' CTs. This comprehensive approach ensures students not only understand the problem-solving process but also apply their knowledge to real-world scenarios, fostering meaningful learning outcomes.

Same as the previous learning pattern, learning activities T → P are carried out through five stages but with different stages: (1) problem discovery; (2) problem analysis; (3) receiving verbal material; (4) elaboration through investigation; (5) conclusions, integration, and evaluation. In the problem discovery, students recognize the symptoms of browning reactions on potatoes, indicating quality and marketability issues. Through discourse and probing questions, they explore the impact of these reactions, laying the groundwork for subsequent problem-solving endeavors. By identifying areas needing attention and improvement, students initiate their problem-solving journey. Moving on to the problem and issue analysis, students delve deeper into the root causes and implications of browning reactions. Through systematic examination and critical thinking, they analyze the mechanisms behind the oxidation reaction of PPO enzymes, which lead to melanin formation. This phase involves developing an investigation plan to analyze factors influencing enzyme action on the subsequent investigative stage. As students progress to receiving verbal material, they absorb verbal instructions, explanations, or presentations relevant to the identified problem. Students receive verbal discussions on the classification of enzymes, substrate concentration, enzyme concentration, effect of temperature, and effect of pH. After students understand the learning material, they subsequently validate what they have learned through practical activities in the elaboration through investigation stage. Students engage in practical experiments to isolate and characterize PPO enzyme activity in potatoes. They conduct tests with various substrates of PPO, determine optimal pH and temperature conditions, and identify effective inhibitors of PPO. All findings are compiled into a practicum report, showcasing students' hands-on exploration and analytical skills in the conclusions, integration, and evaluation stage. Student link their results to learning indicators, such as enzyme classification and the effects of substrate concentration, temperature, pH, and inhibitor to PPO activity. This phase also encourages reflection on the problem-solving journey, facilitating continuous learning and skill refinement. In the evaluation phase, students answer the enzyme-CTs test as a posttraining assessment.

The difference between the two learning stages lies in the third stage. In the first experimental class (P → T), after students analyze the problem, they investigated to find answers and analyzed problem through practical experimentation. The results of the experiment are then presented and followed up in classroom activities. Meanwhile, in the second experimental class (T → P), students follow up on the problem through a presentation by the lecturer in the classroom. Students then follow up, validate, and substantiate the lecturer's explanations through practical experimentation. This difference not only lies in the learning stages but also extends to the nature of the conducted practicum. In the P → T learning activity, the practicum serves to explore and discover new concepts not yet known to the students. However, in the T → P learning activity, the practicum is more of a verification or confirmation to prove the concepts they have previously learned. In essence, while both activities involve problem discovery and analysis, the P → T learning activity is more extensive, combining a practicum and detailed investigation into enzyme activity. On the other hand, the T → P learning activity is more focused on understanding the phenomenon through material explanation and practical validation, with a slightly streamlined learning process.

2.2 | Location and sample

This research was conducted on one of the higher educations in Indonesia (department of chemistry education). Purposeful sampling was used to select 80 preservice chemistry teachers in 2019 through voluntary recruitment. Research permission was obtained from the department head. Based on the departmental data obtained for freshmen at the time of taking the lecture notes taken during organic chemistry classes in the previous semester. Specifically, there were two classes taking the biochemistry course, each class consisting of 40 students who had passed the organic chemistry course. Before the students were involved in the study, the purpose and technicalities of the study were explained. Those who agreed to participate were then randomly divided into two parallel classes, A and B. These two groups received different treatments from the same instructor.

2.3 | Data collection

The research instrument used enzyme-CTs test. The test was constructed three-tier test, consisting of the first-tier as a multiple-choice and the second-tier as the reason from the first-tier option and third-tier asks the trust in the answer provided in the second-tier (See Supporting Information Appendix S1). The instrument was developed based on indicators of CTs.[36] The enzyme-CTs test consists of 14 items that have been judged by five panelists to measure its content validity. The critical value of content validity ratio (CVR) for the five panelists is 0.877 at the significance level (α) of 0.05.[37] From the 14 items were analyzed, 11 items are in the appropriate interpretation (CVR = 1), and 3 items must be revised (CVR = 0.6). Content validity index (CVI) for each form of this test is 0.86. In Table 2, we found that the internal consistency of the items is acceptable with range of Cronbach's alpha from 0.621 to 0.751. The mean interitem correlation analysis had variation from 0.313 to 0.497. The results of this analysis can be said to have met the criteria where the recommended mean interitem correlation is in the range of 0.2–0.4 and the Cronbach's alpha value is greater than 0.5.[38] Data were collected before and after the learning intervention. The pretest will measure students' CTs before learning intervention, and the posttest will measure students' CTs after learning intervention.

2.4 | Data analysis

To analyze the enzyme-CTs test results, we used the scoring guide shown in Table 3. Tier 1 and tier 3 have a score of 1, while tier 2 has a score of 2. Tier 2 has a greater score than the other tiers, because tier 2 describes and explains the item question. Scoring of pretest and posttest items was made on a scale of 100. To analyze the improvement in both classes, it was calculated using normalized gain (N-gain).[39] The analysis is also conducted by analyzing the achievement of N-gain on each

TABLE 2 Subscales of enzyme-CTs test with internal consistency measurement.

CTs subscales	Enzyme content	Cronbach's alpha	Mean inter-item correlation	No. of item
Inducing and judging inductions	Classification of enzyme	0.621	0.428	1, 2
Making and judging value judgment	Enzyme–substrate interaction	0.712	0.497	3, 4
	Reaction rate	0.677	0.313	5, 6
Judging the credibility of a source	Substrate concentration	0.751	0.367	7, 8
	Enzyme concentration	0.623	0.351	9, 10
Observing and judging observation reports	Effect of temperature	0.714	0.579	11, 12
Deducing and judging deductions	Effect of pH	0.815	0.413	13, 14

Abbreviation: CTs, critical thinking skills.

TABLE 3 Scoring guide of enzyme-CTs test.

	Tier-score			
Item score	Tier 1 (score 1)	Tier 2 (score 1)	Tier 3 (score 2)	Description
None	-	-	-	Students cannot answer even one-tier
0	x	x	x	Students' answers are not correct in all tiers
1	√	x	x	Students answer the first or third tiers correctly but not the second
	-	x	√	
2	√	x	√	Students answer correctly in the first- and third-tiers but get a score of 0 in the second tier; or students answer correctly in the second tier but not the first and third
	x	√	x	
3	√	√	x	Students answer correctly either the first- or third-tier combined with a correct answer in the second tier but not the remaining tier
	x	√	√	
4	√	√	√	Students answer all tiers correctly

Abbreviation: CTs, critical thinking skills.

indicator of CTs. To analyze the mean difference between the two classes, we used descriptive statistics on each item, including the mean and standard deviation for pretest, posttest, and N-gain. Q–Q plots were used to assess the normality of the data distributions visually, which revealed that the data for N-gain in experimental class 1 and 2. The normal distribution was corrected by the Kolmogorov–Smirnov test with the Lilliefors. For comparing group means, we used *t*-tests with equal variance assumptions. In cases where the assumption of equal variances was violated, we used Welch's *t*-test to establish statistical differences. Additionally, when dealing with significantly different group sizes (1.5-fold difference), nonparametric Mann–Whitney *U* test was preferred. To determine statistical significance, we set the threshold at $p < 0.05$ for all tests. The data were analyzed with SPSS 20 statistics package.

3 | RESULTS AND DISCUSSION

The scoring average of students' CTs in experiment classes 1 and 2 was analyzed by the score of pretest, posttest, and N-gain. The results of descriptive analysis of pretest, posttest, and N-gain are shown in Table 4. Table 4 showed that the learning intervention in both classes can improve students' CTs. It is because, learning intervention in both classes is developed by using the problem as the initial unit of learning. Some studies show that learning that begins with problem can improve students' CTs.[27,40,41] Moreover, learning in experimental classes 1 and 2 was developed in an integrated manner. Integrated learning guided students to explore their abilities by analyzing problem and building connection between theory and practice. The N-gain analysis results in both classes concluded that students in experimental class

TABLE 4 The descriptive statistics of pretest, posttest, and N-gain students' CTs in experiment class 1 and 2.

	Experimental class 1 (P → T) ($N = 40$)			Experimental class 2 (T → P) ($N = 40$)		
	M	SD	*R*	*M*	SD	*R*
Pretest	12.40	5.64	0–22	14.20	7.28	0–30
Posttest	76.00	14.50	46–92	65.70	19.17	34–93
N-gain	72.46	17.05	34–91	59.87	22.42	25–91

Abbreviations: CTs, critical thinking skills; *M*, mean; *R*, range; SD, standard of deviation.

TABLE 5 Test of significance N-gain in experimental class 1 and 2.

		N-gain	*t*-test	*p*-value
Students' CTs*	Experimental class 1 ($N = 40$)	72.46	2.470	0.018
	Experimental class 2 ($N = 40$)	59.87		

Abbreviation: CTs, critical thinking skills.
*Differences between the groups are significant ($p < 0.05$).

TABLE 6 Mean of pretest, posttest, and N-gain students' CTs in each indicator.

		Experimental class 1 ($N = 40$)			Experimental class 2 ($N = 40$)		
CTs	Concepts	Pre	Post	N-gain	Pre	Post	N-gain
Inducing and judging inductions	Classification of enzyme	3.00	71.50	69.50	1.00	59.50	59.09
Making and judging value judgment	Enzyme–substrate interaction Reaction rate	13.00	86.00	79.67	8.00	72.00	69.57
Judging the credibility of a source	Substrate concentration Enzyme concentration	6.00	85.00	81.00	4.00	65.00	63.54
Observing and judging observation reports	Effect of temperature	8.00	74.00	74.00	8.00	39.00	33.70
Deducing and judging deductions	Effect of pH	34.00	89.00	86.33	36.00	79.00	67.19

Abbreviation: CTs, critical thinking skills.

1 (72.47; high category) have a better N-gain than experimental class 2 (59.87; medium category). The results of a test significance between N-gain experimental classes 1 and 2 are shown in Table 5.

Table 5 showed a significance test between N-gain experimental class 1 and N-gain experimental class 2 (sig. 0.018). In general, it can be concluded that experimental class 1 is better than experimental class 2. Although the basic level CTs of experimental class 2 is better than experimental class 1, but students in experimental class 1 has a better N-gain than experimental class 2. In this case, it seems that experimental class 1 is able to show significant improvement in CTs despite having a lower basic level of CTs. The increase is due to learning in experimental class 1 begins with a practicum to theory. It allows students to explore learning experiences independently and conduct discussions to share their findings with other students. Previous studies found that problem as the initial learning unit and independently elaborated through investigative activities can improve students' CTs.[42] Through investigation activities in the laboratory, students in the experimental class 1 analyzed data, identify patterns, and draw evidence-based conclusion. Students learn to question assumptions, evaluate evidence critically and develop problem-solving skills through hands-on activites, thereby enhancing their overall ability to think critically and independently. Similarly, previous study found that improving students' CTs can be done by involving students with factual and procedural knowledge and depth exploration with hands-on activities.[14] This enabled information acquired to be better maintained through an immediate application.

Further analysis was carried out on each CTs indicator in the experimental classes 1 and 2 (Table 6). In experimental class 1, indicator of inducing and judging inductions (69.50) has the lowest N-gain score, while the highest N-gain score is deducing and judging deduction (86.33). Deducing and judging deductions is a logical conclusion process by interpreting the evidence obtained during the investigation. This pattern of thinking develops the concept

TABLE 7 Test of significance N-gain students' CTs in each indicator

CTs	Concepts	*t*-test	*p*-value
Inducing and judging inductions	Classification of enzyme	0.991	0.321
Making and judging value judgment	Enzyme–substrate interaction Reaction rate	0.302	0.763
Judging the credibility of a source	Substrate concentration Enzyme concentration	0.921	0.357
Observing and judging observation reports*	Effect of temperature	2.491	0.013
Deducing and judging deductions	Effect of pH	0.855	0.393

Abbreviation: CTs, critical thinking skills.
*Differences between the groups are significant ($p < 0.05$).

"if and then" or "if and only if."[43] This activity is embedded through inquiry-based practicum activities (laboratory activities [LA]), which students seek knowledge independently by involving mental activity, physical activity, or both. In experimental class 2, the indicator of observing and judging observation reports (33.70) has the lowest N-gain score, while the highest N-gain score is making and judging value judgment (69.57). Making and judging value judgment is a skill that involves the application of principles or facts that have been previously known based on alternative considerations.[43] Principles and facts are acquired from classroom activities (CA) through direct instructions and elaborated through LA.

The significance tests between N-gain in experimental classes 1 and 2 was shown in Table 7. Significant differences are only found in observing and judging observation reports. This indicator is developed through the concept of the effect of temperature on enzyme activity. In this section, students in both classes did practice by observing different temperature conditions (10, 25, 35, and 50°C), but students' ability in experimental classes 1 and 2 is different. Students in experimental class 1 do not know the optimum temperature conditions to increase the enzyme reaction rate. They understand that the rate of enzyme reactions will increase with increasing temperature. However, an increased temperature will cause the enzyme to denaturation and cause its activity to decline. Students already possess this knowledge in experiment 2, which they were first given direct instructions regarding the structure of the enzyme. This difference in knowledge caused observing and judging observation reports in experimental class 1 to be more meaningful than experimental class 2. Observing and judging an observation report is the process of records something carefully to gain information. However, this observation would not occur if the learning activities are not interesting and challenging for students.

Learning in experimental classes 1 and 2 were developed by using problem as the initial unit of learning. The problem "browning reaction on potatoes" is an authentic and contextual problem that must be solved. This problem will motivate students, develop their curiosity and actively participate in learning to get answers. Students in experimental class 2 receive knowledge based on direct instruction, and students in experimental class 1 receive knowledge through investigation, and discussion. These activities facilitate students to interact in group discussions and creates a platform for students to experience an environment conducive to growing critical thinking.[44] Improvement of CTs is accommodated by interaction, reflection, and feedback in the problem.[45]

4 | CONCLUSION

CTs was an essential dimension in science education. Developing CTs can be used to facilitate students to facing the problem and solve the problem critically. Integrated biochemistry course is interactive learning that enhances the students' awareness of their ideas, beliefs, and thinking processes and prompts them to engage in reflection and seek alternative solutions. The result shows that developing CTs from practice to theory (P → T) is better than theory to practice (T → P), especially, in observing and judging observation reports. This study suggests that in curriculum development in chemistry or chemistry education programs should consider to place biochemistry and practical biochemistry courses in the same semester. Placement in the same semester allows the instructor to integrate practice and theory in biochemistry courses. Further research must analyze the discriminant of CTs indicator to different students in P → T class and T → P class.

AUTHOR CONTRIBUTIONS

Andi Wahyudi played a key role in data collection, facilitating classroom activities, conducting detailed assessments of the participants' critical thinking skills, and preparing the practicum worksheets. In addition, he was responsible for initial drafting of the manuscript and the subsequent collation of input and redrafting. Yusinta Dwi Ariyani contributed significantly to the conceptualization, design, and data analysis of this study. She was instrumental in observing the integrated biochemistry course and supervising its implementation. All authors critically revised the manuscript and approved the final version. All authors have read and agreed to the published version of the manuscript.

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DATA AVAILABILITY STATEMENT

The data supporting the findings of this study are available upon reasonable request. Researchers interested in accessing the data can contact to corresponding author for further information. While no specific datasets are publicly deposited, we are committed to transparency and open science practices, and we will make every effort to provide access to relevant data for the purpose of further inquiry. The data are not publicly available due to privacy or ethical restrictions.

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REFERENCES

1. Wahyudi A, Liliasari S, Supriyanti T. Biochemistry course achievement of pre-service chemistry teachers at one of Islamic institution of teachers training program in Bandung. International conference on mathematics, science, and education (ICMScE). Bristol: IOP publishing. 2019;1157:1–5. https://doi.org/10.1088/1742-6596/1157/4/042020
2. Thomas T. Developing first year students' critical thinking skills. Asian Soc Sci. 2017;7(4):26–35. https://doi.org/10.5539/ass.v7n4p26
3. Murawski LM. Critical thinking in the classroom…and beyond. J Learn High Educ. 2014;10(1):25–30. https://doi.org/10.1021/acs.jchemed.6b00406
4. Tiruneh DT, De Cock M, Weldeslassie AG, Elen J, Janssen R. Measuring critical thinking in physics: development and validation of a critical thinking test in electricity and magnetism. Int J Sci Math Educ. 2017;15(4):663–82. https://doi.org/10.1007/s10763-016-9723-0
5. Wang X, Sun X, Huang T, He R, Hao W, Zhang L. Development and validation of critical thinking disposition inventory for Chinese medical college students (CTDI-M). BMC Med Educ. 2019;19(200):1–14.
6. Masek A, Yamin S. The effect of problem based learning on critical thinking ability: a theoretical and empirical review. Int Rev Soc Sci Humanit. 2011;2(1):215–21.
7. Kim K, Sharma P, Land SM, Furlong KP. Effects of active learning on enhancing student critical thinking in an undergraduate general science course. Innov High Educ. 2013;38(3):223–35. https://doi.org/10.1007/s10755-012-9236-x
8. Valdez AV, Lomoljo A, Dumrang SP, Didatar MM. Developing critical thinking through activity-based and cooperative learning approach in teaching high school chemistry. Int J Soc Sci Humanity. 2015;5(1):139–41. https://doi.org/10.7763/IJSSH.2015.V5.440
9. Welch KC, Hieb J, Graham J. A systematic approach to teaching critical thinking skills to electrical and computer engineering undergraduates. Am J Eng Educ. 2015;6(2):113–23.
10. Zhou Q, Huang Q, Tian H. Developing students' critical thinking skills by task-based learning in chemistry experiment teaching. Creat Educ. 2013;4(12):40–5. https://doi.org/10.4236/ce.2013.412A1006
11. Care E, Griffin P, Wilson M. Assessment and teaching 21st century skills. Cham: Springer; 2018. https://doi.org/10.1007/978-3-319-65366-2
12. Kennedy MM. How does professional development improve teaching. Rev Educ Res. 2016;86(4):945–80. https://doi.org/10.3102/0034654315626800
13. Sharma K. The role of ICT in higher education for the 21st century: ICT as a change agent for education. VSRD Int J Comput Sci Inform Technol. 2011;1(1):1–9.
14. Ku KYL, Ho IT, Hau KT, Lai ECM. Integrating direct and inquiry-based instruction in the teaching of critical thinking: an intervention study. Instr Sci. 2014;42(2):251–69. https://doi.org/10.1007/s11251-013-9279-0
15. Madhuri GV, Kantamreddi VSS, Prakash Goteti LNSS. Promoting higher order thinking skills using inquiry-based learning. Eur J Eng Educ. 2012;37(2):117–23. https://doi.org/10.1080/03043797.2012.661701
16. Pinto G, Prolongo L. Stoichiomestry in context: inquiri guided problems chemistry for encouraging critical thinking in engineering student. J Educ Train Stud. 2013;5(6):84–8.
17. Stephenson NS, Sadler-Mcknight NP. Developing critical thinking skills using the science writing heuristic in the chemistry laboratory. Chem Educ Res Pract. 2016;17:72–9. https://doi.org/10.1039/c5rp00102a
18. Van Winkle LJ, Burdick P, Bjork BC, La Salle S, Viselli SM, Robson C. Critical thinking and reflection on community service for a medical biochemistry course raise students' empathy, patient-centered orientation, and examination scores. Med Sci

Educ. 2014;24(3):279–90. https://doi.org/10.1007/s40670-014-0049-7
19. Espinosa AA, Monterola SLC, Punzalan AE. Career-oriented performance tasks in chemistry: effects on students' critical thinking skills. Educ Res Int. 2013;2013:1–10.
20. Kazusa I. Usage of critical thinking strategies in the chemistry course for a future doctor. Probl Educ 21st Cent. 2012;41:18–27.
21. Suharta, Luthan PLA. Application of cooperative problem-based learning model to develop creativity and foster democracy, and improve student learning outcomes in chemistry in high school. J Educ Pract. 2013;4(25):55–61.
22. Soltis R, Verlinden N, Kruger N, Carroll A, Trumbo T. Process-oriented guided inquiry learning strategy enhances students' higher level thinking skills in a pharmaceutical sciences course. Am J Pharm Educ. 2015;79(1):1–8. https://doi.org/10.5688/ajpe79111
23. Thaiposri P, Wannapiroon P. Enhancing students' critical thinking skills through teaching and learning by inquiry-based learning activities using social network and cloud computing. Procedia Soc Behav Sci. 2015;174:2137–44. https://doi.org/10.1016/j.sbspro.2015.02.013
24. Van Winkle LJ, Cornell S, Fjortoft N, Bjork BC, Chandar N, Green JM, et al. Critical thinking and reflection exercises in a biochemistry course to improve prospective health professions students' attitudes toward physician-pharmacist collaboration. Am J Pharm Educ. 2013;77(8):169. https://doi.org/10.5688/ajpe778169
25. Wannapiroon P. Development of research-based blended learning model to enhance graduate students' research competency and critical thinking skills. Procedia Soc Behav Sci. 2014;136:486–90. https://doi.org/10.1016/j.sbspro.2014.05.361
26. Zhou Q. Integrating webquest into chemistry classroom teaching to promote students' critical thinking. Creat Educ. 2012;3(3):369–74. https://doi.org/10.4236/ce.2012.33058
27. Carriger MS. What is the best way to develop new managers? Problem-based learning vs. lecture-based instruction. Int J Manag Educ. 2016;14(2):92–101. https://doi.org/10.1016/j.ijme.2016.02.003
28. Ulger K. The effect of problem-based learning on the creative thinking and critical thinking disposition of students in visual arts education. Interdiscip J Probl-based Learn. 2018;12(1):3–6.
29. Mataka LM, Kowalske MG. The influence of PBL on students' self-efficacy beliefs in chemistry. Chem Educ Res Pract. 2015;16(4):929–38. https://doi.org/10.1039/c5rp00099h
30. Voet JG, Bell E, Boyer R, Boyle J, O'Leary M, Zimmerman JK. Recommended curriculum for a program in biochemistry and molecular biology. Biochem Mol Biol Edu. 2003;31(3):161–2. https://doi.org/10.1002/bmb.2003.494031030223
31. Chen H, Ni JH. Teaching arrangements of carbohydrate metabolism in biochemistry curriculum in peking university health science center. Biochem Mol Biol Educ. 2013;41(3):139–44. https://doi.org/10.1002/bmb.20695
32. Harrison MA, Dunbar D, Lopatto D. Using pamphlets to teach biochemistry: a service-learning project. J Chem Educ. 2013;90(2):210–4. https://doi.org/10.1021/ed200486q
33. Bretz SL, Linenberger KJ. Development of the enzyme-substrate interactions concept inventory. Biochem Mol Biol Educ. 2012;40(4):229–33. https://doi.org/10.1002/bmb.20622
34. Wahyudi A, Liliasari S, Supriyanti T. Isolation and characterization of polyphenol oxidases (ppo) on potatoes (Solanum tuberosum) using age and environmental control. J Eng Sci Technol. 2019;1(1):1–9.
35. Wrenn J, Wrenn B. Enhancing learning by integrating theory and practice. Int J Teach Learn High Educ. 2009;21(2):258–65. http://www.isetl.org/ijtlhe/
36. Ennis RH. Critical thinking dispositions: their nature and assessability. Informal Log. 1996;18(2):165–82. https://doi.org/10.22329/il.v18i2.2378
37. Wilson FR, Pan W, Schumsky DA. Recalculation of the critical values for Lawshe's content validity ratio. Meas Eval Couns Dev. 2012;45(3):197–210. https://doi.org/10.1177/0748175612440286
38. Briggs SR, Cheek JM. The role of factor analysis in the development and evaluation of personality scales. J Pers. 1986;54(1):106–8. https://doi.org/10.1111/j.1467-6494.1986.tb00391.x
39. Meltzer DE. The relationship between mathematics preparation and conceptual learning gain in physics: A possible 'hidden variable' in diagnostic pretestt scores. Am Assoc Phys Teach. 2002;70(12):1259–67.
40. Kharismawan B, Haryani S, Nuswowati M. Application of a PBL-based modules to increase critical thinking skills and independence learning. J Innov Sci Educ. 2018;7(1):78–86.
41. Sari YI, Maulana A, Jamil M. The role of ICT in higher education for the 21st century: ICT as a change agent for education. Proceedings of the 1st International Conference on Geography and Education (ICGE 2016), 79, 316–319. 2017.
42. Birgili B. Creative and critical thinking skills in problem-based learning environments. J Gift Educ Cre. 2015;2(2):71–80. https://doi.org/10.18200/JGEDC.2015214253
43. Ennis RH. Goals for critical thinking curriculum. In: Costa AL, editor. Developing of minds. Virginia: ASCD; Virginia 1988. p. 54–7.
44. Polnueangma O. The first year nursing students' achievement and critical thinking in local wisdom course using problem based learning process. Wirel Pers Commun. 2013;69(3):1077–85. https://doi.org/10.1007/s11277-013-1067-2
45. Kivunja C. Teaching students to learn and to work well with 21st century skills: unpacking the career and life skills domain of the new learning paradigm. Int J High Educ. 2014;4(1):1–11. https://doi.org/10.5430/ijhe.v4n1p1

SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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