Developing complexity science-problem based learning model to enhance conceptual mastery

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ABSTRACT

Implementing a proper learning model during the post COVID-19 pandemic is fundamental for learning quality enhancement, specifically for students' conceptual mastery. The research aims to develop a Complexity Science-Problem Based Learning (CS-PBL) model assisted by the *Sistem Informasi Pengelola Pembelajaran* (SIPEJAR) e-learning platform that is valid, practical, and effective to enhance students' conceptual mastery during the post COVID-19 pandemic. The research and development model were adapted from Plomp & Nieven consisted of three phases: preliminary research, prototyping phase, and assessment phase. The first phase research result was that the learning process in during COVID-19 pandemic was less interactive, which led to less effective learning. The students' score on conceptual mastery was in the poor category. The second phase resulted in a book of CS-PBL model assisted by SIPEJAR and supporting instruments considered valid by three experts. The third phase result was that the CS-PBL model assisted by SIPEJAR was considered practical in the learning process implementation. The CS-PBL model can enhance students' conceptual mastery where the N-gain was sufficiently effective. It is concluded that the CS-PBL model assisted by SIPEJAR was considered valid, practical, and effective to enhance students' conceptual mastery during the post COVID-19 pandemic.

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1. INTRODUCTION

The era of technology and information nowadays brings changes in learning. The use of electronic-based teaching materials is a demand to support students' technological literacy skills [1], [2]. Critical thinking, communication, collaboration, connectivity, creativity, and culture, known as 6Cs, are essential skills required for problem-solving [3], [4]. Students learn to master biology concepts by solving problems around them through problem-solving skills [5], [6]. Conceptual mastery is linked to someone's cognitive process. Levels of the cognitive process according to the revised version of Bloom's taxonomy are remembering (C1), understanding (C2), applying (C3), analyzing (C4), evaluating (C5), and creating (C6) [7].

Before the pandemic, Problem-Based Learning (PBL) was implemented in the Human and Animal Physiology class. The implementation of PBL was ineffective in utilizing a variety of disciplines to solve problems. It affected the students' conceptual mastery. Students' good conceptual mastery in biology will help solve complex problems in their surroundings as it becomes an essential foundation for a network of ideas that lead someone's thinking [8], [9]. Solutions students offered by implementing PBL used mono discipline [10], [11], and this was not in line with the main characteristic of PBL that utilizes various disciplines [12].

At the beginning of 2020, the COVID-19 pandemic was stated as a health emergency that the government around the world, including Indonesia, set the restriction of gathering activities, such as learning activity in schools and universities [13], [14]. Activity restrictions at schools and universities had face-to-face learning [15], replaced with distance learning [16], [17]. Distance learning during pandemic utilized various virtual meeting applications such as ZOOM, Google Classroom, Moodle, dan Blackboard [18], [19]. The learning process using virtual meeting applications without intensive accompaniment caused issues; one of those was difficulty understanding the content material [20], [21]. Students' difficulty in understanding concepts was caused by the lack of face-to-face interaction between students and lecturers and fellow students [22], [23] and the lack of lecturers' experience in implementing distance learning [24]. The arising obstacles indicated that students would not participate effectively in distance learning during the pandemic.

Observation of learning process was conducted in biology department faculty of mathematics and science at State University of Malang, Indonesia. The biology department implemented the learning process through a virtual meeting application for 15 minutes/credit during the pandemic. Short and limited duration made the learning activity and students' reinforcement suboptimal. The effect of the limited virtual learning process was that students' conceptual mastery became suboptimal, indicated by the score of conceptual mastery of 42.4, which was in the poor category. Hence, a learning model that could help students enhance conceptual mastery to solve problems in their environment is required. One of the learning models that could facilitate conceptual mastery enhancement is Complexity Science-Problem Based Learning, abbreviated as CS-PBL. CS-PBL learning model developed with the basic principle of complexity science approach and problem-based learning.

Complexity Science (CS) is an approach that helps someone in the process of thinking to understand and solve complex natural problems [25]. The CS approach has a basic principle in studying problems interdisciplinary [26], [27]. The CS approach and PBL share the basic principle of using the occurring problem in students' environment and then studying it comprehensively [28], [29]. The problem given to students helps them enhance the cognitive process in the aspect of analyzing, evaluating, and creating as part of higher-order thinking skills [30]. The integration of the CS approach into PBL can improve students' conceptual mastery and apply various disciplines in problem-solving.

The CS-PBL model utilized the mind map technique in the learning process. Mind map as a tool for thinking can be applied in all cognitive processes, particularly memory, creativity, and analysis [31]. Mind mapping activity gets students focused when organizing information and allows them to review obtained information. The mind map also helps students understand basic ideas and connect them with other ideas, which leads them to comprehend a concept thoroughly [32], [33].

State University of Malang (UM), Malang, Indonesia, provides a learning system based on digital media known as *Sistem Informasi Pengelola Pembelajaran* (SIPEJAR). As an online platform of UM, it is expected to facilitate interaction between lecturers and students. SIPEJAR also facilitates students to access semester plan (*rencana pembelajarn semester*/RPS) and lesson plan (*satuan acara pembelajaran*/SAP), student worksheet (*lembar kerja mahasiswa*/LKM), and assignment management. SIPEJAR is part of the Learning Management System (LMS), a web-based system used as learning media [34]. LMS provides an online learning service for students and lecturers as a platform [35].

The research specifically aimed to develop a learning model based on a complexity science approach through problem-based learning utilizing the mind map. The learning model is developed to enhance students' conceptual mastery.

2. RESEARCH METHOD

The research adopted the Plomp and Nieveen [36] research and development model consisting of three phases: preliminary research, prototyping, and assessment. The research was conducted in Human and Animal Physiology class at Biology Department, Faculty of Mathematics and Science, State University of Malang, Malang, Indonesia.

2.1. Preliminary research phase

Preliminary research aimed: i) Analyze the implementation of the learning process performed so far; ii) Analyze obstacles during the learning process; iii) Gather information about the profile of students' conceptual mastery; and iv) Analyze supporting learning instruments: semester plan (RPS), lesson plan (SAP), student's worksheet (LKM), and assessment instrument. Need analysis was then followed by a literature study to acquire learning theories supporting the development of the CS-PBL learning model that would be implemented in the learning process.

2.2. Prototyping phase

The objectives of the prototyping phase are to compile, develop, and evaluate the product. The prototype I is a result of compiling and developing the product in the form of a book containing the CS-PBL learning model, complemented with supporting learning instruments such as semester plan (RPS), lesson plan (SAP), student worksheet (LKM), and assessment instrument. The prototype I was evaluated by education experts, particularly learning strategy experts, human and animal physiology experts, and lecturers. Levels and categories of validity of the developed product were adopted from Supartini *et al*. [37]. The evaluation was then followed by a limited trial for three meetings to identify occurring obstacles during the limited implementation of the CS-PBL model. Prototype II was a revised product after underwent expert validation and limited trial. The product will then be implemented on a more extensive scale in the assessment phase.

2.3. Assessment phase

The assessment phase aimed to test the practicality and effectiveness of the developed product. Data of practicality was obtained from the consistency of syntax implementation and students' questionnaire response after attending the learning process conducted with the CS-PBL model. The effectiveness data obtained from the pretest and posttest scores of conceptual mastery was then analyzed using the normalized gain formula to determine the N-gain score [38]. The CS-PBL model was implemented in the subject of Human and Animal Physiology for 16 meetings. All instruments (RPS, SAP, LKM, and assessment instrument) were uploaded on SIPEJAR. The implementation of the CS-PBL model applying pretest-posttest nonequivalent control group design with three treatments. Treatment groups consisted of experiment group (CS-PBL), control positive group (PBL), and control negative group (conventional). Pretest was performed in the first meeting to test students' initial skills.

3. RESULTS AND DISCUSSION

3.1. Preliminary research phase

Through the observation, it was discovered that the learning process had applied the PBL model. The problems given to students were focused on the laboratory practicum activities and were still close-ended. Based on its characteristics, the PBL problem should be open-ended and not have a single answer [39], [40]. Open-ended would train students' logic when creating the best solutions and hold them accountable [41]. One of the weaknesses of laboratory activity includes the lack of connection between students' experience in the laboratory and real-life problems [42], [43] that would lead to incomprehensive solutions focused on one single discipline. The 21st century problem-solving in biology stimulates students to think at a higher level. One of its purposes is to discover alternative solutions that students are required to comprehend and master a particular concept thoroughly by involving a variety of disciplines, such as social, cultural, and humanities, to solve a complex problem [44]. Based on the findings during observation, a proper learning model that trains students to think to master a concept comprehensively by involving various disciplines is urgently required. An approach that could be applied is complexity science. The integration of the CS approach through the PBL model is expected to improve students' conceptual mastery.

3.2. Prototyping phase

Prototype I of the CS-PBL model is completed with learning instruments (RPS, SAP, dan LKM) and assessment instruments. Learning model syntaxes of CS-PBL can be seen in Table 1.

Table 1. CS-PBL learning model syntax

No	CS-PBL learning model syntax	Students' activities
1	Problem orientation	Students analyze the given phenomenon through students' worksheet
2	Organizing students to learn	Students gather information from various resources related to the existing problem
3	Identifying required disciplines and concepts	Students identify disciplines and concepts required to solve the problem and create a mind map to connect or link the main problem with required disciplines
4	Conducting research and clarification to the team of experts	Students investigate to gather information and acquire explanations directly from the expert
5	Analyzing and connecting information and data	Students analyze and connect obtained data by creating a mind map to find the source of the problem and generate ideas from the problem
6	Presenting problem-solving ideas	Students perform presentations to report problem-solving ideas and carry out a discussion
7	Evaluating	Students evaluate and reflect on ideas and the problem-solving process

The result of CS-PBL validation by three expert validators was that it generally fell in the valid category. The aspect of principle reaction was considered very valid with a mean score of 4.00. The complete explanation is presented in Table 2.

Table 2. Average validation score of CS-PBL model

No	Aspect	Validator			Average	Criteria
		1	2	3		
1	Supporting theory	4.00	4.00	3.50	3.83	Valid
2	Syntax	4.00	4.00	3.75	3.92	Valid
3	Social system	4.00	4.00	3.67	3.89	Valid
4	Principle reaction	4.00	4.00	4.00	4.00	Very valid
5	Supporting system	4.00	4.00	3.75	3.92	Valid
6	Instructional and accompaniment impact	4.00	4.00	3.75	3.92	Valid
7	Language use	4.00	3.00	4.00	3.67	Valid

Validators:
1 : Learning Media Expert
2 : Learning Material Expert
3 : Practitioner

The validated learning instruments, which consisted of RPS, SAP, LKM, and problem-solving skills, were considered valid during the validation process. Further explanation is shown in Table 3. In general, the validation result showed that the product developed of the CS-PBL learning model and its supporting instruments was considered valid and, therefore, could be brought to the assessment phase.

Table 3. Mean score of learning instruments validation process

No	Learning instruments	Validator			Mean	Criteria
		1	2	3		
1	RPS	3.95	4.00	3.53	3.82	Valid
2	SAP	3.80	3.93	3.60	3.77	Valid
3	LKM	3.88	3.81	3.56	3.75	Valid
4	Assessment instruments	4.00	3.85	3.77	3.87	Valid

Validators:
1. : Learning Media Expert
2. : Learning Material Expert
3. : Practitioner

3.3. Assessment phase

The CS-PBL learning model assisted by SIPEJAR was applied in the Physiology of Animal and Human class. The learning model gained a very positive response from students with a mean score of 3.50. The detailed information is given in Table 4.

Table 4. Average score of students' responses on CS-PBL model

No	Aspect	Average	Criteria
1	The easiness of joining the learning with CS-PBL	3.52	Very positive
2	The benefits of learning with CS-PBL	3.40	Very positive
3	The usage level of LKM in learning	3.59	Very positive
	Mean	3.50	Very positive

The CS-PBL learning model applied seven syntaxes that took two meetings for each cycle during the learning process. The mean score of CS-PBL learning model implementation was 3.57 that is in the category of very practical. The summary of observational data of the implementation score of CS-PBL learning model syntaxes is provided in Table 5. The data summary of the effectiveness of the CS-PBL learning model assisted by SIPEJAR to improve the students' conceptual mastery is presented in Table 6.

Table 5. Mean score of CS-PBL learning model syntaxes implementation

Material	CS-PBL syntax model 1	2	3	4	5	6	7	Mean
Nervous system	3.25	3.25	3.00	3.34	3.50	3.25	3.00	3.23
Muscle and movement system	3.50	3.50	3.25	3.17	3.38	3.75	3.25	3.40
Sensory system	3.75	3.50	3.00	3.63	3.38	3.38	3.25	3.41
Gas exchange system	3.50	3.75	3.50	3.84	3.63	3.50	3.25	3.57
Digestive system	4.00	3.00	3.75	3.67	3.38	3.25	3.75	3.54
Circulation system	3.50	3.75	3.50	4.00	3.75	3.50	3.75	3.68
Excretion and osmoregulation	3.75	3.25	4.00	3.84	3.83	4.00	4.00	3.81
Thermoregulation System	4.00	4.00	4.00	4.00	3.88	4.00	3.75	3.95
Mean	3.66	3.50	3.50	3.69	3.59	3.58	3.50	3.57
Category	Very practical	Very practical	Very practical	Very practical	Very practical	Very practical	Very practical	Very practical

Table 6. Result analysis of learning model effectiveness

Learning model	Pretest mean score	Posttest mean score	Gap	Improvement (%)	N-Gain	Category
Conventional (Direct Learning)	41.94	52.53	10.59	25.25	18.23	Ineffective
PBL	52.24	78.63	26.39	50.51	55.25	Less effective
CS-PBL	49.09	79.98	30.89	62.92	60.67	Sufficiently effective

Among three classes chosen as the research sample, the class that gained the highest score in conceptual mastery improvement was the class that applied the CS-PBL learning model with a score of 62.92% with the N-gain category of sufficiently effective. The class that gained the highest score in conceptual mastery improvement among three classes was CS-PBL learning class with a score of 62.92 with the N-gain category of sufficiently effective. The conventional class was in the category of ineffective with a mean score N-gain of 18.23%, while the PBL class was in the category of less effective with an improvement percentage of 50.51%.

The development of CS-PBL assisted SIPEJAR was considered valid, practical, and effective to improve the conceptual mastery of the Animal and Human Physiology class members during the post COVID-19 pandemic. CS-PBL learning model combines complexity science approach, problem-based learning model, and mind map note-taking technique. The characteristics of the CS-PBL model are i) Emphasized the inter-disciplinary knowledge that trains students to think comprehensively; ii) highlighted the social interaction between students and the circles outside their educational setting; and iii) Building their environmental awareness.

The complexity science approach in education has purposes to help students recognize, respect, and understand complex natural phenomena. Students are demanded to comprehend the components in biology, such as in medical health, environment, and social. The understanding of biological complexity could happen when learning various levels of biological organization, from molecule to ecosystem level, and this is the main challenge in developing biology learning in the 21st century [45], [46].

The problem orientation phase consists of formulating and analyzing the problem by identifying relevant facts. These activities help students represent existing problems [47]. Problem orientation is an analysis process involving individuals' cognition that shows how they think and analyze components related to a specific issue [48], [49]. CS-PBL learning model provides problems close to students' daily life. Real-life problems are complex biological problems [50], [51]. Biological problems in people's life involving complex systems, such as: i) Problems in a system involving numerous variables; ii) Relation and dependence between variables that make a system; and iii) Applying various analysis levels when solving the problem [52], [53]. The learning process with a complexity science approach could help students learn biological systems comprehensively. CS approach is an approach to study a particular complex system focused on the interaction between components that make a system [54].

During the second syntax, the students must conduct a literature study related to the issue they investigate. One of the second syntax activities is reading. Conceptual mastery is the goal of reading; hence, reading failure could create long-term learning problems that could lead to the misconception [55], [56]. Reading is the fundamental of learning and an active process to build new knowledge [57]. Learning activity relates to the metacognitive process and the construction of active knowledge through reviewing concepts related to an authentic phenomenon experienced by students [58], [59].

The third syntax of the CS PBL learning model identifies disciplines and concepts required to solve the problem. The problem-solving process, particularly contextual and complex problems, would train students to understand the problems comprehensively or see the problems from various points of view [44]. In the 21st century, biological problems usually apply the basic principles of complexity science approach based on interdisciplinary science, such as social, culture, technics, computing, physics, chemistry, and mathematics to solve complex problems, like problems in health, food, energy, and environment [60]. Students in the experimental group treated with CS-PBL utilized the mind map technique to gain knowledge [61] and identify problems that would help them create the right solutions or ideas [62]. The students made a mind map during the third syntax of CS-PBL is shown in Figure 1.

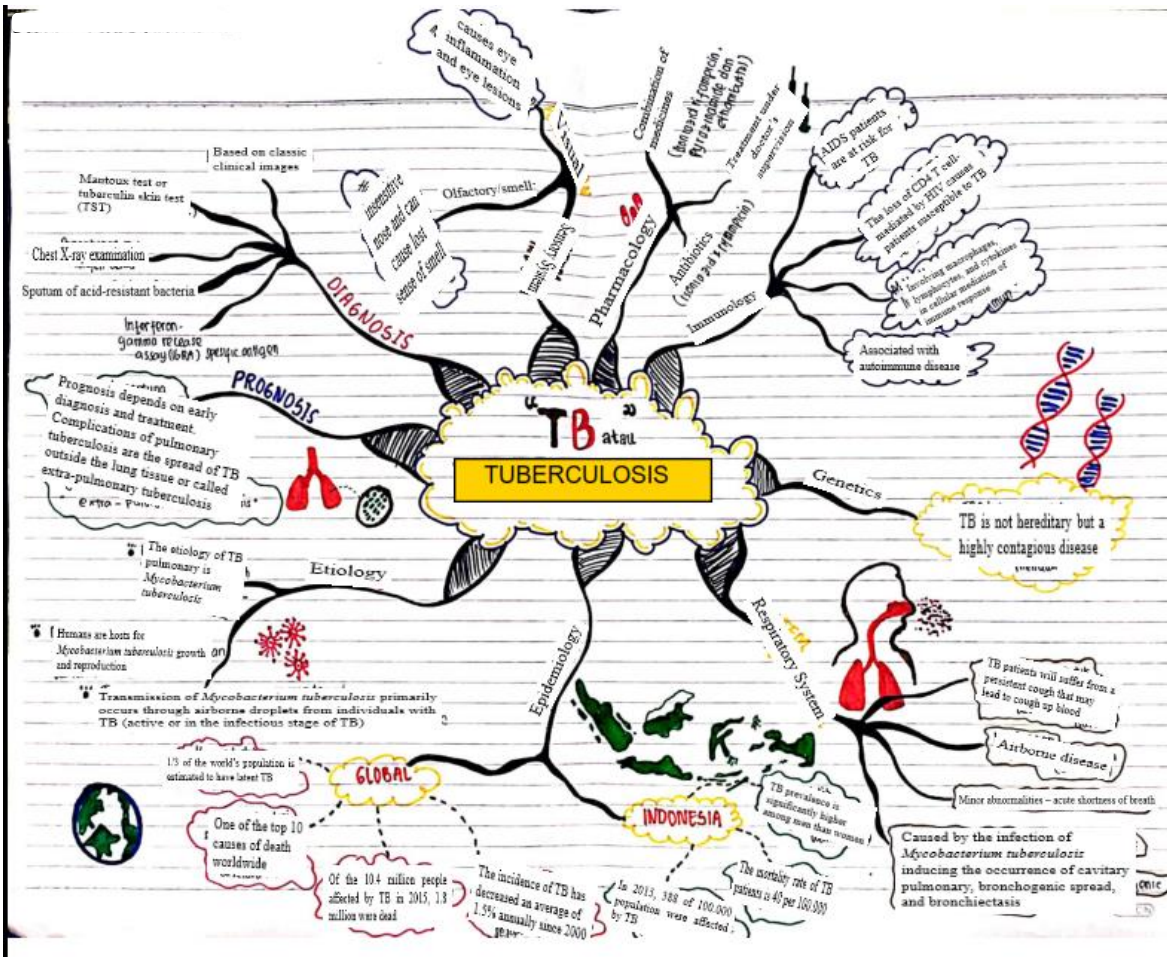

Figure 1. Students' mind map in the third syntax

The fourth syntax of CS-PBL learning is to conduct an investigation and make a clarification to the team of experts. The problem-solving process involves collaboration with experts or someone who masters the field, particularly in solving complex problems in their neighborhood [63]. By discussing with experts, students could analyze and see the problems with various perspectives that might be missed [64]. Collaborative, in this sense, requires social and cognitive skills to develop understanding, make correct decisions or solutions, and build and maintain teamwork to solve the problems [65], [66]. The benefits of collaboration with experts in solving the problems, among others, are to: i) Improve communication skills; ii) Develop organizational and leadership skills; iii) Create respect and uphold ethical standards; iv) Share information and knowledge; and v) Improve the quality of decision and solution making for solving the problems [67], [68]. The fundamental theory is based on social constructivism learning, emphasizing learning through social interaction [69].

After the investigation, students go to the fifth syntax, analyzing and connecting between information and data gathered by making a mind map to create the ideas. The mind map is a proper technique to solve the problem [70]–[72] as it connects information that brings to a big main idea to solve the problem. Figure 2 is the result of students' teamwork during the fifth syntax.

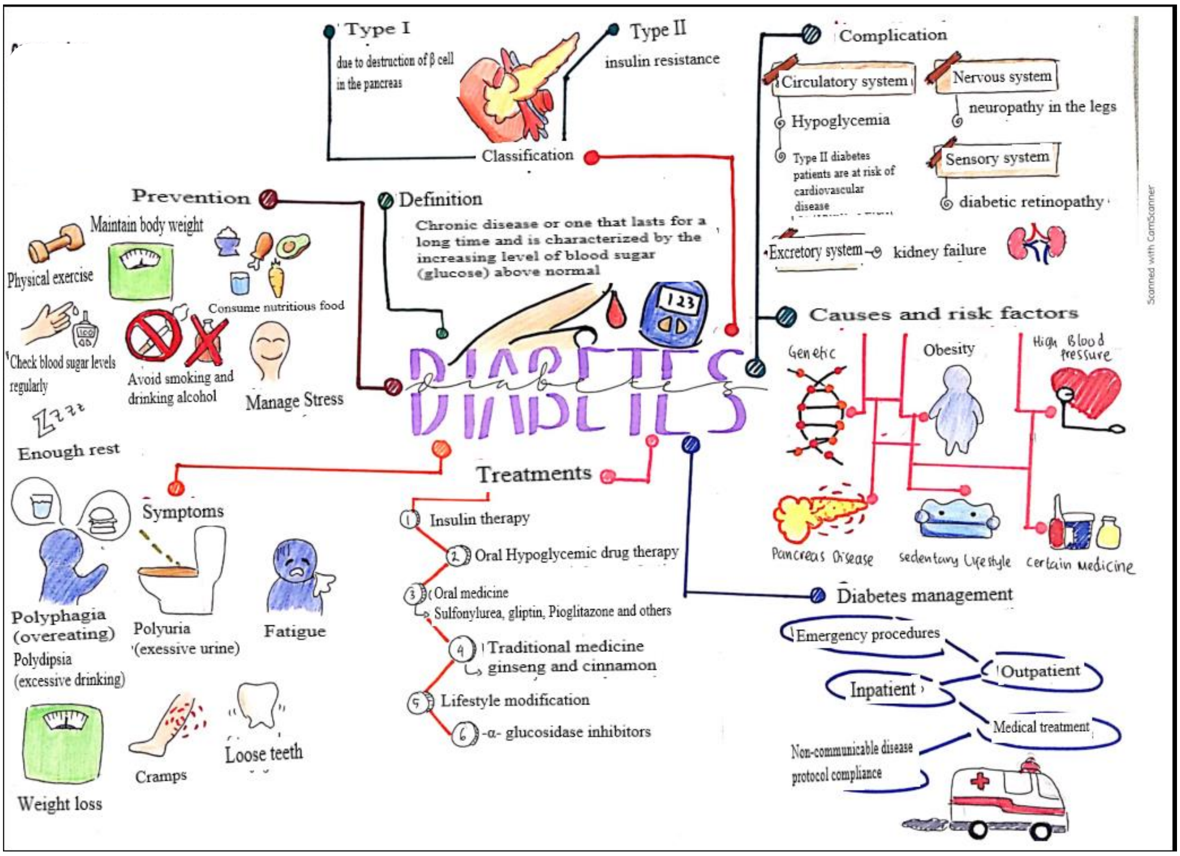

Figure 2. Students-made mind map during the fifth syntax

The sixth syntax of the CS-PBL learning model is the presentation of ideas. Selected groups present their work and deliver their ideas related to the given problem. The primary purposes of this activity are to improve students' communication skills and widen their knowledge [73]. After presenting their ideas, students open question and answer discussions to stimulate their communication skills and develop their thinking skills [73]. The last syntax of the CS-PBL learning model is evaluation. Its main objective is to evaluate the team's work conducted with the peer evaluation method [74]. Peer evaluation strongly affects students in receiving feedback during the learning process. The effects, among others, are improving their self-confidence, developing their thinking process, providing learning assessment transparency [75], and decreasing students' passiveness level during the learning process [76].

4. CONCLUSION

The development of the CS-PBL learning model assisted by SIPEJAR is proven to be valid in content, social system, supporting system, and the learning effect. CS-PBL learning model assisted by SIPEJAR is considered practical since all syntaxes were implemented entirely, and they gained very positive responses from students. CS-PBL learning model assisted by SIPEJAR is proven to be effective in improving students' conceptual mastery during the post COVID-19 pandemic. This model application is recommended to facilitate the improvement of students' conceptual mastery.

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