RESEARCH ARTICLE

Improving critical thinking and problem-solving skills through POGIL combined with digital mind map

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Abstract: Critical thinking and problem-solving skills are necessary skills in the 21st century learning. However, the initial tests of students' critical thinking and problem-solving skills showed low scores. Therefore, the purpose of this study was to improve students' critical thinking and problem-solving skills through the POGIL (Process Oriented Guided Inquiry Learning) model combined with a digital mind map based on online learning. This study uses the Classroom Action Research (CAR) method following the design of Kemmis & McTaggart, which consists of 4 stages, namely planning, implementing the action, observing, and reflecting. The stages of the POGIL model consist of orientation, exploration, concept formation combined with making digital mind maps, applications, and closings. The research subjects were students of class XI MIPA 4 of SMAN 2 Malang, totalling 28 students which consisted of twenty girls and eight boys. The percentage of critical thinking skills achievement increased by 29.61% from 66.87% in the first cycle to 86.67% in the second cycle. Problem-solving skills increased by 22.16% from 70.27% in the first cycle to 85.84% in the second cycle. The results showed that the POGIL model combined with a digital mind map based on online learning could improve students' critical thinking and problem-solving skills.

Keywords: digital mind map; online learning; POGIL; the 21st century skills

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Introduction

Critical thinking skills are fundamental skills in the 21st century learning (Binkley et al., 2012; Reeve, 2016). Critical thinking skills also include other skills such as communication skills as well as the ability to examine, analyze, interpret, and evaluate evidence (Abrami et al., 2014). Students need critical thinking skills because they can help students make decisions from various points of view carefully, thoroughly, and logically (Strauss, 2016). If critical thinking skills are embedded in students, human resources who are intelligent in thinking and critical in solving problems will be produced. Critical thinking skills are needed because a person can think logically, answer various issues well, and make rational decisions by having critical thinking skills (Dwyer et al., 2014).

In addition to having critical thinking skills, students also need problem-solving skills. The ultimate goal of learning is to produce students who have knowledge and skills in solving problems that will be faced in the community. Problem-solving skills also include other skills such as identifying, evaluating, organizing, considering alternatives, and interpreting information (Dostál, 2015; van Merriënboer, 2013). Therefore, problem-solving skills and critical thinking skills are essential skills that are interrelated in the problem-solving process (Peter, 2012; van Laar et al., 2017).

A preliminary study at SMAN (State Senior High School) 2 Malang on October 15, 2020, through interviews with Biology teachers, showed that students' critical thinking and problem-solving skills were quite good when authentic assessments were carried out. However, the results were still unsatisfactory when a non-authentic assessment (given homework) was carried out. This is because students do not understand the meaning of the questions given. The results of the initial test of critical thinking skills on the Motion System material show an average of 56.1, which is included in the good category. The average of each indicator is as follows: (1) formulating a problem is 63.9, (2) giving an argument is 64.8, (3) doing induction is 51.9, (4) deduction is 58.3, and (5) making conclusion is 41.7. Meanwhile, the results of the initial test of problem-solving skills showed an average of 59.5, which was included in the good category. The average of each indicator is as follows: (1) identifying problems is 59.3, (2) applying the stages of problem-solving is 64.8, (3) identifying solutions is 62, and (4) maintaining the solution is 51.9. Based on the observations and initial test results, students' critical thinking and problem-solving skills are sufficient and still need improvement. In addition, the results of the interview explained that students had difficulties in understanding the Respiration System material related to (1) respiration bioprocess chemical reaction of oxygen with blood, (2) disassembling sugar into H_2O and CO_2 in the form of respiratory, metabolic waste, (3) and understanding external and internal respiration. Meanwhile, on the material of the Excretory System, students had difficulties in understanding (1) the bioprocess of excretion of the chemical reactions of the metabolism of urea, ornithine, citrulline, arginine, (2) the blood filters substances that are physiologically needed and excreted, (3) and the relationship between the excretory system of the skin, lungs, kidneys, and liver, where if one of them is abnormal, then the organs in the system are affected.

The COVID-19 pandemic that has hit the world, especially Indonesia, since March 2020, has brought about quite a big change in teaching and learning activities that previously had to be done face-to-face, After the pandemic strikes, such activities had to be done online. Online learning brings changes to new habits, namely students' readiness to learn from home, support for students' learning facilities from parents, the creation of rubrics suitable for online learning by teachers, and the selection of suitable learning models to be applied. During the implementation of online learning, the Biology teacher at SMAN 2 Malang applies the PBMP (Thinking Empowerment Through Questions) learning pattern by asking questions according to the number of students in the class, which are answered based on attendance numbers. However, when applying the PBMP pattern, the teacher does not provide PBMP sheets to students. Therefore, a learning model is needed to improve students' critical thinking and problem-solving skills, which should be suitable for online learning.

One of the student-centered learning models that can improve students' thinking skills is POGIL (Process Oriented Guided Inquiry Learning) (Artuz & Roble, 2021; Hein, 2012; Soltis et al., 2015). POGIL is a learning model that combines guided inquiry with cooperative learning (Rodriguez et al., 2020). The POGIL model is a learning model that emphasizes the constructivism process (Simonson, 2019), where students get facilities to practice process skills, build cognitive abilities independently, and foster positive attitudes. Furthermore, the POGIL model is implemented with a cooperative approach designed with small groups consisting of 3 to 4 students with different roles. Learning activities with POGIL are oriented towards a more constructive and interactive concept discovery process, and each student has their own role and contribution to capture concepts (Kussmaul, 2018). The advantage of the POGIL model is that it can help students discover their knowledge and it is easy to apply at all levels.

As supporters of learning, students need tools to understand and remember learning material more easily. Aids in the learning process can provide knowledge in a more systematic and conducive manner. Mind maps can be used as a medium that can stimulate the brain to solve problems and facilitate students in learning (Novita et al., 2018). The use of mind map also allows students to develop thinking competence to come up with new ideas to solve problems (Ismail et al., 2010). Coggle™ is one of the software that can facilitate the creation of a digital mind map. This software supports the POGIL learning model with a small group design consisting of 3 to 4 students in one group. Besides its attractive appearance, Coggle™ is also equipped with interactive capabilities that facilitate students to collaborate and discuss mind mapping (Sutton et al., 2017). When making digital mind maps through Coggle™, images or links can be added to each keyword to make it clearer (Kamrozzaman et al., 2019). Moreover, Coggle™ can be integrated with various interesting images and links on the mind map branches. Not only that, combining the POGIL model with a digital mind map can support the role of the POGIL model in improving learning constructivism.

The implementation of the POGIL learning model combined with a digital mind map in Biology learning is the first time it has been carried out in Indonesia, and it is rarely implemented at the international level (as far as international publications are concerned). The POGIL model has been proven to improve critical thinking (Artuz & Roble, 2021) and problem-solving skills (Irwanto et al., 2018; Muhammad & Purwanto, 2020). However, so far, other researchers have only investigated the effectiveness of the POGIL learning model (Mata, 2022; Samosir, 2022; Vincent-Ruz et al., 2020) and the influence of the POGIL model assisted by realia media (Aiman et al., 2020). Therefore, this study aims to improve students' critical thinking and problem-solving skills by implementing the POGIL learning model

combined with a digital mind map based on online learning at SMA Negeri 2 Malang.

Method

The type of this study is Classroom Action Research (CAR), carried out in two cycles. Each cycle is implemented according to Kemmis and McTaggart's designs that consist of planning, implementation and observation, as well as reflection.This study was conducted in class XI MIPA (Mathematics and Natural Sciences) 4 of SMA Negeri 2 Malang, Jalan Laksamana Martadinata No. 84, Sukoharjo, Klojen District, Malang City, East Java. This study takes place from November 2020 to June 2021. The material discussed is the Respiratory System and Excretion System. The research subjects were 28 students of SMA Negeri 2 Malang consisting of 20 female students and 8 male students.

In the planning stage, teachers design learning device such as syllabus, Lesson Plans (RPP), Independent Learning Activity Unit (UKBM), think about the pretest and posttest, sheet enforceability of the lessons learned from the activities of teachers and students, the assessment rubric, and observation sheet of critical thinking and problem-solving skills. In addition, they also evaluate digital mind map, instrument validation of material experts, tools, and field practitioners. Learning devices are validated by 3 validators who are experts in their fields. Overall, the results of the validation of the learning devices show that the learning devices that have been assembled have obtained an evaluation that is widely regarded as valid. Based on the results of the validation, the researchers applied the learning devices in this study. The learning implementation observation sheet instrument is used to ensure that the learning carried out is in accordance with the syntax.

Teachers implement instructional models by combining POGIL digital mind map-based online learning with the appropriate syntax of POGIL, namely orientation, exploration, concept formation, application, and closure (Table 1) by utilizing online platforms such as Google Classroom, CoggleTM, and Google Meet.

Table 1. The syntax of POGIL

Phases	Activities
Orientation	A problem is presented and students are asked to make a problem formulation.
Exploration	Students make hypotheses from the problem formulations that have been made.
Concept Formation	Students discuss in small groups (4-5 students). Then, they are asked to present the concepts found in the form of a mind map through Coggle™.
Application	Students are asked to analyze the problems presented at UKBM.
Closure	Students conclude learning and evaluate and reflect on learning achievements, what has been achieved and has not been achieved, then improve their performance at the next meeting.

The observation stage is conducted by the observer by simultaneously observing learning by teachers and students using sheet enforceability, critical thinking skills using the rubric of critical thinking by Istikhomah (2015) and students' problem-solving skills using the rubric of problem-solving by Greenstein (2012). The reflection stage is carried out after the implementation of learning. The teacher and observers evaluate the learning to improve the next cycle of learning.

The data obtained in this study are qualitative and quantitative data. Qualitative data was obtained from the description of the teacher and student activity observation sheets. Quantitative data was obtained from the average value of students' critical thinking and problem-solving skills. The data analyzed consisted of (1) the implementation of learning syntax with the POGIL model combined with a digital mind map based on online learning which was said to be implemented if the percentage of learning implementation was 61% (Istiqfaroh & Nasrudin, 2018), (2) critical thinking skills from UKBM are said to be good if they achieve a minimum percentage of 66% (Arikunto, 2012), (3) problem-solving skills from UKBM are said to be good if they reach a minimum percentage of 66% (Arikunto, 2012).

Results and Discussion

The implementation of learning using the POGIL model combined with a digital mind map based on online learning cycle I and cycle II was carried out for 3 meetings in each cycle. Cycle I was held on February 8 – 22, 2021, while cycle II was held on March 1 – 15, 2021. Learning was carried out every Monday with an allocated time of 3x30 minutes starting at 07.00 – 08.30 WIB. The material studied in the first cycle was the Respiratory System, specifically (1) the Structure and Function of the Organs of the Respiratory System in Humans, (2) Bioprocesses and Factors Affecting the Respiratory System in Humans, (3) Disorders and Technology of the Respiratory System in Humans. In the second cycle, the material studied was the Excretory System, particularly (1) Organ Structure and Function and

Bioprocesses in the Kidneys and Lungs, (2) Organ Structure and Function and Bioprocesses in Liver and Skin, (3) Disorders and Technology in the Human Excretory System.

The POGIL learning model combined with a digital mind map based on online learning has five stages, namely orientation, exploration, concept formation, application, and closure, integrated into UKBM. The teacher opens the learning process through Google Classroom at the orientation stage and then directs students to open the available UKBM and PPt. Next, the teacher gives an apperception in articles or videos links contained in UKBM. Finally, the teacher directs students to read the phenomenon in the article/watch the video, identify the problems in the article/video, and then make a problem formulation related to the material studied.

At the exploration stage, students are directed to make hypotheses based on the problem formulation that has been made at the orientation stage from various literatures. However, online learning does not allow practicum. As an alternative, the teacher provides an example of a practicum video of the respiratory system mechanism in Google Classroom that students must observe. Students are directed to design practical procedures from the video and collect and analyze data in groups.

At the concept formation stage, students answer guided questions at UKBM in groups which are then presented in a digital mind map by utilizing the CoggleTM platform. Students can discuss in the chat rooms available in Google Classroom or CoggleTM. Students are very creative in making digital mind maps by adding images to each keyword so they look more attractive and clearer. An example of the results of a digital mind map about respiratory system disorders made by group 2 can be seen in Figure 1.

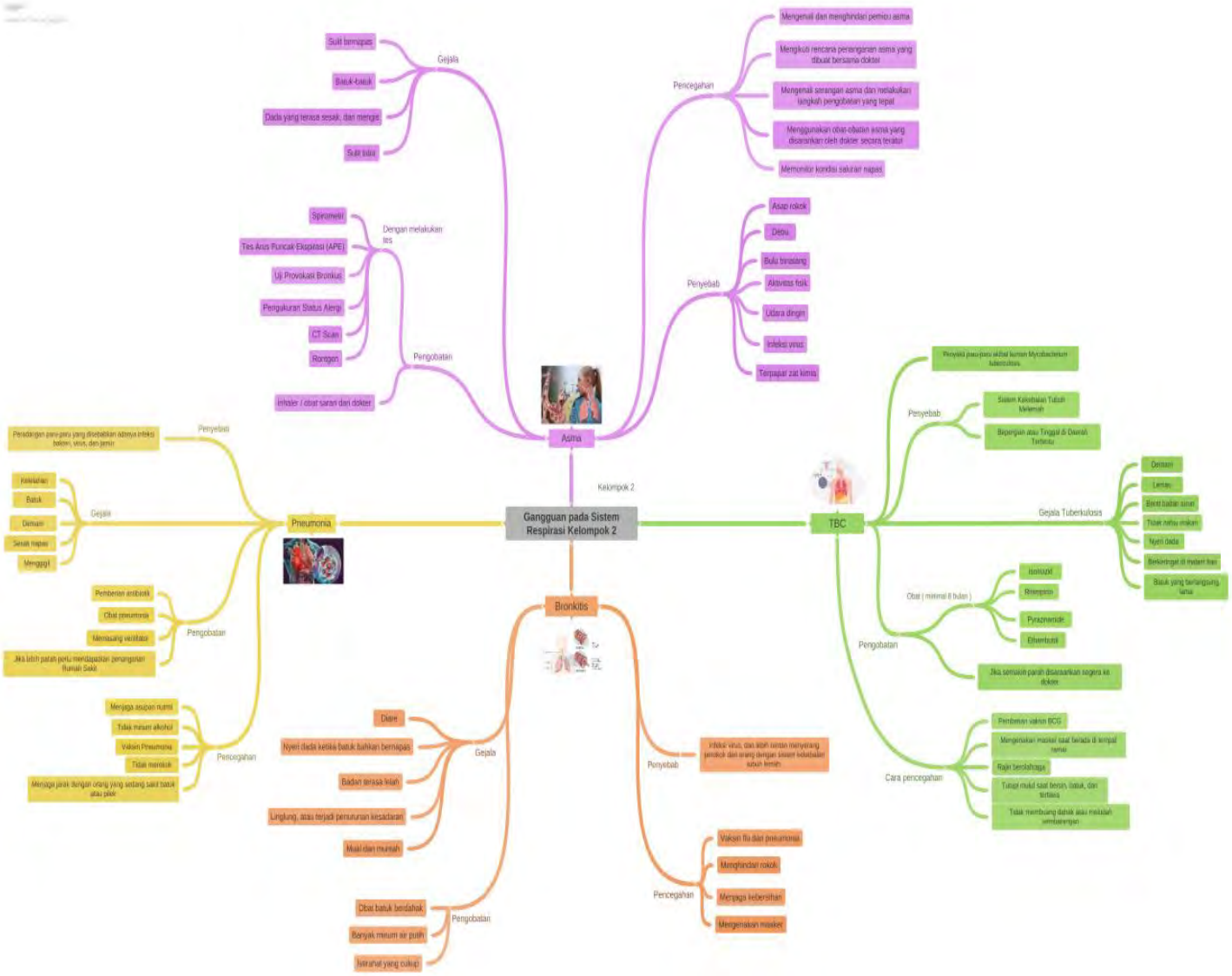


Figure 1. Results of the digital mind map of group 2 for the material of disorders of the respiratory system

In making the digital mind map above, students must explain several things such as disorders of the respiratory system, namely asthma which is indicated by purple branches, tuberculosis which is indicated by green branches, pneumonia which is indicated by yellow branches, and bronchitis which is indicated by orange branches. The causes, symptoms, treatment, and prevention of each disease are explained. The digital mind map made by group 2 has the advantage that the material presented is complete and is following the assessment criteria mind map according to Buzan (2008).

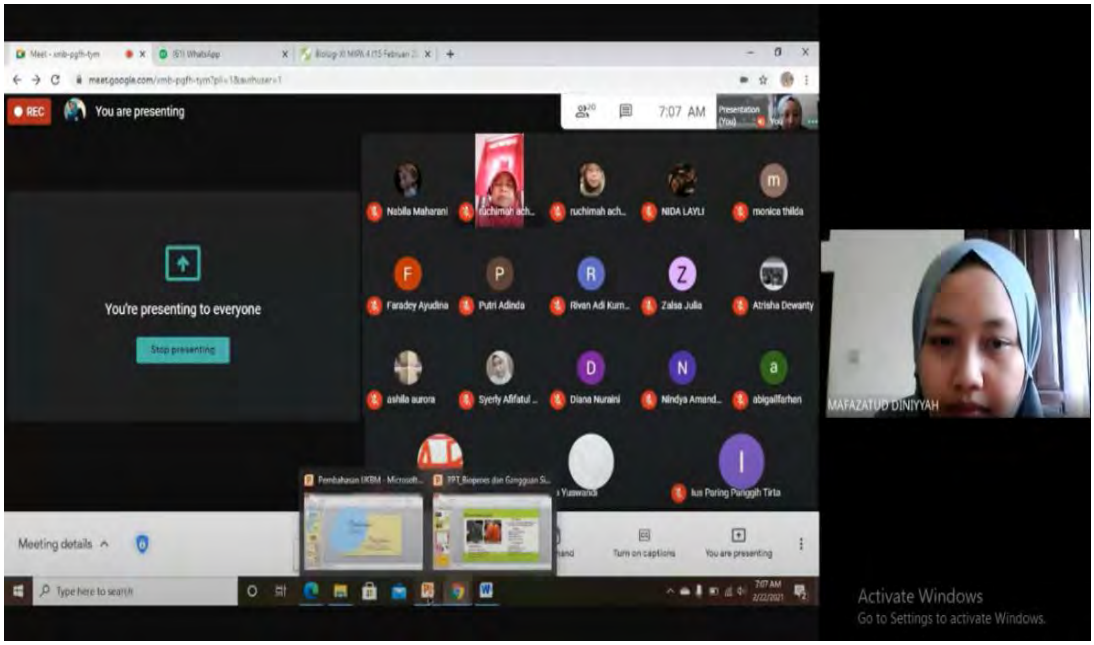


Figure 2. Discussion activities through Google Meet

Students discuss in groups through Google Classroom chat rooms at the application stage to answer the HOTS questions contained in UKBM by applying concepts found previously to train their critical thinking and problem-solving skills. The teacher allows students to ask questions if they encounter any difficulties when working on the questions. After they finished working on the questions, students were directed to switch to Google Meet to conduct class discussions and present the results of the UKBM work. Students communicate the results of UKBM work starting from problem formulation, hypotheses, digital mind maps, and answers to HOTS questions. The teacher appreciates students who have submitted the results of their group discussions and provides reinforcement for the replies submitted by students. Discussion activities through Google Meet can be seen in Figure 2.

At the closing stage, students convey conclusions and reflect on the learning activities that have taken place. First, the teacher reinforces the studied material and appreciates students who have conveyed findings and reflections on learning. Then the teacher motivates students to keep the spirit of learning from home and maintain health. The teacher also reminds students to upload the results of the UKBM work on Google Classroom and close the lesson by praying and saying goodbye.

Based on observations, the implementation of the POGIL learning model combined with a digital mind map based on online learning can improve students' critical thinking skills. This can be seen in students who are active in the implementation of learning and the results of UKBM work which show a 29.61% increase in all indicators of critical thinking skills from 66.87% in the first cycle to 86.67% in the second cycle. Data on increasing students' critical thinking skills on each indicator can be seen in Figure 3.

Based on Figure 3, all indicators of critical thinking skills have increased from cycle I to cycle II. The highest increase was found in the conclusion indicator, in which there was a 71.15% increase from 52% in the first cycle to 89% in the second cycle. This shows that after participating in learning with the POGIL model combined with a digital mind map based on online learning, students become trained to conclude the studied material. It is proven that in cycle II almost all students can make conclusions from the material that has been studied well. Another indicator that experienced a fairly high increase was doing induction, which increased by 56.60% from 53% in the first cycle to 83% in the second cycle. This is due to the application stage containing HOTS questions at UKBM with the POGIL syntax, which can properly support this indicator's implementation.

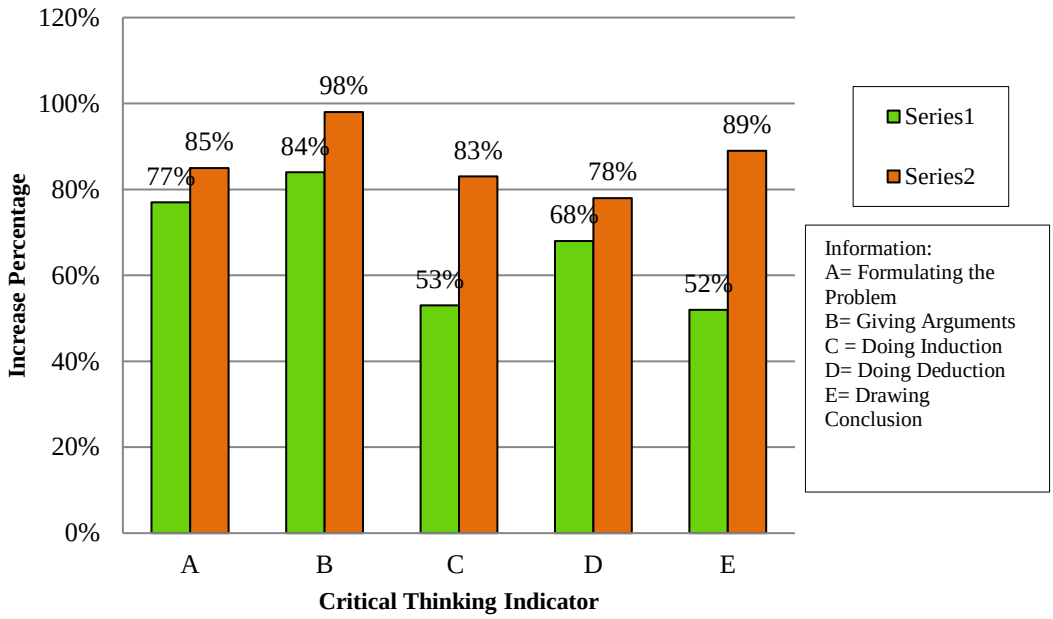


Figure 3. Data on increasing students' critical thinking skills on each indicator

The lowest increase can be observed in the indicator of formulating problems, which increased by 10.49% from 77% in the first cycle 77% to 85% in the second cycle. This is because the students' ability to formulate problems that is related to the material to be discussed is quite good, although there are some students whose problem formulations are still not related to the material to be discussed. In cycle II, students are better at writing problem formulations that are related to the material to be discussed.

The implementation of the POGIL model combined with a digital mind map based on online learning can also improve students' problem-solving skills. Data on problem-solving skills were obtained from assessment sheets based on students' UKBM answers, which showed a 22.16% increase in all problem-solving skills indicators from 70.27% in the first cycle to 85.84% in the second cycle. Data on improving students' problem-solving skills on each indicator can be seen in Figure 4.

Based on Figure 4, there was an increase in all problem-solving skills indicators from cycle I to cycle II. The highest increase is found in identifying problem-solving solutions, which increased by 33.33% from 72% in the first cycle to 96% in the second cycle. This is due to the application stage, which contains HOTS questions at UKBM with the POGIL syntax, which can properly support this indicator's implementation. It is proven by the results of the identification, in which it was discovered that the students' problem-solving solutions found in UKBM were getting better at each meeting. The indicator of identifying problems experienced the second highest increase, undergoing a 21.92% increase from 73% in the first cycle, to 89% in the second cycle. This is evidenced by the results of students' identification of problems, which has increased at each meeting.

The indicator of implementing the problem-solving stages experienced the lowest increase at 12.33%, from 73% in the first cycle to 82% in the second cycle. This is due to the ability of the students to be good in applying the stages of problem-solving to answer questions in UKBM well. Students solve problems by compiling problem-solving measures for problems presented by the teacher at the application stage.

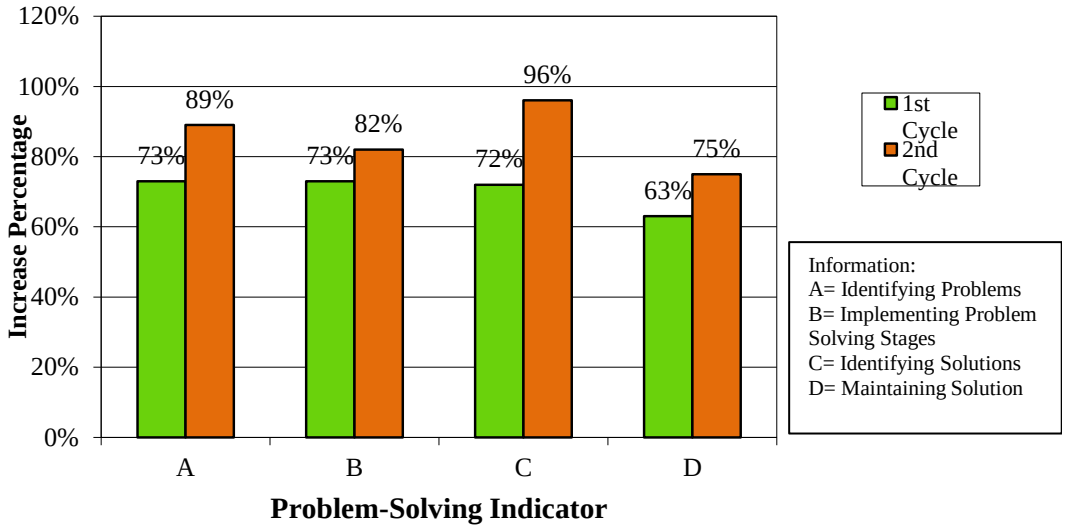


Figure 4. Data on improving students' problem-solving skills on each indicator

The POGIL learning model is a construction of 3 components: learning teams, guided inquiry activities, and metacognition. The three components are embedded in a learning cycle consisting of 3 stages: exploration, concept formation, and application. In its implementation, POGIL is related to the guided inquiry which aims to facilitate the teachers and students in carrying out observations inside and outside of the classroom (Rodriguez et al., 2020; Simonson, 2019). Hanson (2006) explained that metacognition or metacognitive abilities in POGIL learning serve to facilitate students in growing an attitude of responsibility for their learning by monitoring management, self-regulation, self-assessment, and reflecting to what they have learned. stated that students who study using POGIL model are more coordinated and collaborate more in building and understanding concepts (Simonson & Shadle, 2013). The advantage of the POGIL model is that it can help students find their knowledge and is easy to apply at all levels.

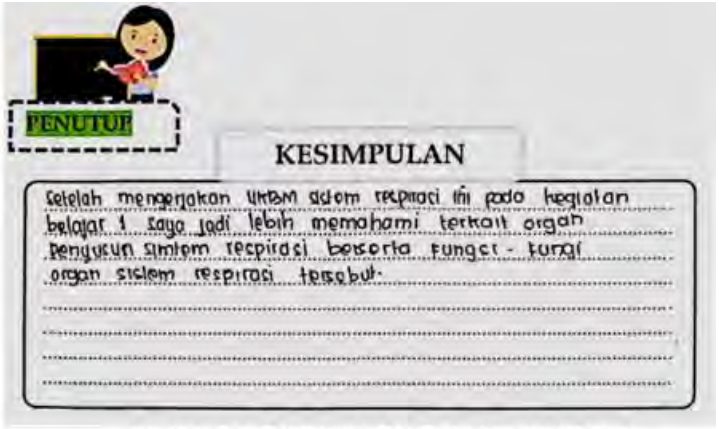
The POGIL learning model combined with a digital mind map based on online learning can improve the critical thinking skills of students of class XI MIPA 4 of SMAN 2 Malang. It is proven by the increasing percentage of students' critical thinking skills from 66.87% in the first cycle to 86.67% in the second cycle, signifying an increase of 29.61%. The stages in the POGIL learning model can improve critical thinking skills. This is in line with Andani's opinion (2019) that exploration and application stage in the POGIL learning model support the implementation of critical thinking skills indicators because at that stage, students are given training in the form of problem studies that can guide students to connect new knowledge with the previous one to solve a problem. More real problems according to the facts.

Based on the five indicators of critical thinking skills, the indicators for concluding have the highest increase, in which increased by 71.15% from 52% in the first cycle of 52% to 89% in the second cycle. This is because, in every meeting, students are trained to make conclusions based on the material that has been studied. It is proven that in cycle II, almost all students can make conclusions based on the material that has been studied well. This is owing to the fact that students are trained to make conclusions from the experimental data in each meeting. Learning activities with the POGIL model always involve students rebuilding information and knowledge and developing their understanding of solving a problem (Hanson, 2006). The sample of student answers that showed an increase in the indicators of making conclusions can be seen in Figure 5.

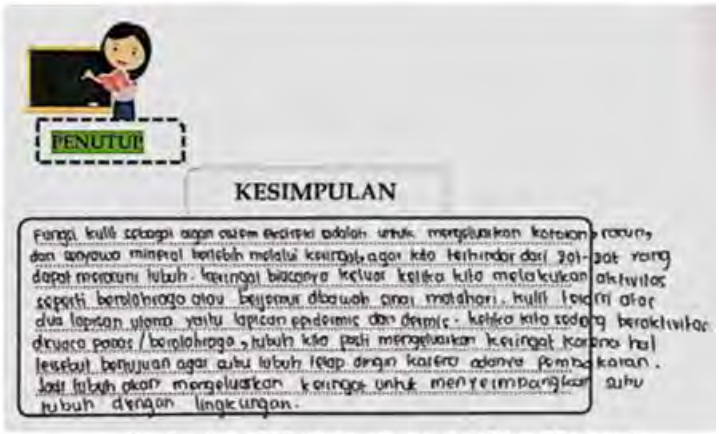
Indicators of doing induction experienced the second-highest increase from 53% in the first cycle to 83% in the second cycle, marking a 56.60% increase. This is due to the application stage that contains HOTS questions on the POGIL learning model that can properly support this indicator's implementation. (Andani, 2019) stated that at the application stage, students were given exercises in the form of problem studies or research case studies to strengthen understanding and provide opportunities for students to develop their confidence by giving simple exercises.

The indicator argues that it experienced the third-highest increase, particularly a 16.77% increase from 84% in the first cycle to 98% in the second cycle. This is due to the concept discovery stage in the POGIL model that can properly support this indicator. The concept discovery stage leads students to predict or

conclude based on their understanding (Hanson, 2006). This is supported by Andani (2019) who stated that the concept discovery stage in the POGIL model can support the application of indicators to provide arguments.



(a) Conclusions Made Leading More to the Learning Reflection



(b) Conclusions Made In Accordance with the Materials Learned

Figure 5. Sample of student's answers showing improvement in making conclusions indicator

The indicator for deduction experienced the fourth highest increase from 68% in the first cycle, increasing 14.71% to 78% in the second cycle. This is due to the concept discovery stage in the POGIL model that can properly support this indicator. The concept discovery stage leads students to predict or conclude based on their understanding and can help students develop their understanding of the concepts they have learned (Hanson, 2006). On the other hand, the indicator for formulating the problem experienced the lowest increase, namely 10.49% from 77% in the first cycle to 85% in the second cycle. This is because the students' ability to formulate problems is quite good and relates to the material discussed. However, there are still some students whose problem formulations are not related to the material discussed. In cycle II, students are better at writing problem formulations and relate to the material. This shows that the orientation stage in the POGIL model can prepare students to learn and to be more motivated, make them concentrate more, and make the topics to be discussed important to be studied so that students have an understanding of what will be learned and can build their knowledge (Hanson, 2006).

The results also show that implementing POGIL learning model combined with a digital mind map based on online learning can improve students' problem-solving skills in class XI MIPA 4 of SMAN 2 Malang. It is proven by the 22.16% increase in the percentage of problem-solving skills from 70.27% in the first cycle to 85.41% in the second cycle. This shows that the stages in the POGIL learning model can help improve students' problem-solving skills because during learning, by using the POGIL model, students are designed in small groups that interact with each other in groups with the teacher as a facilitator. The POGIL learning model can maximize student involvement and interaction in groups and effectively measure understanding in process-oriented learning. Not only that, the POGIL model can also grow students' ability to solve problems. In this study, students' problem-solving skills were trained at the application stage. Then, students are given guided questions to apply concept formation to more

complex problems with problem-solving indicators. Then, students discuss in groups and apply the concepts obtained in the previous stage to answer guided questions in UKBM.

Based on the four problem-solving skills indicators, the indicator of identifying problem-solving solutions experienced the highest increase, namely 33.33% from 72% in the first cycle to 96% in the second cycle. In identifying problem-solving solutions, students are asked to solve the problems presented at the Application stage. POGIL could train students' problem-solving skills as seen from the students' efforts to propose their best strategy to solve a problem. As a result, students accustomed to solving problems have a deeper understanding and become more responsive to new problems given. The second-highest increase was found in identifying problems which increased by 21.92% from 73% in the first cycle to 89% in the second cycle. This is evidenced by the results of problem identification made by students becoming more better at each meeting. Guided questions at each stage of the POGIL model serve as problems for students while the solution to the problem is the output of student's understanding from which the indicators to identify problems can be trained properly.

The indicator of maintaining problem-solving solutions experienced the third highest increase, from 63% in the first cycle to 75% in the second cycle, indicating a 19.05% increase. Although, in the first cycle, some groups did not write down the reasons for choosing the solution, a change was spotted where at each meeting, the students were more thorough in answering and writing down the reasons.

The indicator of implementing the problem-solving stages experienced the lowest increase of 12.33%, from 73% in the first cycle to 82% in the second cycle. This is due to the ability of students to be good in applying the stages of problem-solving to answer questions in UKBM well. Students solve problems by compiling the problem-solving of those presented by the teacher at the application stage. Learning with the POGIL model combined with a digital mind map also utilizes the Coggle™ platform. The researcher uses the Coggle™ platform for making digital mind maps since the platform can be used collaboratively by group members online following the conditions of this pandemic, and because this platform is very easy to use. Coggle™, in addition to its attractive appearance, is also equipped with interactive capabilities that facilitate students to collaborate and discuss in the mind map making (Sutton et al., 2017). Not only that, creating a digital mind map through Coggle™ can also add images or links to each keyword to make it clearer. Furthermore, Coggle™ can be integrated with various interesting images and links on branch mind maps (Kamrozzaman et al., 2019). This makes Coggle™ attracts more students' attention and helps them remember the material more easily. Learning by utilizing mind maps can help students explore ideas, help them remember information more easily, take notes and plan assignments, and make it easier for them to organize ideas and concepts.

The use of digital mind maps also supports students' critical thinking and problem-solving skills. By using mind maps, students find it easier to understand the material and obtaian higher learning achievement (Jaafarpour et al., 2016) and thinking skills (Canas et al., 2017). This finding is also supported by the other research results which shows that the inquiry model combined with a mind map can improve student academic achievement because it is effective for teaching difficult concepts (Jack, 2013). Learning through mind mapping can develop students' creativity, activity, memory, and knowledge. Besides that, mind mapping is one way of taking creative and effective notes, and can actually map one's mind in the process so as to be able to cultivate students' problem-solving skills. Mind maps in learning can help students find the right solution because it contains problem elements in one visual display with colors and images to stimulate the brain and explores more of the students' ability to solve problems. Furthermore, by combining the inquiry process with mind maps in learning, students can be facilitated to understand information effectively and systematically (Zubaidah et al., 2017).

Conclusion

Based on the results of the research and discussion, it can be concluded that the implementation of the POGIL (Process Oriented Guided Inquiry Learning) model combined with a digital mind map based on online learning can improve critical thinking skills and problem solving for students of class XI MIPA 4 of SMAN 2 Malang. It is proven by the 29.61% increase in the percentage of students' critical thinking skills from 66.8% in the first cycle to 86.6% in the second cycle. Meanwhile, the percentage of students' problem-solving skills was 70.27% in the first cycle and increased by 22.16% to 85.41% in the second cycle.

Based on the findings in this study, there are some suggestions that can be considered as great inputs for improvement in further research, such as: (1) other researchers should pay more attention to time allocation because the POGIL model takes a long time in its implementation; (2) other researchers are recommended to implement the POGIL model combined with a digital mind map based on online learning to develop other 21st Century skills; (3) pre-test, post-test, and N-gain scores are highly advised to show an increase in critical thinking skills and more accurate problem-solving; and (4) the Coggle platform can also be used to develop collaboration skills and students' creativity by making digital mind maps in groups.

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Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

Author Contributions

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