Effectiveness of Lumio by SMART-Assisted Discovery Learning in Improving Students' Collaboration Skills in Particle Dynamics

Dya Atul Fahmi[1], Khusaini[1*], & Lia Yuliati[1]
[1]Departemen of Physics, State University of Malang, Indonesia
*Corresponding Author: khusaini.fmipa@um.ac.id

Received: 23rd June 2026; **Accepted**: 15th October 2026; **Published**: 19th October 2026
DOI: https://dx.doi.org/10.29303/jpft.v12i2.12389

Abstract - *Collaboration skills are an essential 21st-century competency in physics learning, as they enable students to construct conceptual understanding through interaction, discussion, and collaborative problem-solving. However, previous studies have indicated that students' collaboration skills in Indonesia remain relatively low, partly due to limited motivation and active engagement during the learning process. This study aims to examine the effect of integrating Lumio by SMART, an interactive learning platform, with the Discovery Learning (DL) model on the collaboration skills of eleventh-grade students studying particle dynamics. The novelty of this study lies in the integration of the Lumio collaborative digital platform with the DL model, an approach that remains relatively unexplored in physics education, particularly in mechanics learning, which requires active student collaboration. This study employed a quasi-experimental design involving two eleventh-grade classes from the Engineering Expertise Program at SMA Negeri 1 Bululawang during the 2024/2025 academic year, comprising an experimental class (n = 30) and a control class (n = 30). The research instruments consisted of a collaboration skills questionnaire using a five-point Likert scale and observation sheets. The experimental class received Discovery Learning instruction supported by Lumio, whereas the control class received conventional instruction. Questionnaire results showed that collaboration skills in the experimental class improved from the moderate to the very high category, while those in the control class increased from the moderate to the high category. Similarly, observational data indicated greater improvement in the experimental class, with collaboration skills progressing from the low to the high category, compared with the control class, which improved from the low to the moderate category. These findings suggest that integrating DL with Lumio by SMART can enhance the quality of student interaction and collaboration during problem-solving activities. Further research involving inferential statistical analysis and larger samples is recommended to provide stronger empirical evidence of the effectiveness of this instructional approach.*

Keywords*: Collaboration Skills; Discovery Learning; Learning Media; Lumio by Smart*

INTRODUCTION

Learning physics in the 21st century demands more than just conceptual mastery; students must also possess collaboration, communication, problem-solving, and critical thinking skills, which are core to global competencies. Collaborative skills play a crucial role in helping students construct understanding through interaction, negotiation of meaning, and co-construction of complex scientific concepts. International research shows that student-to-student interaction significantly improves conceptual understanding and scientific reasoning skills, particularly in science subjects (Brundage et al., 2023; Chi & Wylie, 2014). In physics classes, collaborative learning environments encourage students to actively participate in scientific discussions, clearly state their reasoning, and evaluate alternative explanations (Kilpeläinen-Pettersson et al., 2025). Such interactions support deeper conceptual change and strengthen students' ability to apply physics concepts to complex and real-world problem situations.

In the context of physics, particle dynamics which encompasses Newton's

laws, force, mass, and acceleration is one of the most challenging topics due to its abstract nature and the need for strong visual representation and mental models. Many international studies have shown that students struggle to explain the relationships between force and acceleration variables without the aid of visualizations or simulations that support exploration (Herrera et al., 2024; McKagan et al., 2008). These challenges are exacerbated by teacher-centered learning practices, such as the conventional use of whiteboards, which have been shown to be ineffective in increasing student engagement in understanding mechanical concepts (Herrera et al., 2024). The lack of student engagement in learning indicates low student collaboration skills, resulting in suboptimal interaction and teamwork in physics activities. This condition limits students' opportunities to exchange ideas, test their understanding of concepts, and build knowledge socially (Pongsophon, 2024). As a result, physics learning tends to be individualistic and does not support the development of 21st-century skills, especially collaboration skills.

Collaborative skills require students to actively interact, synthesize ideas, and integrate various perspectives that arise in group work in order to build a common understanding and solve problems collectively (Li et al., 2023). Effective collaboration is reflected in students' ability to connect the knowledge contributions of each group member, filter relevant ideas, and manage differences of opinion through constructive communication and negotiation (Ferreira et al., 2025). Therefore, collaboration skills are important skills that need to be developed continuously so that students are able to work together effectively, responsibly, and support each other in the learning process. However, based on research Nugroho et al (2023), students' collaboration skills are categorized as low because students are not well-trained in project-based learning.

Several learning models have been applied to improve collaboration skills in physics, such as physical learning-STEM on momentum and impulse (Yulianti & Anjani, 2020), STEM-based physics instructional tool (Atika et al., 2025), Project based learning (Putri et al., 2021), Discovery learning (Agustina et al., 2024). However, these approaches do not necessarily provide an integrated digital environment for facilitating active discussion, visualizing physics concepts, and recording students' ideas collaboratively during the learning process. As a result, the process of concept discovery and group work may still provide limited opportunities for students to develop scientific communication, negotiate meaning, and share responsibility when solving physics problems. In addition, The Discovery Learning (DL) model theoretically offers an opportunity to overcome some of these obstacles through inquiry, exploration, and hypothesis testing. However, empirical evidence shows that DL does not always result in effective collaboration without the support of clear media and interaction structures. In many cases, group activities become unbalanced, dominated by only a few members, or lack meaningful conceptual discussion (Suryandani & Asih, 2024). This suggests that DL has pedagogical potential, but still has limitations when implemented without adequate technology-based scaffolding.

Collaborative learning platforms such as Nearpod, Pear Deck, and Desmos Classroom have been researched internationally for their ability to provide interactive workspaces and synchronous activities that can enhance student engagement during science learning

(Hillmayr et al., 2020). These studies demonstrate increased motivation, engagement, and peer interaction, indicating that digital collaborative platforms can provide useful scaffolding for interactive learning. However, the functions and instructional affordances of these platforms differ, and their effectiveness depends on how the available features are aligned with the learning activities and subject matter. In physics mechanics, where students need to interpret representations, manipulate visual objects, discuss observations, and document ideas collectively, an interactive platform that combines these functions within a shared learning space may be particularly relevant. Thus, there is still a need to investigate how specific digital platform features can be integrated into physics learning to support collaboration while also accommodating the representational demands of physics concepts (Chen et al., 2025; Chiang & Liu, 2023).

Lumio by SMART is an interactive platform that provides a shared workspace, synchronous quizzes, visual object manipulation, video integration, and real-time collaborative activities. Rather than assuming that Lumio is superior to other collaborative platforms, its relevance to this study lies in the combination of these functions within a single interactive learning environment. The shared workspace allows students to contribute and respond to ideas during group activities, while visual object manipulation and multimedia integration can support the representation of physics phenomena. These features are particularly relevant to particle dynamics, in which students need to connect observations, representations, and explanations of force and motion. Several studies have shown that Lumio can improve motivation, engagement, and learning outcomes through interactive multimedia (Suryandani & Asih, 2024; Wirda et al., 2023). However, most of this research is limited to media development or classroom action studies focusing on cognitive outcomes, rather than directly assessing students' collaboration skills in a physics context. Therefore, the empirical evidence regarding the use of Lumio specifically to support and quantitatively examine collaboration skills in particle dynamics remains limited.

Theoretically, the combination of Discovery Learning and Lumio is supported by the ICAP framework and Vygotsky's social constructivism theory. Discovery learning provides a problem-based inquiry structure, while Lumio by Smart provides visualization, digital scaffolding, and collaborative spaces that can facilitate interactive engagement, the highest category in the ICAP framework and one associated with stronger learning outcomes (Chi & Wylie, 2014; Roscoe et al., 2014). The integration of the two therefore provides a theoretically grounded approach for structuring students' collaborative activities, particularly by connecting inquiry-based tasks with opportunities to exchange, manipulate, and document ideas in a shared digital environment. This combination may help address some of the limitations of DL in facilitating collaboration and may improve the quality of interaction between group members when solving physics problems, especially in particle dynamics, which requires representation-based reasoning (Chi & Wylie, 2014; Roscoe et al., 2014). Accordingly, this study focuses on examining the effect of integrating Discovery Learning with Lumio on students' collaboration skills in particle dynamics. The contribution of this study is not the claim that Lumio is universally superior to other digital platforms, but rather the empirical examination of how its particular combination of collaborative and

representational features can be incorporated into an inquiry-based physics learning model to support students' collaboration skills.

RESEARCH METHODS

The methods section should be short, concise, clear, but sufficient. This part explained that research methods, implementation procedures, tools, materials, or instruments must be explained well, but not in the form of theory. If deemed necessary, there is an attachment regarding the lattice of the instrument or fragments of the material used. If statistical formulas are used as part of the method, the commonly used formulas do not need to be written. For example, the researcher set specific provisions to collect and analyze the data described in the methods section of this. This section is written for the maximum 10% (for qualitative research) or maximum 15% (for quantitative research) of the body of the article.

RESEARCH METHODS

Participants

This school is a general interest-based high school but has an engineering class as a vocational strengthening program within the general school system. The sampling technique used cluster random sampling because the sampling unit is an entire class, not an individual, and all classes share the same curriculum, schedule, academic characteristics, and subject teachers. This study invited randomly Class XI-Engineering 2 (n=30 students) and Class XI-Engineering 4 (n=30 students) as experimental and control class, respectively. Thus, the total sample consisted of 60 students. Because the study involved intact classes, the sample size was determined by the available class structure rather than individual randomization. The relatively small sample size is recognized as a limitation of the study and may restrict the generalizability of the findings to other schools and student populations.

The initial demographics of the students were relatively homogeneous: the majority were 16–17 years old, came from middle-class backgrounds, and had similar academic abilities and access to technology, based on information from their teachers and previous semester report card grades. The justification for selecting the sample was because physics learning in this class requires practical and collaborative activities, making it suitable for measuring collaboration skills. Additionally, all engineering classes have the same schedule and teachers, minimizing treatment bias due to differences in instructors. Before treatment, an initial collaboration questionnaire was administered to examine the comparability of the two classes. The results indicated no statistically significant difference in initial collaboration skills between the experimental and control classes (Mann–Whitney U, $p > .05$), supporting their comparability before the intervention.

Research Design

This research design is quasi-experimental, where the experimental class used Lumio by SMART as learning media, while the control class employed the regular learning strategy as usual. A pretest–posttest nonequivalent control group design was employed because the study used intact classes rather than randomly assigning individual students to conditions. This study carried out the Mann Whitney test to determine differences in student collaboration skills between both the experimental and control classes because the assumption of normality was not satisfied and the sample consisted of two independent intact classes.

Research Procedures

The research procedure began with a preparation phase, which involved developing Discovery Learning-based Lumio media containing Particle Dynamics material, complemented by interactive features such as online quizzes, collaborative workspaces, and virtual experiment guides. This media was then validated by five experts, consisting of three physics education lecturers and two experienced physics teachers assessing pedagogical aspects, content, and interactivity, as well as its suitability for classroom use. Content validity was quantified using Aiken's V. The validation results showed Aiken's V coefficients ranging from 0.85 to 0.95, with an overall value of 0.88, indicating that the learning media and research instruments had acceptable content validity. Furthermore, a small group trial of the collaborative skills questionnaire and observation sheets was conducted to ensure the clarity and completeness of the indicators.

The preparation phase also included training observers (teachers and researchers) to consistently assess collaborative skills, including techniques for completing the observation sheets and scoring procedures. Two observers independently assessed the same student behaviors using the observation rubric. Observer agreement was evaluated using an inter-rater reliability coefficient. The resulting inter-rater reliability value was 0.89, indicating good agreement between observers. Discrepancies were discussed after the observation sessions to maintain consistency in the application of the scoring criteria.

The treatment took place over six meetings from the second to fourth weeks. In the experimental class, students used Lumio media with the Discovery Learning model, which emphasizes active student involvement in discovering concepts, discussing, and completing assignments collaboratively. Meanwhile, the control class used existing conventional learning strategies, namely interactive lectures and worksheet discussions, to maintain a consistent learning environment and serve as a natural comparison. During each meeting, two observers observed both classes' collaboration skills, allowing detailed recording of progress. Although the intervention consisted of six meetings, the observation was conducted at every meeting to capture the progression of collaborative behavior rather than relying solely on a single post-intervention observation. Therefore, the six-meeting period was treated as an initial intervention period for examining changes in collaboration skills, rather than as sufficient evidence of long-term stability of collaborative behavior. After each learning session, the observation sheets were completed by both observers, whereas the collaboration questionnaire was administered at the pre-intervention and post-intervention stages. The posttest questionnaire was used to measure students' collaboration skills after the intervention, while repeated observations were used to describe changes in collaborative behavior across the six meetings.

Instruments

The research instrument consisted of a student collaboration skills questionnaire and a collaboration observation sheet. The collaboration questionnaire used a 5-point Likert scale (1 = very non-collaborative to 5 = very collaborative), while the observation sheet was used to assess students' collaborative behavior at each meeting on a scale of 1–5. The collaboration skills instrument is an adaptation of the Collaborative Work Skills Rubric developed by ReadWriteThink (2005), which refers to

Vygotsky's (1978) social constructivism theory. The adaptation process was carried out by translating and adjusting the indicators to the physics learning context and the Discovery Learning model without changing the main construct of collaboration. Collaboration indicators include contribution and participation, time management, problem solving, cooperation with others, and investigation techniques (Johnson & Johnson, 1994; ReadWriteThink, 2005).

The validity of the instrument's content was tested through expert judgment by lecturers of Physics Department at Universitas Negeri Malang and physics teachers in Malang using the Aiken's V index, while the reliability of the collaboration questionnaire was analyzed using Cronbach's Alpha, and the reliability of the observation sheet was tested using inter-rater reliability. The observation sheet obtained an inter-rater reliability coefficient of 0.83, indicating good agreement between the two observersThe instrument was declared suitable for use after going through a validation and revision process according to the validator's suggestions. These validity and reliability procedures were conducted before the main intervention to ensure that the instruments adequately represented the intended collaboration construct and could be applied consistently during classroom observations.

Data Analysis

Data obtained from the questionnaire and observation sheets were analyzed using Mann–Whitney U Test. Pre-intervention data was used to determine initial similarities. Post-test data was then subjected to a Mann-Whitney U test to determine the effect of the Discovery Learning model using Lumio by SMART. The analysis was conducted by calculating the average score for each collaboration skill indicator, then converting it into assessment categories as shown in Table 1 to determine the level of collaboration skill achievement in each class. Furthermore, observation results from six meetings were analyzed to describe trends in the development of students' collaboration skills throughout the learning process. The questionnaire and observation data are presented in tables and diagrams to illustrate changes in collaboration skill categories between the experimental and control classes, thus demonstrating the impact of learning using Lumio by SMART compared to conventional learning.

Table 1. Percentage Criteria for Classifying Collaboration Skills

Criteria	Percentage (%)
Very High	81 – 100%
High	61- 80%
Medium	41 - 60%
Low	21 – 40%
Very Low	0 – 20%

RESULTS AND DISCUSSION

The research results are described The research results, consisting of student questionnaires and observations, were used to measure students' collaboration skills. The data were collected from the experimental and control classes. Collaboration skills questionnaires were administered to students before and after the treatment, and collaboration skills observations were conducted from meetings 1-6.

1. Measuring Students' Collaboration Skills Using a Student Questionnaire Instrument

Graphs, tables, or descriptive phrases are employed to present research findings. Preceding these results can be discussed, they must be analyzed and interpreted. The descriptive statistics displayed in Table 2

illustrate the data from both the pret and post treatment of the experimental and control classes.

Table 2. Descriptive statistics results

Statistics	Control		Experimental	
	Pre	Post	Pre	Post
N	30	30	30	30
Average	62.1	65.3	65.9	79.6
SD	3.3	9.6	6.4	2.3

Based on descriptive quantitative analysis of student questionnaire data, Table 2 shows the results of students' collaboration skills before and after the treatment. The average score for each indicator in the control and experimental classes before the treatment showed nearly identical initial levels of collaboration skills. This suggests that collaboration skills were not yet evident in either the control or experimental classes. After the treatment, the control and experimental classes experienced an increase in average scores. The average score in the experimental class was higher compared to the control class. It was concluded that in the experimental class, the use of Lumio by Smart learning media with the Discovery Learning model had an effect on improving students' collaboration skills.

Before the intervention was given, initial measurements were taken to determine the equivalence of collaborative abilities among students in the control class and the experimental class. To measure this, the Mann–Whitney U test was used on the questionnaire data before the intervention, as presented in Table 3.

Table 3. Initial Similarity Results

Initial Similarity Test	
p-value	Conclussion
0.594	Equivalent initial collaboration skills

Based on Table 3, the results of the Mann–Whitney U test on the questionnaire data before the intervention showed a significance value of 0.594 (> 0.05), indicating that there was no significant difference in initial collaboration skills between the control class and the experimental class. Thus, both classes can be said to have had equivalent initial collaboration skills before the treatment was given. Next, the intervention was carried out over six meetings, with the experimental class applying the Lumio by SMART-assisted Discovery Learning model, while the control class used the lecture learning model. After the intervention was completed, the questionnaire was given again to measure the collaboration skills of students in both classes. The results of the treatment effect test are presented in Table 4.

Table 4. Mann-Whitney U test Results

Mann–Whitney U test	
p-value	Conclussion
0.000	there are differences in collaboration skills

Table 4 shows the results of the Mann–Whitney U test on the questionnaire data after the intervention, indicating a significance value of 0.000 (< 0.05), which indicates a significant difference in collaboration skills between the experimental class and the control class. Beyond statistical significance, the descriptive results indicate a meaningful practical difference between the two groups. The experimental class achieved a post-treatment mean score of 79.6, compared with 65.3 in the control class, representing a 14.3-point difference. This difference suggests that the integration of Lumio by SMART with Discovery Learning was not only associated with a statistically significant improvement but also produced a noticeable difference in students' observed level of collaboration skills. This practical difference is relevant to classroom practice

because the five collaboration indicators in the experimental class reached the high to very high categories, whereas contribution and participation and time management in the control class remained comparatively lower. In practical terms, the results suggest that an interactive digital environment can provide additional opportunities for students to contribute ideas, coordinate group tasks, discuss solutions, and investigate information during physics learning. Thus, the value of Lumio in this study lies not simply in introducing digital technology, but in providing a shared workspace that can be incorporated into the collaborative activities of Discovery Learning.

These findings show that the application of this model can create a learning environment that encourages active interaction, group discussions, and student involvement in the process of discovering concepts together. Rather than merely increasing students' exposure to technology, the combination of Discovery Learning and Lumio appears to create more frequent opportunities for students to exchange ideas and coordinate their work. Through exploration, discussion, and problem-solving activities facilitated by Lumio by SMART, students are more encouraged to share ideas, work together, and appreciate the contributions of group members, so that their collaboration skills develop more optimally compared to lecture-based learning. The results of this study are in line with previous findings that applied the Discovery Learning (Agustina et al., 2024) and Project-Based Learning models (Yanti et al., 2023) in physics education, which proved to be effective in improving students' collaboration skills The present study extends these findings by showing how Discovery Learning can be supported by a shared digital workspace in which collaborative activities and learning resources are integrated. The support of this interactive digital media provides space for students to collaborate more intensively, particularly during group discussion, investigation, and joint problem-solving activities (Martínez-Cerdá et al., 2018).

To determine each indicator's value in the experimental and control classes, as shown in Figure 1.

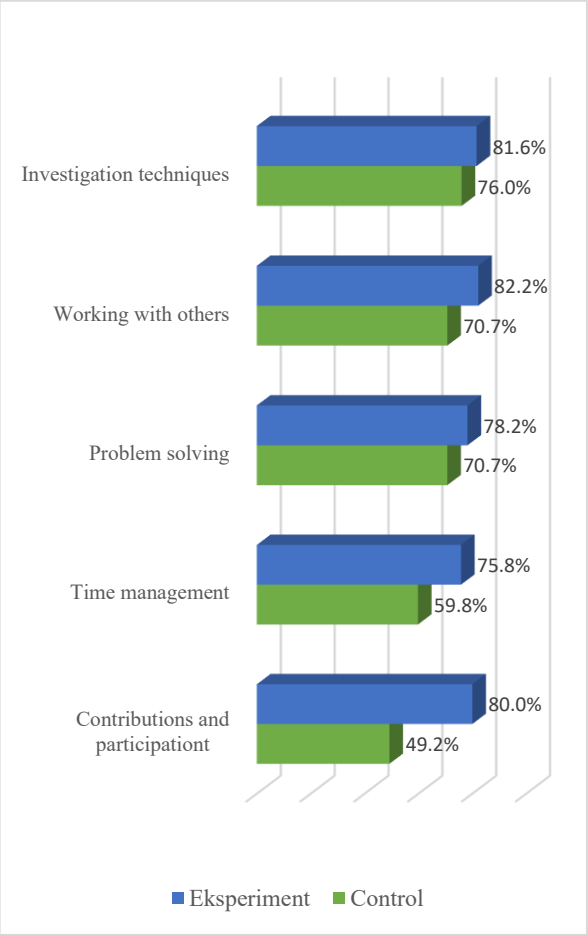

Figure 1. Frequency Distribution of Students for Each Indicator in the Control and Experimental Classes

Based on Figure 1, the order of indicators for the control class in terms of collaboration skills from highest to lowest is investigation techniques (76.08%), problem solving and working with others (70.7% each), time management (59.8%), and contributions and participation (49.2%). Meanwhile, for the experimental class, the order of collaboration ability indicators from highest to lowest is working with others

(82.2%), investigation techniques (81.6%), contributions and participation (80.0%), problem solving (78.2%), and time management (75.8%).

Figure 1 shows that in the control class, the contributions and participation indicator was in the medium category (49.2%), indicating that student involvement in expressing ideas and actively participating in group discussions was still limited. The time management indicator was also in the medium category (59.8%), indicating that students were not yet fully able to manage their time effectively during group activities. In contrast, the problem-solving and working with others indicators each reached the high category (70.7%), indicating that even though the learning method used was lecturing, students were still able to work together and solve problems when directed by the teacher. The investigation techniques indicator obtained the highest percentage in the control class (76.08%) with a high category, indicating that students are quite capable of collecting and processing information, even though the investigation process is not yet fully collaborative and independent.

In the experimental class, all collaboration ability indicators were in the high to very high category, indicating the positive impact of implementing the Lumio by SMART-assisted Discovery Learning model. The pattern across indicators also provides insight into which aspects of collaboration were most responsive to the intervention. Working with others (82.2%) and investigation techniques (81.6%) obtained the highest scores, suggesting that the shared digital environment was particularly useful for activities requiring students to exchange information, coordinate contributions, and investigate learning resources. Contributions and participation reached 80.0%, problem solving 78.2%, and time management 75.8%. These differences suggest that the intervention may have supported interpersonal interaction and collaborative investigation more directly than individual regulation of task time. Therefore, the practical contribution of the intervention is particularly evident in activities that require students to communicate and construct solutions collectively.

Theoretically, these results can be explained through social constructivism theory, which emphasizes that knowledge is constructed through social interaction and collaboration between individuals. According to Vygotsky's view, the learning process becomes more meaningful when students engage in dialogue, negotiate meaning, and collaborate with peers in the zone of proximal development (Clapper, 2015). The application of the Lumio by SMART-assisted Discovery Learning model provides space for students to interact actively, share ideas, and build shared understanding, which may explain why the experimental class demonstrated stronger collaboration across the measured indicators. The digital environment can function as a form of scaffolding by making students' contributions and shared learning activities more visible and accessible to group members.

In addition, the results of this study are also in line with the 21st century skills framework, which places collaboration as one of the key competencies that must be developed through active and technology-based learning (Asad & Qureshi, 2025). However, the observed improvement should not be attributed exclusively to Lumio itself. A possible alternative explanation is a novelty effect, in which students may initially become more enthusiastic, attentive, or willing to participate because the digital learning environment is different from their

usual learning experience. The intervention also combined Lumio with Discovery Learning, meaning that the present design does not allow the independent contribution of the digital platform and the learning model to be completely separated. Therefore, the higher collaboration scores should be interpreted as the effect of the combined instructional intervention, rather than evidence that Lumio alone caused the improvement. Longer interventions and comparison groups using other digital platforms or Discovery Learning without Lumio would be needed to determine whether the observed effects are sustained and whether they are attributable specifically to Lumio's features rather than to the novelty of technology or the inquiry-based learning structure.

2. Measuring Students' Collaboration Skills Using Observation Instruments

The results of the observations made by the observer are shown in Figure 2. Figure 2 shows the results of observations of student collaboration skills in the control and experimental classes over six meetings based on five indicators: contribution and participation, time management, problem-solving, collaboration with others, and investigative techniques. Rather than interpreting the observation results only as an increase in scores, the six-meeting trajectory provides evidence of how collaborative behaviors developed during the learning process. The more consistent increase observed in the experimental class suggests that repeated opportunities to interact through shared digital activities may have supported the gradual formation of collaborative routines.

The most notable development occurred in collaboration with others and investigative techniques. This pattern is pedagogically meaningful because both indicators require students to exchange information, coordinate actions, and combine individual contributions toward a common task. Lumio's shared workspace may have supported these processes by allowing students to access common learning resources and contribute to group activities within the same learning environment. In contrast, the slower development in the control class suggests that conventional teacher-directed activities may provide fewer structured opportunities for students to continuously practice these behaviors. Nevertheless, the six-meeting observation period should be interpreted as evidence of short-term behavioral development rather than stable long-term collaboration. The continued increase in the experimental class may partly reflect students' growing familiarity with the learning procedures and the technology. A novelty effect cannot therefore be excluded. Future studies involving longer interventions and follow-up measurements would be useful to determine whether these collaborative behaviors remain stable after students become accustomed to the digital platform.

There are similarities and differences between the two instruments. The highest improvement in the control class was the same between the questionnaire and observation instruments for indicator 5, namely, investigation techniques. However, the highest improvement in the experimental class was not the same between the questionnaire and observation instruments. The questionnaire instrument produced the highest improvement only in indicator 4, namely working with others. Meanwhile, the observation instrument produced the highest improvement in indicator 4, namely working with others, and indicator 5, investigation techniques. This is because teacher observations during class have shown the

active participation of most students in seeking references during group discussions. The difference between the questionnaire and observation instruments is also due to the possibility that students do not fill out the questionnaire according to the actual situation. As mentioned in the book (Rohmad & Sarah, 2021), one of the weaknesses of using questionnaire instruments is that respondents simply fill out the questions in the questionnaire.

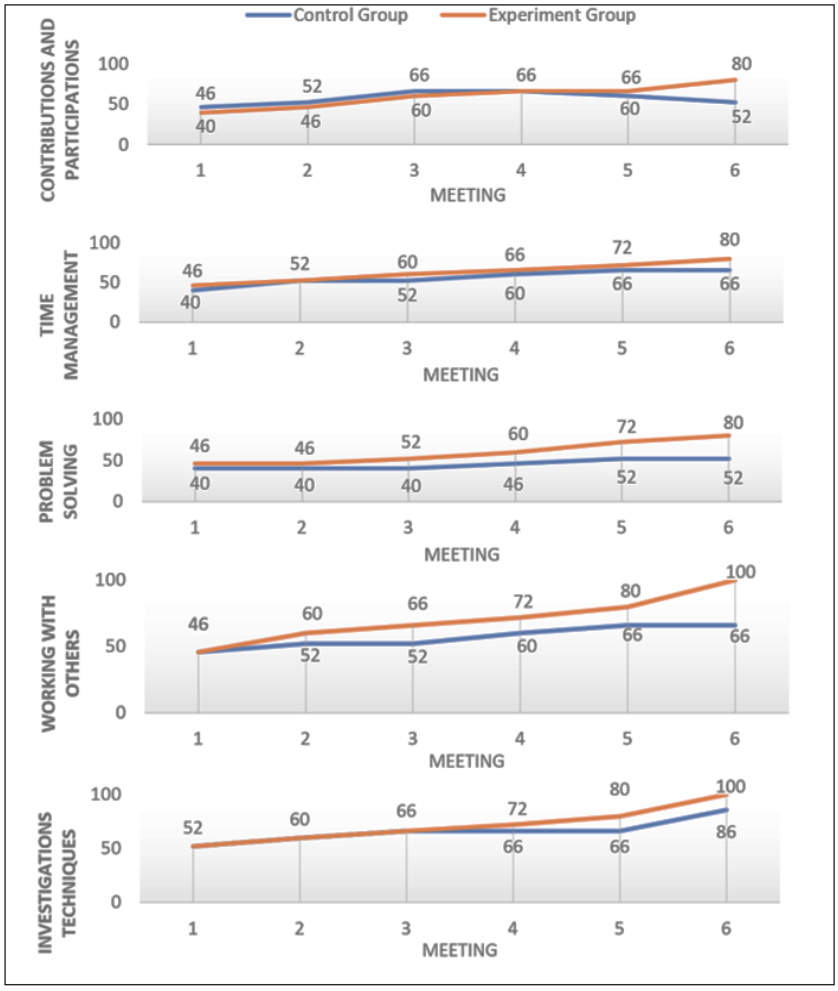

Figure 2. Results of Observations on Collaborative Skills of the Control and Experimental Classes at Meetings 1-6

These results align with research conducted by Ifada et al (Ifada et al., 2024) which showed an increase from the "neutral" to "collaborative" category in the experimental class. The indicators used were the same, but the specific indicators of improvement were different; this was due to the differences in the conditions of the students who were the subjects of the study. This research is also in line with several previous studies conducted by Syafii (2022), Muslimah et al (2024), and Hastri et al (2024). These studies have shown that the discovery learning model is effective in improving students' collaboration skills. The present study complements these findings by incorporating an interactive digital environment into Discovery Learning rather than treating technology as a separate component of instruction. The results suggest that the combination can provide additional opportunities for students to interact, investigate information, and coordinate group activities. However, because this study did not directly compare Lumio with other digital platforms or with

Discovery Learning using equivalent activities without digital technology, the findings should not be interpreted as demonstrating that Lumio is superior to other platforms. Its practical value is more appropriately understood as the provision of a shared digital environment that can be used to structure and support collaborative activities in physics learning (Suari, 2017; Wirda et al., 2023).

CONCLUSION

The study found that students in the experimental class who participated in the Discovery Learning intervention supported by Lumio by SMART demonstrated significantly higher collaboration skills than students in the control class. Furthermore, the questionnaire data showed an increase in the experimental class from the medium to very high category, while the control class increased from the medium to high category. Observation data also showed a greater improvement in the experimental class, with collaboration skills developing from the low to high category, whereas the control class developed from the low to medium category.

These findings are consistent with Vygotsky's social constructivism perspective, which emphasizes the role of social interaction and cooperation in developing students' collaborative learning processes. From a practical perspective, Lumio by SMART can be considered a potential digital learning medium to support student engagement, interaction, and collaborative activities in physics learning, particularly when integrated with Discovery Learning for abstract topics such as particle dynamics. However, the findings should be interpreted within the context of the present study and should not be generalized broadly beyond similar learning settings because the study involved only 60 students from two intact classes and a six-meeting intervention. Further research is recommended to involve larger and more diverse samples, longer intervention periods, and comparisons with other digital collaborative platforms to examine the consistency and generalizability of the findings.

ACKNOWLEDGMENT

Thank you to God Almighty for His grace and guidance, enabling the successful completion of this article. Thank you to the Research Institute for Research and Community Service (LPPM) of Malang State University for providing facilities during this research. I also express my gratitude to my parents and family for their prayers, support, and encouragement throughout every step of this journey.

REFERENCES

Agustina, R. D., Putra, R. P., Cesariyanti, Y., & Putri, N. M. (2024). Collaborative Skill Improvement Analysis in Real Laboratories Based on Discovery Learning for Undergraduate Physics Education Major. *KnE Social Sciences*. https://doi.org/10.18502/kss.v9i13.16026

Asad, M. M., & Qureshi, A. (2025). Impact of technology-based collaborative learning on students' competency-based education: Insights from the higher education institution of Pakistan. *Higher Education, Skills and Work-Based Learning*, *15*(3), 562–575. https://doi.org/10.1108/HESWBL-07-2024-0202

Atika, I. N., Buana, S. H. A., & Yusrika, A. Z. (2025). Encourage Students' Collaboration Skills in Inclusive High. *Jurnal Penelitian Pendidikan IPA (JPPIPA)*, *11*(7).

Brundage, M. J., Malespina, A., & Singh, C. (2023). Peer interaction facilitates co-construction of knowledge in quantum mechanics. *Physical Review Physics Education Research*, *19*(2), 20133.

https://doi.org/10.1103/PhysRevPhysEducRes.19.020133

Chen, C., Abdul Rabu, S. N., & Jamiat, N. (2025). Enhancing Physics Learning Achievement, Motivation and Inquiry Skills in a Flipped Classroom: A Structured Inquiry-Based Virtual Lab Approach. *Journal of Baltic Science Education*, *24*(1), 37–52. https://doi.org/10.33225//jbse/25.24.37

Chi, M. T. H., & Wylie, R. (2014). The ICAP Framework: Linking Cognitive Engagement to Active Learning Outcomes. *Educational Psychologist*, *49*(4), 219–243. https://doi.org/10.1080/00461520.2014.965823

Chiang, Y.-C., & Liu, S.-C. (2023). The Effects of Extended Reality Technologies in Stem Education on Students ' Learning. *Journal of Baltic Science Education*, *22*(4), 568–578. https://doi.org/10.33225/jbse/23.22.568

Clapper, T. C. (2015). Cooperative-Based Learning and the Zone of Proximal Development. *Simulation & Gaming*, *46*(2), 148–158. https://doi.org/10.1177/1046878115569044

Ferreira, J. M., Zabolotna, K., & Lee, S. (2025). Teaching twenty-first-century skills: Examining collaborative learning in initial teacher education in Finnish universities. *Scandinavian Journal of Educational Research*, *69*(7), 1319–1340. https://doi.org/10.1080/00313831.2024.2419078

Hastri Z, A., Danial, M., & Rahman, Y. (2024). Penerapan Discovery Learning Melalui Pendekatan CRT (Culturally Responsive Teaching) Terhadap Keterampilan Kolaborasi Peserta Didik UPT SPF SMPN 2 Makassar [The Application of Discovery Learning Through the CRT (Culturally Responsive Teaching) Approach to the Collaboration Skills of Students at UPT SPF SMPN 2 Makassar]. *Jurnal Pemikiran Dan Pengembangan Pembelajaran*, *6*(2), 1348–1355.

Herrera, L. A., Rodríguez, R. M., & Lopez, C. R. (2024). The Role Of Digital Simulation in Enhancing Conceptual Understanding Of Physics Among University Students. *International Journal of Mathematics and Science Education*, *1*(1), 62–68. https://doi.org/10.62951/ijmse.v1i1.82

Hillmayr, D., Ziernwald, L., Reinhold, F., Hofer, S. I., & Reiss, K. M. (2020). The potential of digital tools to enhance mathematics and science learning in secondary schools: A context-specific meta-analysis. *Computers and Education*, *153*, 103897. https://doi.org/10.1016/j.compedu.2020.103897

Ifada, A. I., Toyib, M., & Marhamah, S. (2024). Peningkatan Kemampuan Kolaborasi dalam Pembelajaran Matematika melalui Problem Based Learning Di Sekolah Menengah Pertama [Improving Collaboration Skills in Mathematics Learning through Problem-Based Learning in Junior High Schools]. *PTK: Jurnal Tindakan Kelas*, *4*(2), 447–460. https://doi.org/10.53624/ptk.v4i2.391

Johnson, D. W., & Johnson, R. T. (1994). Learning together and alone: Cooperative, competitive, and individualistic learning (4th ed.). Boston, MA: Allyn and Bacon.

Kilpeläinen-Pettersson, J., Koskinen, P., Lehtinen, A., & Mäntylä, T. (2025). Cooperative Learning in Higher Education Physics – A Systematic Literature Review. *International Journal of Science and Mathematics*

Education, *23*(7), 2707–2729. https://doi.org/10.1007/s10763-024-10538-3

Li, S., Pöysä-Tarhonen, J., & Häkkinen, P. (2023). Students' collaboration dispositions across diverse skills of collaborative problem solving in a computer-based assessment environment. *Computers in Human Behavior Reports*, *11*, 100312. https://doi.org/10.1016/j.chbr.2023.100312

Martínez-Cerdá, J.-F., Torrent-Sellens, J., & González-González, I. (2018). Promoting collaborative skills in online university: Comparing effects of games, mixed reality, social media, and other tools for ICT-supported pedagogical practices. *Behaviour & Information Technology*, *37*(10–11), 1055–1071. https://doi.org/10.1080/0144929X.2018.1476919

McKagan, S. B., Perkins, K. K., Dubson, M., Malley, C., Reid, S., LeMaster, R., & Wieman, C. E. (2008). Developing and researching PhET simulations for teaching quantum mechanics. *American Journal of Physics*, *76*(4), 406–417. https://doi.org/10.1119/1.2885199

Muslimah, Muhiddin, N. H., & Said, M. (2024). *Peningkatan Keterampilan Kolaborasi Melalui Model Pembelajaran Discovery Learning* [Improving Collaboration Skills Through the Discovery Learning Model]. *6*(2), 181–190.

Nugroho, P. S., Nasir, M., Syafi'i, M., & Erviyenni, E. (2023). Profile Perception of Student's Collaboration and Creative Thinking Skills in Physics. *Jurnal Penelitian Pendidikan IPA*, *9*(2), 775–779. https://doi.org/10.29303/jppipa.v9i2.3055

Pongsophon, P. (2024). Synergizing teacher collaboration to foster active learning strategies, student engagement and achievement in physics: A unified analysis across nine countries. *Physics Education*, *59*(5), 055012. https://doi.org/10.1088/1361-6552/ad61b1

Putri, R. K., Bukit, N., & Simanjuntak, M. P. (2021). *The Effect of Project Based Learning Model's on Critical Thinking Skills, Creative Thinking Skills, Collaboration Skills, & Communication Skills (4C) Physics in Senior High School:* 6th Annual International Seminar on Transformative Education and Educational Leadership (AISTEEL 2021), Medan, Indonesia. https://doi.org/10.2991/assehr.k.211110.103

Rohmad, & Sarah, S. (2021). *Pengembangan Instrumen Angket [Questionnaire Instrument Development]*.

Roscoe, R. D., Gutierrez, P. J., Wylie, R., & Chi, M. T. H. (2014). Evaluating lesson design and implementation within the ICAP framework. *Proceedings of International Conference of the Learning Sciences, ICLS* , *2*(January), 972–976.

Suari, M. (2017). Pemanfatan Arduino nano dalam Perancangan Media Pembelajaran Fisika. *Natural Science Journal*, *3*(1), 474–480.

Suryandani, A. D. A., & Asih, S. S. (2024). Development of Interactive Learning Media Assisted by Lumio by SMART to Increase The Learning Motivation of IPAS. *Jurnal Penelitian Pendidikan IPA*, *10*(11), 9003–9011. https://doi.org/10.29303/jppipa.v10i11.9161

Syafii, I. (2022). Pengaruh Model Pembelajaran Discovery Learning Terhadap Keterampilan Kolaborasi Siswa Pada Materi Larutan Penyangga [The Effect of Discovery Learning Model on Students' Collaboration Skills in Buffer

Solution Material]. *Jurnal Pendiidkan Indonesia : Teori, Penelitian Dan Inovasi*, *2*(5). https://doi.org/10.59818/jpi.v2i5.340

Vygotsky, L. S. (1978). Mind in society: The development of higher psychological processes. Cambridge, MA: Harvard University Press.

Wirda, A., Rhoma Dhoni, A., & Rahayu Setianingsih, E. (2023). Meningkatkan Hasil Belajar Peserta Didik melalui Multimedia Interaktif Berbasis Lumio By Smart [Improving Student Learning Outcomes through Lumio-Based Interactive Multimedia by Smart]. *Journal on Teacher Education*, *5*, 380–386.

Yanti, N., Rahmad, M., & Azhar. (2023). Application of PjBL (Project Based Learning) Based Physics Learning Model to Improve Collaboration Skills and Creative Thinking Ability of Students. *Jurnal Penelitian Pendidikan IPA*, *9*(11), 9973–9978. https://doi.org/10.29303/jppipa.v9i11.5275

Yulianti, D., & Anjani, D. (2020). Implementing Physical Learning Based On Momentum and Impulse Stem Materials to Develop Collaboration Skills. *Jurnal Ilmu Pendidikan*, *25*(1), 27. https://doi.org/10.17977/um048v25i1p27-32