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Improving Collaboration and Problem-Solving Abilities through Digital Mind Map-Based Learning among Elementary School Teacher Education Students

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ABSTRACT

Collaboration and problem-solving are important skills for prospective teachers in the twenty-first century. Digital mind map-based learning is a useful teaching approach. However, there is still limited research on its effectiveness in teacher education, especially in Indonesia. This study aimed to examine the effectiveness of digital mind map-based learning in improving collaboration and problem-solving skills among prospective elementary school teachers. A quasi-experimental study employing a non-equivalent control group design was conducted with 80 second-semester students selected through cluster sampling. The experimental group received digital mind map-based instruction, whereas the control group participated in conventional learning. Data were collected using validated essay-based instruments measuring collaboration and problem-solving skills. Instrument validity was established using the Aiken index, and reliability was confirmed through Cronbach's alpha coefficients. Data were analyzed using Multivariate Analysis of Variance (MANOVA) at a 0.05 significance level. The findings revealed statistically significant differences between the experimental and control groups in both collaboration and problem-solving skills ($p < .001$). Students who participated in digital mind map-based learning achieved substantially higher mean scores than those receiving conventional instruction, indicating the effectiveness of the intervention in enhancing both competencies. Digital mind map-based learning promotes collaborative knowledge construction, meaningful visualization of concepts, and systematic problem-solving processes, making it an effective instructional strategy for developing twenty-first-century competencies among prospective teachers. Future research should employ longitudinal and multi-institutional designs while investigating additional learning outcomes, including creativity, metacognitive awareness, and self-regulated learning.

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1. INTRODUCTION

The challenges of the 21st century require individuals to possess adaptability, creativity, and collaboration skills, with educational institutions bearing full responsibility for facilitating the development of these competencies. Through the implementation of a relevant, technology-integrated, and character-building curriculum, schools can cultivate a generation of lifelong learners prepared to face future dynamics. The learning process must take advantage of these technological advancements to enhance educational outcomes (Hermino & Arifin, 2020). In the 21st century, students are expected to possess the skills, abilities, and competitiveness necessary to build an education system that aligns with global demands (Wahyu & Sri, 2019). The paradigm of 21st-century education emphasizes students' ability to think creatively, relate scientific knowledge to real-life contexts, master technology, communicate effectively, and collaborate productively (Dakhi et al., 2020; Fong, Sidhu, & Fook, 2014).

Collaboration and problem-solving are core 21st-century skills that must be developed throughout the educational process.Through collaboration, students learn to work together and appreciate diversity.Through problem-solving, they learn to think critically, creatively, and adapt to real-life challenges.Both develop essential socio-intellectual competencies for navigating a complex and dynamic global world. Collaboration skills include the ability to show respect for diverse teams and to train flexibility and willingness to make compromises (D'Agostino, 2013). Collaboration involves sharing the rules and participation of team members in their respective roles and finding shared benefits by understanding their strengths and weaknesses. Collaboration allows people to solve mutual problems and achieve common goals (Sahin, Ayar and Adiguzel, 2014). Through the construction, monitoring, and improvement of shared knowledge during interactions that occur when collaborating.

Traditional classrooms have many limitations in preparing students for the challenges of the 21st century.Therefore, teachers need to transform into active learning facilitators, encouraging students to think critically, collaborate, innovate, and adapt to changing times. Traditional classrooms often produce passive and non-independent students. They lack higher-order thinking skills. They create a gap between academic competencies and workplace skills. They also lack adaptability to technological and social changes. To address these challenges, digital technology integration into every learning process is necessary.

Several challenges continue to exist in mathematics learning, and many students struggle to manage their own cognitive processes, such as planning, monitoring, and evaluating, making it difficult for them to develop effective strategies during Digital Mind Map-Based Learning. One promising approach is Digital Mind Map-Based Learning, which is designed to enhance students' collaboration and problem-solving skills. To address this learning challenge, students can be assigned a mind-mapping task. Mind maps help learners visualize and structure their prior knowledge. The radial structure of mind maps allows concepts to be organized visually into branches and highlighted with colors. These maps are arranged hierarchically, with main ideas positioned on the primary branches and supporting details placed on subsequent levels (Stokhof et al., 2020). Mind maps can also be created using digital tools (Iao-qiang et al., 2015), commonly referred to as Digital Mind Maps (DMM). The integration of information technology in education is essential, and DMM creation involves using applications that connect concepts through linking lines to visualize and categorize ideas (Iao-qiang et al., 2015). Incorporating DMM into the learning process is expected to enhance students' active participation and foster collaborative learning in the classroom (Hidayati et al., 2019). This study focuses on examining the impact of digital mind map-based learning on improving students' collaboration and problem-solving skills.

The lack of empirical studies on digital mind mapping in teacher education in Indonesia is an urgent need. One innovation that has the potential to improve the quality of learning is the use of digital mind maps, a technology-based visual aid that helps students and teachers organize ideas, concepts, and relationships between ideas systematically and interactively. However, although the benefits of digital mind mapping have been widely demonstrated in various countries, empirical studies examining its application in the context of teacher education in Indonesia are still very limited. Teachers often deliver subject matter without fostering student interaction or encouraging active participation in expressing ideas, thereby providing limited opportunities for students to analyze the topics discussed in class. Furthermore, problem-solving skills are essential for students to succeed in the 21st century. Effective problem solving should be grounded in scientific reasoning that enables students to draw accurate conclusions (Yanto et al., 2019). Therefore, students must be able to actively apply 21st-century skills, demonstrate initiative, and collaborate effectively (Ahmad et al., 2016). The mathematics learning process is expected to cultivate scientific understanding so that mastery of mathematical concepts promotes deeper thinking and enhances problem-solving abilities.

Based on the preliminary study, Sagita and Sani (2019) state that improvement in student learning outcomes, which reflect the overall enhancement of education quality, can be achieved through the implementation of appropriate learning models. One such model aligned with the scientific approach and designed to foster students' collaboration and problem-solving skills is digital mind map-based learning. According to Jankowska et al. (2019), the development of thinking skills is influenced by multiple factors. As educators, teachers must facilitate students in becoming effective problem solvers by promoting collaborative learning environments. Therefore, mathematics instruction in schools should be oriented toward problem-solving activities. The significance of examining students' problem-solving abilities has been emphasized by several researchers (Afriansyah, 2016; Yusri, 2013; Dewi & Minarti, 2018). In today's world, innovation in problem-solving is essential, as the ability to find effective solutions is a critical aspect of science education (Docktor et al., 2015; Mason & Singh, 2016). However, studies have shown that high school students' problem-solving skills remain relatively low (Azizah et al., 2015). Hence, this research focuses on applying digital mind map-based learning to enhance students' collaboration and problem-solving skills.

The integration of technology in education plays a vital role, and Digital Mind Maps (DMMs) utilize applications that connect concepts through lines, enabling visualization and classification of ideas (Iao-qiang et al., 2015). Incorporating DMM into the learning process is expected to promote students' active engagement and collaborative learning in the classroom (Hidayati et al., 2019). This study seeks to investigate the effect of digital mind map-based learning on enhancing students' problem-solving skills. Drawing from the background and identified issues, the focus of this research is the application of digital mind map-based learning to strengthen students' problem-solving abilities. To implement this approach effectively, teachers must possess a strong understanding of scientific content and be able to integrate technology in communicating these concepts. Accordingly, the research question is: How effective is digital mind map-based learning in improving collaboration and problem-solving skills among prospective elementary school teachers?

2. METHOD

2.1 Research Design

This research aims to investigate the effectiveness of the implementation of the learning-based digital mind maps to improve students' collaboration skills and Problem-Solving skills. This research utilizes a quasi-experimental non-equivalent control group design. The quasi-experimental non-equivalent control group design was selected to accommodate pre-existing class structures. The experimental class was given a treatment using a learning-based digital mind map, while the control class was given treatment by applying the conventional learning model.

The learning process in the two classes takes place with a different syntax. In conventional classes, students carry out discussions, and then the lecturer explains the learning material. The role of the lecturer is more dominant in this class because the lecturer delivers the material using the lecture method. The stages of learning in digital mind map (DMM) class, the learning steps were: i) Students created DMMs to activate prior knowledge.ii) Students were oriented to the problem.iii) DMMs were updated during problem-solving.iv) Reports and presentations followed.v) The session concluded with analysis and reflection.

2.2 Participants

Eighty-second-semester students from a teacher education program were selected through cluster sampling. The research site was chosen for its digital infrastructure supporting technology-enhanced learning. Researchers only need to take samples from a portion of the cluster, not the entire population. Given the large sample size, groups were predetermined for sampling (Sugiyono, 2015).

2.3 Instruments and Data Collection

Data were collected by using tests for measuring student's collaboration skills and Problem-Solving Skills. The tests are in the form of essay tests. The questions in the tests for measuring student's collaboration skills are arranged based on the indicators for each component with a rating scale of 0-5. The criteria for determining the rating scale include 0 (if there is no correct answer), 1 (if there is 1 correct answer), 2 (if there are 2 correct answers), 3 (if there are 3 correct answers), 4 (If four correct responses are provided), and 5 (if all answers are correct). Meanwhile, the test questions for assessing problem-solving abilities are arranged based on the indicators for each component with a rating scale of 0-5. The categories for the rating scale include 0 (if there is no correct answer), 1 (if students can only identify the given quantities correctly), 2 (if students can formulate the problems correctly), 3 (if students can choose an appropriate and correct formula), 4 (if students can put the given quantities into the formula correctly), and 5 (if students can calculate and conclude correctly). These two tests will be given to students before learning (pretest) and after learning (posttest). Table 1 below presents the test grid that will be used to obtain data on the students' collaboration skills, while Table 2 presents the test grid for measuring the problem-solving skills.

Table 1. Student's Collaboration Skills Test Grids

Indicators	Item
Responsibility	1
Respect	2
Contribution	3
Work as a whole team	4
Organize Work	5

Table 2. Problem Solving Ability Test Grid

Aspects	Indicators
Defining Problems	a. Determining the types of problem b. Mentioning all the information provided c. Completing the problem sketch d. Stating the final goals that must be met from the existing problems
Exploring Problems	a. Describing the condition of the objects b. Describing free diagrams c. Making assumptions that must be met
Solving Problems using a well-planned procedure	a. Describing given information b. Specifying the information to be determined c. Constructing the structure of equations from theories, principles, and the appropriate physics laws d. Producing the right solutions
Evaluating and Reflecting on Problem Solving	a. Making conclusions based on solutions completed with appropriate theories b. Evaluating statements based on the theories, principles, and laws of physics

These research instruments have been valid since they have been validated by three educational experts. The validity analysis is used to determine whether the instrument items are valid or not. To prove the validity of the instrument, the researchers assess the expert agreement index based on the Aiken index (V) (Taber, 2018). The results of this assessment are presented in Table 3 below:

Table 3. The results of the Aiken Index Coefficient of Instrument Validity

Instruments	**V**	**Validity**
Student's collaboration skills	0.89	Valid
Problem solving skills	0.88	Valid

Instrument reliability is determined based on Cronbach's alpha coefficient. The reliability of the problem-solving test instrument was 0.87, while the reliability of the student's collaboration skills test instrument was 0.85. Thus, the reliability value of the instrument was in a high category (Taber, 2018).

2.4 Data analysis

The test used was the Manova test at a significance level of 0.05. If the probability <the specified level of significance, there will be an effect of the application of the learning-based digital mind maps to improve students' collaboration skills and Problem-Solving Skills. Several prerequisites for Manova testing, which include normality test, homogeneity test, and covariance matrix test, have been met.

3. FINDINGS AND DISCUSSION

3.1 Findings

The effectiveness of the implementation of the learning base digital mind maps is determined based on the impact of applying the model on increasing student's collaboration skills and Problem-Solving Skills. The difference in the average score between the experimental and the control class presented on table 4 shows that the average collaboration ability in the experimental class is 83.85 while the problem-solving skill is 85.92. Both are higher than the average value in the control class.

Table 4. The Comparison of Average Value of Collaboration Skills and Problem Solving Skills in Control and Experimental Class

	Group	**Mean**	**Std. Deviation**	**N**
Collaboration skills	Control	64.73	4.475	40
	Experimental	83.85	3.523	40
	Total	79.78	12.385	80
Problem solving	Control	62.50	5.742	40
	Experimental	85.92	2.264	40
	Total	75.58	11.484	80

Based on the test of normality, the data are normally distributed because the significance value is greater than 0.05 (see Table 5). Whereas, Table 6 shows that all group variance pairs have significance numbers greater than 0.05.

Table 5. Tests of Normality

		Kolmogorov-Smirnov[a]		
	Group	**Statistic**	**Df**	**Sig.**
collaboration skills	control	.321	40	.243
	experimental	.130	40	.206
Problem solving	control	.172	40	.145
	experimental	.103	40	.132

Table 6. Levene's Test of Equality of Error Variancesa

	F	**df1**	**df2**	**Sig.**
Collaboration skills	1.322	1	80	.421
Problem solving	1.518	1	80	.252

Based on the results of the dependent variable covariance matrix tests, each dependent variable had the same variance in each group because the significant value was .421 (p-value> 0.05). It was also assumed that the correlation between the dependent variables was the same in all groups (see Table 7). Thus, the variance of each pair is homogeneous. The results of the assumption test indicate that the data have met the requirements for conducting the MANOVA test.

Table 7. Box's Test of Equality of Covariance Matrices[a]

Box's M	3.743
F	1.152
df1	4
df2	475620.000
Sig.	.213

The Manova test utilized Hotelling's Trace statistics (see table 8). This test statistic is suitable if there are only two groups of independent variables. The higher the Hotelling's Trace statistical value is, the greater the effect on the learning base digital mind maps will be. Based on the table, the hotelling's trace value is 11.421, which is greater than the pillai's trace value (hotelling's trace> pillai's trace value). Table 8 shows that the statistical values of Pillai's Trace, Wilks' Lambda, Hotelling's Trace, and Roy's Largest Root for each model variable have a significant value of less than 0.05. This indicates that there is an influence of the learning base digital mind maps simultaneously. Thus, testing between subjects can be continued (see table 9).

Table 8. Multivariate Tests

Effects		Value	F	Sig.	Partial Eta Squared
Intercept	Pillai's Trace	.778	17483.157[b]	.000	.818
	Wilks' Lambda	.002	17483.157[b]	.000	.818
	Hotelling's Trace	582.341	17483.157[b]	.000	.818
	Roy's Largest Root	573.353	17483.157[b]	.000	.818
group	Pillai's Trace	.919	342.145[b]	.000	.839
	Wilks' Lambda	.081	342.145[b]	.000	.839
	Hotelling's Trace	11.421	342.145[b]	.000	.839
	Roy's Largest Root	11.421	342.145[b]	.000	.839

Table 9. Tests of Between-Subjects Effects

Source	Dependent Variable	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	collaboration skills	6531.600[a]	1	6531.600	310.683	.000
	Problem Solving	7210.017[b]	1	7210.017	476.437	.000
Intercept	collaboration skills	343166.627	1	343166.627	14305.077	.000
	Problem Solving	351818.447	1	351818.447	26433.275	.000
Group	collaboration skills	6341.500	1	6341.500	320.683	.000
	Problem Solving	7220.027	1	7220.027	416.437	.000

The next analysis is based on the difference in the influence of each factor on the dependent variable (see Table 9). The results show that there is a significant difference regarding the value (p value < .05). Therefore, it can be concluded that there is a significant difference in the value of collaboration skills between students who were taught using the learning base digital mind maps and conventional (p = .000) and there is a significant difference in the value of problem solving skills between students who were taught using the learning base digital mind maps and conventional (p = .000) model. Based on the explanation above, the application of the learning-based digital mind maps in the experimental class is more effective for improving collaboration skills and problem-solving skills than the conventional model in the control class.

3.2 Discussion

The findings of this study demonstrate that digital mind map-based learning significantly improved collaboration and problem-solving skills among prospective elementary school teachers compared with conventional instruction. The MANOVA results confirmed statistically significant differences between the experimental and control groups, indicating that integrating digital mind maps into the learning process effectively promotes higher-order learning competencies. These findings support the premise that visual learning technologies can transform passive learning environments into active, collaborative, and inquiry-oriented classrooms. Rather than functioning merely as a digital note-taking tool, digital mind maps encourage learners to organize information hierarchically, establish meaningful conceptual relationships, and construct knowledge collaboratively, resulting in deeper cognitive engagement and improved learning outcomes.

The improvement in collaboration skills can be explained through the social constructivist perspective, which emphasizes that knowledge is developed through interaction, communication, and shared meaning-making. During digital mind map-based learning, students collaboratively identified problems, negotiated ideas, refined conceptual relationships, and jointly constructed digital representations of knowledge. These collaborative activities promoted responsibility, mutual respect, contribution, teamwork, and work organization, which correspond directly to the collaboration indicators assessed in this study. Unlike conventional learning, where lecturers dominate knowledge transmission and student interaction is relatively limited, digital mind mapping creates opportunities for students to exchange perspectives, justify arguments, and collectively solve learning tasks. Such interactions strengthen interpersonal communication while simultaneously fostering collaborative problem solving. These findings are consistent with Vygotsky's social constructivist theory, which argues that higher-order cognitive development occurs through social interaction within the Zone of Proximal Development, where learners benefit from collaborative engagement with peers and instructors (Vygotsky, 1978).

The positive effect of digital mind mapping on collaboration is also supported by previous empirical studies. Osman et al. (2011) demonstrated that collaborative learning environments significantly enhance students' communication, participation, and shared knowledge construction. Similarly, Prichard et al. (2006) reported that structured teamwork activities improve cooperative learning outcomes by strengthening interpersonal coordination and group accountability. The present findings extend these studies by showing that digital mind maps function not only as visualization tools but also as collaborative platforms that facilitate collective knowledge construction. Through real-time organization of ideas and concept mapping, students become active participants in the learning process rather than passive recipients of information. Consequently, digital mind maps contribute to the development of collaboration competencies that are increasingly demanded in twenty-first-century education.

The significant improvement in problem-solving skills may be attributed to the cognitive processes facilitated by digital mind maps throughout each stage of learning. Students first activated prior knowledge by constructing an initial conceptual map before identifying the learning problem. During the problem-solving process, the maps were continuously revised as students incorporated new information, evaluated alternative solutions, and reorganized conceptual relationships. This iterative process enabled students to monitor their own understanding, identify misconceptions, and refine solution strategies systematically. Such learning activities encourage metacognitive regulation because learners continuously evaluate the relationships among concepts rather than memorizing isolated information. Consequently, digital mind mapping supports deeper conceptual understanding and more effective problem-solving performance.

These findings are consistent with Cognitive Load Theory, which proposes that instructional strategies should reduce unnecessary cognitive demands while facilitating meaningful information processing (Sweller, 1988). Digital mind maps visually organize complex information into interconnected structures, thereby reducing extraneous cognitive load and allowing students to allocate greater cognitive resources toward analyzing problems and generating solutions. Furthermore, the integration of visual representations with verbal information aligns with the Cognitive Theory of Multimedia Learning, which explains that meaningful learning occurs when learners actively organize and integrate verbal and visual information within working memory (Mayer, 2021). Therefore, digital mind maps provide an instructional environment that promotes efficient information processing and facilitates higher-order thinking.

The findings also corroborate previous studies examining the educational benefits of digital mind mapping. Hidayati et al. (2020) reported that integrating digital mind maps with problem-based learning significantly improved students' critical thinking and knowledge acquisition. Likewise, Stokhof et al. (2020) found that mind mapping encourages meaningful questioning, conceptual understanding, and scientific reasoning through visual organization of ideas. Earlier research by D'Antoni and Zipp (2006) and Al-Jarf (2009) similarly concluded that digital mind mapping improves knowledge retention, concept organization, and learning motivation across various educational contexts. While these studies primarily focused on cognitive outcomes, the present study expands existing evidence by simultaneously demonstrating significant improvements in both collaboration and problem-solving skills among prospective elementary school teachers. This dual improvement suggests that digital mind mapping supports not only individual cognitive development but also interpersonal competencies essential for future educators.

Another important contribution of this study lies in its educational context. Most previous studies investigating digital mind mapping have focused on school students or language learning environments, whereas relatively limited research has examined its implementation in teacher education programs, particularly in Indonesia. Preparing prospective teachers with collaboration and problem-solving competencies is crucial because these skills influence future classroom practices and instructional quality. Teachers who experience collaborative, technology-enhanced learning during their professional preparation are more likely to implement similar student-centered pedagogies in their future classrooms. Therefore, integrating digital mind mapping into teacher education programs contributes not only to improving university students' competencies but also to strengthening the quality of future elementary education.

From a practical perspective, the findings suggest that digital mind map-based learning offers an effective instructional alternative for higher education institutions seeking to strengthen twenty-first-century competencies. Lecturers can integrate digital mind mapping into collaborative projects, inquiry-based learning, and problem-based instruction to encourage active participation and meaningful knowledge construction. Nevertheless, successful implementation requires adequate technological infrastructure, appropriate digital literacy among instructors and students, and sufficient instructional time for collaborative activities. Institutional support and professional development programs are therefore essential to maximize the educational benefits of digital mind mapping.

Despite these promising findings, several limitations should be acknowledged. The study involved participants from a single teacher education institution and employed a relatively short intervention period, which may limit the generalizability of the results. Furthermore, collaboration skills were assessed within the instructional context rather than through authentic long-term collaborative performance. Future studies should employ longitudinal designs involving multiple universities, incorporate observational measures and peer assessment of collaboration, and investigate additional outcomes such as creativity, self-regulated learning, digital literacy, and metacognitive awareness. Such investigations would provide a more comprehensive understanding of how digital mind map-based learning contributes to sustainable competency development in teacher education.

4. CONCLUSION

This study demonstrates that digital mind map-based learning is significantly more effective than conventional instruction in improving collaboration and problem-solving skills among prospective elementary school teachers. By facilitating visual knowledge organization, collaborative interaction, and active engagement in problem-solving activities, digital mind maps provide a meaningful learning environment that supports the development of essential twenty-first-century competencies. These findings highlight the potential of digital mind mapping as an innovative pedagogical strategy for teacher education programs, enabling future teachers to acquire both cognitive and collaborative skills necessary for technology-enhanced classrooms. However, this study has several limitations, including the use of participants from a single institution, a relatively short intervention period, and the reliance on essay-based assessments that may not fully capture authentic collaborative performance. Therefore, the generalizability of the findings should be interpreted with caution. Future research is recommended to involve larger and more diverse samples across multiple institutions, employ longitudinal or mixed-methods designs, incorporate authentic measures such as observation and peer assessment, and examine additional outcomes including creativity, self-regulated learning, digital literacy, and metacognitive skills to provide a more comprehensive understanding of the long-term educational impact of digital mind map-based learning.

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