



INTEGRATING THE CLARITY LEARNING MODEL WITH STEAM AND DIGITAL MIND MAPPING TO ENHANCE STUDENTS' CONCEPTUAL MASTERY

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ABSTRACT

Newton's laws are fundamental physics concepts that form a crucial basis for understanding more complex subjects. However, many students still struggle to understand and apply these concepts, particularly in interpreting force diagrams, vector representation, mathematical relationships, and diverse problem situations. This study evaluates the effect of a STEAM-integrating Clarity Learning Model (STEAM-integrating CLM) supported by digital mind mapping (DMM) on students' conceptual mastery. A mixed-method approach with an embedded experimental design was used, and samples were selected using cluster random sampling. The experimental group was taught using the STEAM-integrating CLM with DMM, while the control group received instruction using CLM. Data were collected using a conceptual mastery (CM) test. The data were analyzed using an independent-samples t-test, normalized gain, and effect size. The results show that students in the experimental group achieved significantly higher CM than those in the control group. The normalized gain was large, with an effect size of 1.6. These findings indicate that integrating STEAM and DMM within CLM effectively improves students' CM.

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Keywords: clarity learning model; conceptual mastery; Newton's laws; STEAM

INTRODUCTION

Newton's laws are closely related to force and motion, which are very familiar in our daily lives. Newton's three laws (law I: inertia; law II: force, mass, and acceleration; and law III: action and reaction) explain how forces acting on objects cause them to interact and move (Serway et al., 2019). The link between force and object motion must be described mathematically in order to comprehend Newton's laws fully (Mustofa et al., 2024). Newton's laws are not only part of classical mechanics but also a key foundation for understanding various physical phenomena and technological advancements (Thorne & Bland-

ford, 2017). The principles governing the relationship between force, mass, and motion form the basis for analyzing the motion of objects in various systems, from vehicles, machines, and building structures to mechanical systems and engineering technologies (Johnson & Sherwin, 2017). Understanding Newton's laws also helps students connect mathematical models with physical phenomena, so the concepts they learn go beyond mastering equations and allow them to explain and predict system behavior in real-life contexts (Motlhabane, 2025).

Students' initial conception of Newton's First Law is that an object's natural state is rest, without considering that objects can also move at a constant speed (Suwasono et al., 2023). In addition, in their initial conception of Newton's

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Second Law, students assume that a constant force results in a constant velocity rather than the law's stated constant acceleration (Fратиwi et al., 2020; Aksit & Wiebe, 2020). Furthermore, in Newton's Third Law, students initially conceive that the force arising from the interaction of two objects is not always the same, but is influenced by other factors such as mass, velocity, and the motion conditions of each object (Savinainen et al., 2017). These conditions indicate that students' mastery of Newton's laws is not yet fully developed and balanced, so that everyday intuitive experiences still influence their understanding. Persistent misconceptions regarding these three laws pose a significant problem because they can hinder students from developing a coherent knowledge structure regarding the relationship between force and motion (Nie et al., 2019). When appropriate instruction does not restructure intuitive conceptions from everyday experience, students may struggle to integrate verbal, mathematical, and visual representations of Newton's laws (Tighe & Shepp, 2019). This situation not only causes students to answer certain questions incorrectly but can also affect their ability to apply concepts to new situations and different phenomena (Resbiantoro & Setiani, 2022). Thus, addressing misconceptions and building a deeper conceptual understanding are essential in teaching Newton's laws.

Conceptual mastery (CM) requires students to have a deep grasp of a concept, not just memorizing formulas, but also being able to interpret the meaning of concepts and apply them in various situations. Concept understanding reflects students' ability to relate new knowledge to prior knowledge, connect relevant concepts, and identify inappropriate or irrelevant information (Winget & Persky, 2022). CM requires students to integrate and process concepts logically and critically, as well as interpret phenomena, so it is not merely memorization but a structured, complex thinking skill (Vaipoulou et al., 2023). According to Putra & Heriyanto (2020), students' CM level for the complexity dimension of Newton's law material was low, averaging 26.7%. This was due to the complexity of Newton's law material itself, which includes concepts such as vectors, forces, force diagrams, and mathematical models (Putra & Heriyanto, 2020). Although various approaches have been developed to improve mastery of Newton's laws, learning that focuses solely on solving conceptual problems or representing specific concepts does not necessarily provide a learning experience that simultaneously accommodates the processes of investigation, reason-

ing, clarification, evaluation, and application of concepts in authentic contexts (Parra-Zeltzer et al., 2025). Students need opportunities to test their initial conceptions, connect evidence with scientific explanations, and use the concepts they have learned to understand or solve real-life problems (Tan et al., 2023). These limitations highlight the need for a learning approach that is not only oriented toward problem-solving outcomes but also provides a systematic process for building, testing, and reconstructing students' conceptual understanding.

Several learning methods have been applied to construct CM. Improvements in CM include conceptual problem solving (Diyana & Sutopo, 2024), mind maps (Anafitriani et al., 2019), and the cognitive conflict model-STEM (Nabila et al., 2025) for Newton's laws. These studies show that individual instructional approaches can address specific aspects of students' conceptual difficulties; however, they do not integrate a structured, reasoning-oriented learning model, an interdisciplinary and creative learning approach, and a digital tool for organizing conceptual relationships. Meanwhile, the clarity learning model (CLM) has been developed for critical thinking skills (CTS), which are significantly related to CM, indicating that students skilled in critical thinking have a higher level of CM than those who are less skilled (Rizki & Suprpto, 2024). CLM emphasizes learning activities through problem orientation, investigation, reasoning, clarification, evaluation, and reflection, which encourage students to connect prior knowledge with scientific concepts and construct rational arguments during learning (Saputro et al., 2022). Through these phases, students are guided not only to solve problems but also to analyze, justify, and systematically strengthen their conceptual understanding. Therefore, CLM can support students' concept mastery, especially when learning physics concepts such as Newton's laws that require a deep conceptual grasp.

CLM presents simulated and conceptual problems, as well as learning activities dominated by individual simulations (Saputro et al., 2022). Although these activities support students' reasoning and conceptual clarification, the original implementation of CLM does not explicitly emphasize interdisciplinary design activities that require students to apply physics concepts through authentic and creative products. Therefore, integrating the STEM approach could help address these limitations. By applying authentic problem-based projects, STEM can strengthen CLM with more contextual learning experiences

while encouraging students' mastery of concepts. Furthermore, integrating the arts into STEM learning transforms the approach into STEAM, which emphasizes not only scientific and technological problem-solving but also creativity, innovation, and design thinking in the learning process (Belbase et al., 2022). By encouraging students to express concepts creatively through designing and building items related to physics principles, the STEAM approach makes learning more engaging and relevant (Ellianawati et al., 2025). By integrating science, technology, engineering, the arts, and mathematics, students are inspired to link conceptual knowledge with creativity and practical applications, fostering deeper conceptual mastery and higher-order thinking abilities (Wannapiroon & Pimdee, 2022). This approach encourages students to connect physics concepts with phenomena occurring in nature, thereby developing their reasoning and logical thinking skills and enabling them to apply this knowledge in everyday contexts (Yusrizal, 2016).

The complexity of concepts in Newton's law material often fragments students' understanding, hindering concept integration and CTS development. Digital mind mapping (DMM) can address this complexity (Debbag et al., 2021) by showing relationships among ideas, facts, and information (Bhattacharya & Mohalik, 2020; Al-jaser, 2017). In addition, DMM enables students to organize concepts hierarchically and systematically, allowing them to connect prior knowledge with newly acquired information more effectively (Liu & Wang, 2024). Using DMM in physics learning also helps students simplify abstract concepts into more structured and meaningful representations, thereby facilitating concept retention and conceptual understanding. Furthermore, DMM can support CTS development by encouraging students to analyze, categorize, evaluate, and synthesize information as they construct mind maps. However, in this study, DMM is not intended merely as a visualization tool. Rather, DMM is positioned as a cognitive representation tool that connects the reasoning and conceptual clarification processes in CLM with the interdisciplinary knowledge and design experiences provided by STEAM. In this way, DMM helps students organize and connect concepts developed during investigation, reasoning, clarification, and STEAM-based activities into a coherent conceptual structure.

Integrating CLM, STEAM, and DMM addresses complementary aspects of students' conceptual learning rather than simply combining three separate instructional approaches.

CLM provides a structured process for investigation, reasoning, clarification, and evaluation, enabling students to examine and reconstruct their understanding of Newton's laws. STEAM extends this process by providing interdisciplinary and authentic learning experiences in which students apply physics concepts through problem solving, creative design, and practical activities. Meanwhile, DMM serves as a cognitive representation tool that helps students organize, connect, and visualize the concepts developed through reasoning and STEAM-based activities. Thus, CLM functions as the reasoning and conceptual clarification framework, STEAM provides opportunities for interdisciplinary application, and DMM supports knowledge organization and integration. Integrating these components is expected to provide a coherent learning process in which students investigate phenomena, reason from evidence, apply concepts in authentic contexts, and organize their understanding into connected conceptual structures.

Developing conceptual understanding through learning that integrates science, technology, engineering, the arts, and mathematics is also relevant to the Sustainable Development Goals (SDGs), particularly SDG 4 on quality education. SDG 4 emphasizes inclusive, high-quality education and the development of knowledge and skills relevant to students, including technical skills and competencies that support their future lives and careers (Adipat & Chotikapanich, 2022). In addition, Target 4.7 emphasizes ensuring that students acquire the knowledge and skills needed to support sustainable development (Holst et al., 2024). In this context, physics instruction that fosters conceptual mastery through investigative activities, problem-solving, design, creativity, and real-world application can help develop competencies relevant to education for sustainable development (Musengimana et al., 2025). Integrating CLM, STEAM, and DMM in teaching Newton's laws thus aims not only to improve physics learning outcomes but also to support the achievement of quality education goals by developing conceptual understanding and thinking skills applicable in various contexts.

Based on the above discussion, there remains a need to develop instructional approaches that address misconceptions about Newton's laws while facilitating knowledge integration through systematic, contextual, and multimodal activities. The CLM approach can foster reasoning and clarify concepts, while STEAM can broaden learning experiences by applying concepts in interdisciplinary activities and authentic problem-solving. On

the other hand, DMM can help students organize and visualize complex relationships between concepts. Integrating these three components could provide a more comprehensive approach to supporting mastery of Newton's laws than using each approach separately. However, studies that specifically integrate CLM, STEAM, and DMM to support conceptual mastery of Newton's laws remain limited. Therefore, empirical research is needed to test the effectiveness of this integration in improving students' conceptual mastery.

METHODS

This research used an embedded experimental design and a mixed-methods approach (Creswell, 2022). This research aims to determine how concept mastery of Newton's laws was affected by applying an integrated CLM with DMM assistance. The research was conducted in three main stages, systematically designed to obtain comprehensive quantitative and qualitative data. The following describes the research phases.

First was the qualitative stage before the experiment; the research began with qualitative steps prior to intervention, namely interviews with students about the learning process. These interviews aimed to gather preliminary information about students' conditions, their perceptions of prior learning, and the needs and obstacles they faced in understanding the material. The results of stage 1 served as the basis for designing the intervention as learning tools. The first

stage was followed by an experiment with an intervention stage that included a quantitative premeasure (pre-test), followed by qualitative interviews to analyze initial conceptual mastery of Newton's laws. Next, the intervention stage applied the CLM model with a STEAM approach, supported by DMM, in accordance with the learning design. Qualitative data were gathered by observation throughout the intervention (qualitative during the intervention stage). Following the intervention, a post-test using devices to gauge concept comprehension served as a quantitative postmeasure. The post-test aimed to assess how well pupils developed their skills after studying. The instrument consisted of 12 two-tier multiple-choice items covering Newton's First, Second, and Third Laws. For each Newton's law subtopic, four items were developed to assess the cognitive levels of C2 (understanding), C3 (applying), C4 (analyzing), and C5 (evaluating), resulting in four items for each subtopic and 12 items in total. Each two-tier item included a multiple-choice question in the first tier and a second tier requiring students to select the reason or explanation underlying their answer. This format assessed not only students' ability to select the correct answer but also their conceptual reasoning. The items were scored using the conceptual mastery scoring rubric developed by Coştu et al. (2007) for two-tier items, which considers students' responses to both tiers. The instrument demonstrated good reliability, with a Cronbach's alpha coefficient of 0.841. Table 1 shows the rubric.

Table 1. Concept Mastery Assessment Rubric

Category	Score
Correct answer, correct reasoning	3
Incorrect answer, correct reasoning	2
Correct answer, incorrect reasoning	1
Incorrect answer, incorrect reasoning	0

(Coştu et al., 2007)

Post-test interviews were then used to gather more qualitative data. The final stage involved collecting qualitative data through interviews to determine students' responses, perceptions, and learning experiences after participating in CLM-based learning integrated with STEAM, assisted by DMM. This data complemented the quantitative results and enriched the researchers' understanding of the model's effectiveness. The quantitative research stages used a nonequivalent (pretest-posttest) control-group design (Creswell & Creswell, 2023). The research design included two courses: an experimental class and a control

class. The experimental class used DMM to implement the STEAM-integrated CLM, whereas the control class used the CLM. The qualitative stage used phenomenological research, which covers four main elements (Moustakas, 2009): epoche, phenomenological reduction, imaginative variation, and synthesis of meanings and essences.

This study was conducted at a high school in Pamekasan Regency, East Java, in the 2025/2026 academic year. The study used in-person classroom instruction. All grade XI students at the high school were included in the study po-

pulation. To ensure each person in the population had an equal chance of being selected, the researchers used cluster random sampling (Lohr, 2021). The sample was selected using cluster random sampling, in which the class rather than the individual student was treated as the sampling unit. The researchers randomly selected two intact classes from the available classes at the participating school. The researchers selected the classes based on their enrollment in physics courses. One class, consisting of 35 students, was assigned as the experimental group and received the CLM integrated with STEAM and DMM, while the other class, also consisting of 35 students, was assigned as the control group and received CLM

without the STEAM and DMM integration. Thus, the total sample consisted of 70 students. Furthermore, the qualitative sample was selected using purposive sampling (Creswell & Creswell, 2023), selecting students with high, medium, and low scores based on pre-test and post-test results. With DMM as the aid, this selection seeks to investigate the many perspectives and experiences students have when engaging in CLM-based learning connected to STEAM.

The experimental class integrated CLM, STEAM, and DMM across the CLM phases, with each component serving a specific role in supporting students' conceptual mastery, as shown in Table 2.

Table 2. Integration of CLM, STEAM, DMM, and Conceptual Mastery

CLM	STEAM	DMM	Conceptual Mastery
Problem Orientation	Science Engineering	Draft 1	Understand
Investigation	Science Engineering Art Technology Mathematics	Draft 2	Understand, apply, analyze, evaluate
Reasoning	Science Mathematics		Analyze
Clarification and Evaluation	Science Mathematics		Analyze, apply
Reflection	Science Mathematics	Draft final	Evaluate

The intervention began with problem orientation, in which students examined contextual problems and developed an initial understanding of the relevant concepts. During investigation, students engaged in STEAM-based activities and developed the second DMM draft to organize emerging concepts. In the reasoning phase, students analyzed evidence and established relationships among physical quantities. During clarification and evaluation, students examined and evaluated their conceptual understanding. Finally, students reflected on the learning process and completed the final DMM to consolidate the relationships among concepts.

The research tools included observation sheets, interview procedures, and pre-test and post-test questions verified by construct and empirical tests with a reliability of 0.841 (extremely high). Meanwhile, the interview results were integrated with an independent-samples t-test, normalized gain (N-gain), and effect size

analysis. The independent-samples t-test determined whether students' conceptual mastery differed significantly between the experimental and control classes (Leech et al., 2005). This test was selected because the study involved two independent groups, each with one group, and the analysis focused on comparing mean conceptual mastery scores between the two groups (Leech et al., 2005). The independent-samples t-test was applied to the post-test scores to examine differences in students' conceptual mastery after the learning intervention. N-gain was used to determine the extent of improvement in students' conceptual mastery from pre-test to post-test, while effect size was used to determine the magnitude of the difference between the two groups. The interpretation of N-gain and effect size values followed the classification criteria. Table 3 presents the categories and criteria used to interpret the N-gain values obtained from the pre-test and post-test scores.

Table 3. N-gain Value Category

N-gain Value Category	Criteria
$N\text{-gain} \geq 0.7$	High
$0.3 \leq N\text{-gain} < 0.7$	Medium
$N\text{-gain} < 0.3$	Low

(Hake, 1998)

The N-gain classification describes the extent of improvement in students' conceptual mastery following the learning intervention. A higher N-gain value indicates a greater improvement

in conceptual mastery from pre-test to post-test. Table 4 presents the categories and criteria used to interpret the effect size values.

Table 4. Effect Size Categories

Effect size	Interpretation
0 – 0.20	Weak
0.21 – 0.50	Modest
0.51 – 1.00	Moderate
>1.00	Strong

(Cohen et al., 2002)

The effect size classification was used to determine the magnitude of the difference in conceptual mastery between the experimental and control classes. Thus, the effect size complements the independent-samples t-test by indicating the practical magnitude of the observed difference between the two groups.

The quantitative and qualitative data were analyzed separately and integrated during interpretation. Quantitative pre-test and post-test data were analyzed using an independent-samples t-test, N-Gain, and effect size to examine differences and learning improvement between the experimental and control groups. Interview data were analyzed qualitatively through data reduction, categorization, and interpretation to identify students' experiences and explanations related to the learning process and conceptual mastery. The qualitative findings were then compared with and used to explain the quantitative results, particularly the observed differences in students' conceptual mastery. Thus, the independent-samples t-test was applied only to the quantitative data, while the interview data served as qualitative evidence to contextualize and explain the quantitative findings.

The research flow consisted of five sequential stages: preliminary study, instrument development, research implementation, data analysis, and reporting and conclusion. The preliminary stage involved a literature review and interviews with students to identify problems in physics learning. The second stage involved developing and validating the research instruments. The third stage involved administering the pre-test, conducting initial interviews, implementing the CLM integrated with STEAM and supported by Digital Mind Mapping (DMM), conducting observations, and administering the post-test and final interviews. The fourth stage involved analyzing the data using an independent-samples t-test, N-Gain, and effect size, followed by data triangulation and data reduction. Finally, the fifth stage involved preparing the research report and drawing conclusions based on the research findings.

RESULTS AND DISCUSSION

The concept understanding scores were obtained from the pre-test and post-test scores on Newton's laws. Table 5 presents descriptive statistics for the pre-test concept understanding scores.

Table 5. Statistic Descriptive

Statistic	Control Classes		Experiment Classes	
	Pre-test	Post-test	Pre-test	Posttest
N	36	36	36	36
	32.29	58.75	33.69	76.08
SD	17.36	12.10	19.32	9.20

Table 5 demonstrates that the pre-test scores for the experimental and control groups are nearly identical, indicating that both groups have nearly equal starting proficiency with the idea. The control and experimental classes appear to have substantially different average post-test scores, with a difference of 17.33. Before conducting the independent-samples t-test, the assumptions of normality and homogeneity were examined. The Shapiro–Wilk test showed significance values of 0.349 for the control group and 0.367 for the experimental group for the pre-test scores, while the post-test scores yielded significance values of 0.109 and 0.083, respectively. All significance values were greater than 0.05, indicating that the pre-test and post-test data were normally distributed. The homogeneity test using Levene’s

test yielded significance values of 0.865 for the pre-test and 0.102 for the post-test. Since both values were greater than 0.05, the variances of the two groups were considered homogeneous. Furthermore, the initial equivalence test showed a p-value greater than 0.05, indicating no statistically significant difference in students’ conceptual mastery between the experimental and control groups before the intervention. Therefore, the assumptions for the parametric independent-samples t-test were satisfied, and the test was subsequently conducted to determine the difference in students’ conceptual mastery between the two groups after the intervention.

Furthermore, a parametric independent-samples t-test was conducted, as shown in Table 6, because the results met the prerequisites.

Table 6. T-test Results for Concept Understanding

Hypothesis testing		
Data	Significance	Conclusion
Post-test	0.000	Sig. 0.05 (there are differences)

Table 6 suggests that the significance value is less than 0.05. This suggests that the experimental and control groups differ significantly. This shows how the STEAM-integrated CLM learning approach supported by DMM affects students’ conceptual mastery. These findings show that, compared with the CLM model in the control class, the STEAM-integrated CLM model with DMM assistance in the experimental class yielded noticeably higher concept attainment. This is because the experimental class utilized the STEAM-integrated CLM model with DMM assistance, whereas the control class used the CLM model. Integrating STEAM and DMM

into the CLM syntax can bridge the gap between the abstract theory of Newton’s Laws and their practical application. Creating product miniatures and mapping ideas forces students to think more systematically, so their cognitive abilities to analyze and evaluate problems develop much faster (Beisly & Moffitt, 2025; Ismail, 2024) than in students who follow CLM without STEAM support and digital mind mapping tools.

The n-gain findings for the experimental class in the intermediate category (0.610) and the control class in the low category (0.301), as shown in Table 7, indicate that the experimental class performed better than the control class.

Table 7. N-gain Values for the Control and Experimental Classes

Statistic	Control Classes		Experiment Classes	
	Value	Category	Value	Category
N-gain	0.301	Medium	0.610	Medium

This significant difference shows that student involvement in designing, building, and evaluating products (STEAM) and synthesizing information digitally (DMM) creates a more in-depth learning experience. This leads to higher concept mastery in the experimental class than in the control class. In addition, DMM serves as a cognitive aid for visually mapping relationships between concepts. In contrast, in the control class, although students used the CLM model, their knowledge construction process was not supported by practical experiences and idea-or-

ganizing tools as comprehensive as those in the experimental class. The findings of this investigation are consistent with those of Yulianti et al. (2025) on temperature and heat through the STEAM approach, which shows that STEAM learning encourages students to understand concepts through contextual, visual, and applicable learning experiences, so that students not only memorize concepts but are also able to relate them to real phenomena. Similar results align with Satar et al. (2025) on science learning with digital mind mapping, which shows that digital

mind mapping can enhance students' mastery of concepts through visual, systematic organization of information. Therefore, applying the integrated CLM model with STEAM, supported by DMM, reinforces previous findings that this intervention effectively improves mastery of Newton's Law concepts. This finding lies not merely in demonstrating that STEAM can improve conceptual mastery, but in showing the added value of integrating STEAM and DMM within the CLM framework for Newton's laws. Previous studies have shown STEAM's contribution to students' conceptual understanding and conceptual change, while research on concept mapping has separately shown positive effects on science achievement. However, the present study combines the structured reasoning stages of CLM, the interdisciplinary and product-oriented experiences of STEAM, and the visual organization

of knowledge through DMM within a single learning intervention. The significantly higher post-test performance and the medium N-gain obtained by the experimental group therefore provide empirical evidence that this integrated configuration can strengthen conceptual mastery beyond implementing CLM alone. This finding extends previous research by demonstrating that the complementary functions of the three components can be applied specifically to the conceptually challenging topic of Newton's laws, rather than examining STEAM or mind mapping as isolated instructional strategies.

Differences in Conceptual Mastery Across Cognitive Levels

N-gain value for each concept proficiency indicator was analyzed; the results are shown in Table 8.

Table 8. N-Gain Score for Concept Mastery

Indicator	Control classes		Experimental Classes	
	Value	Category	Value	Category
C2 (understand)	0.433	Medium	0.745	High
C3 (apply)	0.458	Medium	0.669	Medium
C4 (analyze)	0.377	Medium	0.549	Medium
C5 (evaluate)	0.236	Low	0.610	Medium

Based on Table 8, the experimental class's average n-gain was generally higher than that of the control classes. The average n-gain for each indicator of concept mastery through the integrated CLM-STEAM model assisted by DMM increased concept mastery across all indicators, especially in the experimental class. For the understanding indicator (C2), the experimental class's n-gain was 0.745, falling in the high range. By contrast, the control group received only a modest score of 0.433. The significant difference in n-gain values shows that CLM integrated with STEAM, supported by DMM, is more effective in helping students build their understanding of Newton's laws. This improvement was driven by screening apersepsi videos, problem videos, and technology application videos that required students to interpret physical phenomena and explain them in their own words. Through these activities, students not only memorized the laws and formulas but also began to understand the meaning of force, mass, and acceleration, and their relevance in real-life situations. The DMM draft 1 also helped students organize basic concepts visually, making their initial understanding more structured and meaningful.

In contrast, the control class had minimal visual activities, resulting in lower N-Gain C2 scores. Before implementing the learning model, many students struggled to explain Newton's laws in their own words. Most students memorized the laws and formulas but could not relate them to everyday phenomena. For example, when asked why an object can move faster if the applied force is greater, or why the body feels pushed backward when the bus suddenly moves forward, students often responded with explanations that lacked a clear understanding of the connection between force, mass, and acceleration. A similar pattern also emerged when students were asked to explain force interactions; they often stated "there is an action-reaction force" without being able to describe the actual force pairs that occur. This study is in line with Rachmayati et al. (2020) on Pascal's Law through STEM-Project Scientific Inquiry, because students are actively involved in observing phenomena, so that conceptual understanding is not only rote memorization, but is formed in a meaningful way.

Regarding indicator C3, the experimental class achieved an n-gain value of 0.669, which falls in the moderate category. Meanwhile, the

experimental class's n-gain value was 0.669, falling into the moderate range. The control group, on the other hand, only received a score of 0.458, which falls into the medium range. This occurred because students were consistently trained to use Newton's law concepts in various learning contexts. Practical activities, miniature product creation, problem solving, and poster design encouraged students to apply physics concepts and formulas in calculations and product design. In addition, DMM draft 2 helped students connect concepts to the results of investigations and experimental activities, so their application of concepts was not mechanical but based on understanding through the activities carried out. In the control class, although students also worked on problems and practical work, the activities in the learning process were still more complex than in the experimental class, so their ability to apply concepts did not develop optimally. Thus, this series of activities integrately encouraged students to optimally master Newton's Law concepts because students not only memorized formulas but also built conceptual understanding through direct experience, problem solving, and visual representation of concepts, which proved to be effective in improving concept mastery in

science learning (Amanda et al., 2022; Kefalis et al., 2025). These findings align with Saleh et al. (2020) on Newton's laws using the STEM-project model, which show that student involvement in project-based activities can improve conceptual mastery.

On the analysis indicator (C4), the experimental class's n-gain value was 0.549, falling into the moderate range. The control group, by contrast, scored 0.377, also in the moderate range. Although the learning exercises required students to identify correlations between variables and do in-depth studies of physical events, the experimental group's n-gain value was higher than the control group's. Activities such as formulating hypotheses, searching for literature, analyzing practical results, designing several alternative miniature product designs, and presenting work results encouraged students to compare theory with empirical results and examine the advantages and limitations of each solution. Using DMM draft 2 and DMM final helped students map cause-and-effect relationships between concepts, so their ability to analyze Newton's Law concepts developed systematically; Figure 1 shows an illustration of the DMM created by the students.

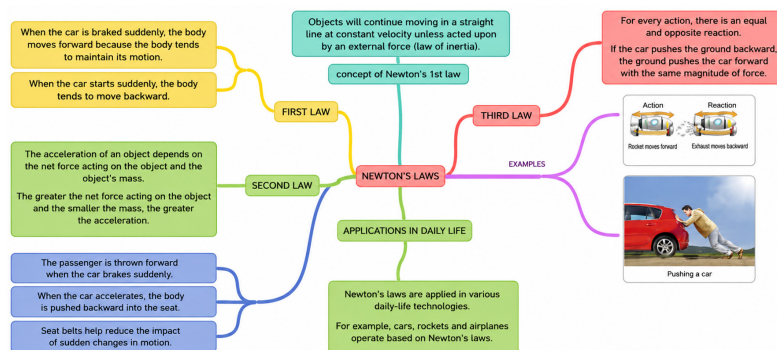


Figure 1. An Illustration of the DMM Created by The Students

In contrast, the control class did not carry out activities to design several alternatives and a DMM, so their analytical skills did not develop optimally. In this indicator, students' ability to analyze Newton's law concepts is demonstrated through their ability to describe the relationship between force, mass, and acceleration in a phenomenon. In addition, students can identify conceptual errors in a situation, such as distinguishing between action-reaction pairs and forces acting on a single object. The findings of this study are consistent with Hanif et al. (2019) on light and optics using STEM-project-based learning, which show that student involvement in project-based activities can significantly improve students' ability

to analyze concepts. Thus, CLM learning integrated with STEAM, supported by digital mind mapping, effectively develops students' analytical skills (C4).

In the evaluation indicator (C5), the experimental class's n-gain value was 0.610, falling into the moderate range. By contrast, the control group had a low result of 0.236. This shows that students in the experimental class could evaluate the learning process and results using scientific criteria. Activities such as choosing the best design from several alternatives, testing and modifying products, evaluating practicum results, defending arguments during presentations, and reflecting through the final DMM encouraged stu-

dents to assess the suitability of concepts against the results obtained and provide logical reasons for their decisions. These reflective activities helped students realize the strengths and limitations of their understanding, thereby deepening their mastery of the concepts. In the control class, the limitations of evaluative activities meant that students were rarely trained to critically assess and reflect on their learning outcomes, resulting in relatively lower C5 indicator achievement. Thus, student involvement in the evaluative, argumentative, and reflective processes encourages optimal mastery of concepts, as students assess the suitability of theoretical concepts and empirical results and revise their understanding based on evidence (Zhou et al., 2025; Divena et al., 2021).

An important contribution of the present findings is the differentiated improvement across the C2–C5 indicators. The experimental group achieved its highest N-gain at C2 (0.745), followed by C3 (0.669), C5 (0.610), and C4 (0.549). This pattern suggests that the intervention was particularly effective in helping students reconstruct and understand conceptual meanings before progressing toward higher-order applications, analysis, and evaluation. The relatively lower gain at C4 indicates that analyzing complex relationships among force, mass, acceleration, and interaction pairs remains more demanding, even with project-based and visual learning experiences. This finding adds an important dimension to previous STEAM research because it shows that the effective-

ness of an integrated intervention should be interpreted not only through overall achievement, but also through the cognitive level at which conceptual improvement occurs. Recent research has similarly emphasized conceptual change as a gradual process in which students move from non-canonical understanding toward more scientifically coherent explanations. The indicator-level findings also show how the proposed integration works pedagogically. CLM primarily structures students' reasoning and clarification processes (Saputro et al., 2022), STEAM provides opportunities to apply and test concepts through authentic design activities (Leavy et al., 2023), and DMM externalizes relationships among concepts visually (Wu & Chen, 2025). The increasing N-gain from the experimental group across C2–C5 therefore suggests that these components may function complementarily rather than merely additively. In particular, the C4 and C5 activities required students to compare alternative product designs, interpret experimental evidence, justify decisions, and revise their understanding (Schwchow et al., 2022), which may explain why the experimental group maintained higher gains than the control group even at more complex cognitive levels.

Differences in Conceptual Mastery Across Newton's Laws

The N-gain values for each subtopic are shown in Table 9.

Table 9. Subtopic Concept Mastery N-Gain Score

Subtopic	Control classes		Experimental Classes	
	Value	Category	Value	Category
Newton's first law	0.462	Medium	0.699	Medium
Newton's second law	0.272	Low	0.639	Medium
Newton's third law	0.319	Medium	0.616	Medium

Based on Table 9, the average n-gain in each sub-material through the application of the integrated CLM model assisted by DMM provided an increase in concept mastery in all sub-materials, especially in the experimental class. The experimental class's n-gain value in Newton's first law sub-material was 0.699, while the control class's was 0.462, both of which were categorized as moderate. The experimental class had a greater n-gain value while being in the same category. This improvement was influenced by a series of learning activities that emphasized understanding phenomena through screening apersepsi videos, problem videos, and technology application videos that helped students visualize the concept

of inertia in everyday life. The activities of formulating hypotheses, searching for literature, and conducting practical work further encouraged students to relate resultant force to the conditions of objects at rest or moving in a straight line. Preparing DMM draft 1, draft 2, and the final DMM helped students organize concepts in stages, so their understanding of Newton's first law was not merely rote memorization but was developed conceptually and structurally. Conversely, in the control class that used the CLM model without STEAM and DMM, the limited use of visual media and concept mapping resulted in less profound understanding of inertia, despite increased concept mastery after learning. Thus, students in

the experimental class were better able to explain the logical reasons why objects maintain their state of rest or uniform linear motion through systematic idea mapping than the control class. The results align with Utami & Nurlaela (2021) on Newton's laws through STEM learning, which shows that STEM-based learning encourages students to understand inertia conceptually and contextually through active involvement in observing phenomena, analyzing problems, and relating physics concepts to real-life situations. These consistent findings confirm that integrating the STEAM approach helps pupils develop a logical, organized understanding of the fundamental ideas of Newton's first law when supported by visual aids like DMM.

The experimental class's n-gain value in the Newton's second law subtopic was 0.639, falling into the moderate range. The control group, by contrast, had a low result of 0.236. This resulted from educational exercises that highlighted the connection between force, mass, and acceleration by screening issue-and-technology application movies, which helped students understand the causal relationship between variables. Formulating hypotheses, searching the literature, and conducting Atwood machine practicums gave students opportunities to test the effects of force and mass on acceleration empirically, so they did not understand the concepts abstractly. Preparing DMM draft 2 played an important role in linking theoretical concepts with investigation results and experimental activities, so that applying concepts was not mechanical but grounded in an understanding of the problem context. In the control class, although students conducted the same practicum, the absence of contextual videos and DMM led them to focus on procedures and calculations, so their mastery of Newton's second law concepts did not develop optimally. The results align with Addido et al. (2023) on Newton's second law through STEM-based learning with robots, which shows that student involvement in technology- and engineering-based activities can significantly improve mastery of concepts in the sub-material of Newton's second law. Thus, STEM-based learning that emphasizes active, contextual engagement has been shown to improve mastery of physics concepts, particularly in Newton's Second Law material.

The experimental class's n-gain value for Newton's third law was 0.616, while the control class's was 0.319; both were categorized as moderate. Although both groups fell into the same category, the experimental class showed a significantly higher N-gain value. This was influenced

by the full integration of the STEAM approach through the activity of making miniature boats without engines, which included designing several alternative designs, selecting a design, making and testing the product, modifying it, and preparing posters and presentations. Through this activity, students directly observed and analyzed the action-reaction pairs at work on the boats, gaining a concrete, contextual understanding of Newton's third law. The practicum and product-creation activities, reinforced by the final DMM and reflection, helped students evaluate the concept's suitability against the product test results. In the modification activity, students who initially used only balloons to propel the boat then added rubber and sticks to make the boat move faster and more stably. This modification demonstrates the application of art in the STEAM approach, where aesthetic value not only appears as a visual display but is also integrated with scientific concepts, particularly Newton's third law. The design changes reflect the students' understanding of the action-reaction principle, as they added components to optimize the reaction force generated, improving the boat's performance. In contrast, in the control class, which did not involve product design and manufacturing activities, the students' understanding of the action-reaction concept tended to be theoretical and less contextual. The results align with Yulianti et al. (2025) on temperature and heat through the STEAM approach; this demonstrates how incorporating artistic components into science instruction may inspire pupils to develop conceptual understanding through design, modification, and reflection.

The comparison across the three Newtonian laws further indicates the contribution of the integrated intervention. Although the experimental group achieved higher N-gain values than the control group across Newton's first, second, and third laws, the learning mechanisms underlying these improvements differed according to the conceptual characteristics of each law. Newton's first law benefited from contextual visualization and progressive DMM construction, Newton's second law from empirical investigation of the relationships among force, mass, and acceleration, and Newton's third law from designing, testing, and modifying a physical product. This finding suggests that the strength of CLM-STEAM-DMM integration is not limited to a particular Newtonian concept but lies in its capacity to connect different types of conceptual difficulty with appropriate forms of investigation, design, representation, and reflection. Such an integrated pattern extends previous studies that have gene-

rally examined STEAM or concept mapping as individual instructional approaches (Corrigan et al., 2025). Recent evidence indicates that concept mapping can support the visualization of conceptual structures and conceptual change, while STEAM can facilitate conceptual understanding through interdisciplinary and experiential learning. This study advances the literature by sho-

wing how these functions can be coordinated within a CLM learning sequence and applied across the three Newtonian laws.

Magnitude of the Treatment Effect

Table 10 presents the effect size results for the concept mastery variable.

Table 10. Cohen’s d Results Concept mastery

Variable	Cohen’s d	Interpretation
Concept mastery	1.6	Strong effect

According to the effect size results presented in Table 10, Cohen’s d was 1.6, indicating a large effect of the intervention on students’ conceptual mastery. Because both the experimental and control groups received CLM, and the experimental group also received the integrated STEAM and DMM components, the observed difference should be interpreted as the effect of the integrated instructional approach rather than the independent effect of any single component. The large effect size suggests that the integrated intervention was associated with a substantial difference in students’ conceptual mastery between the two groups. However, the present research design does not allow the separate contribution of STEAM or DMM to be determined because these components were implemented simultaneously within the experimental treatment. The improvement in conceptual mastery can be understood in relation to the learning sequence provided by the integrated intervention. Students were not only exposed to conceptual explanations but were engaged in investigating phenomena, reasoning from evidence, clarifying their initial conceptions, applying physics concepts in interdisciplinary activities, and organizing relationships among concepts through DMM. These activities gave students opportunities to connect qualitative explanations, mathematical relationships, experimental evidence, and contextual applications of Newton’s laws. Therefore, the findings suggest that integrating CLM, STEAM, and DMM as a coherent instructional sequence was associated with substantial improvement in conceptual mastery, while the relative contribution of each component remains an issue for further investigation.

The contribution of this integration lies in the complementary roles of the three components within a coherent learning sequence, in which CLM guides students through investigation, reasoning, clarification, evaluation, and reflection, STEAM provides opportunities for authentic and interdisciplinary application of physics concepts,

and DMM helps students organize and connect the concepts developed throughout the learning process. The findings indicate that this integrated approach can enhance students’ conceptual mastery and provide a learning experience that goes beyond formula-based problem solving toward conceptual reasoning, application, and knowledge organization. Practically, the findings suggest that physics teachers can integrate structured reasoning, STEAM-based activities, and digital mind mapping when teaching conceptually complex topics such as Newton’s laws. At the same time, researchers can further examine this approach across different physics topics, educational levels, and learning contexts.

Although these findings are promising, this study has limitations worth considering. Although DMM was used throughout the learning process through the development of initial drafts, subsequent drafts, and final mind maps, this study primarily examined its contribution through students’ conceptual mastery scores, rather than by systematically analyzing the development and quality of the DMM products themselves. Therefore, the extent to which changes in students’ conceptual representations through DMMs contribute to their conceptual mastery cannot be fully identified. Furthermore, researchers should pay close attention to the stages of engineering, particularly the product modification stage, as this constitutes the core activity of the engineering design process. Consequently, future research should examine the development of students’ DMMs from the initial to the final version and systematically analyze the relationship between the quality of their conceptual maps and their conceptual mastery, while consistently paying attention to the details of the STEAM stages.

CONCLUSION

The findings indicate that integrating the Clarity Learning Model (CLM), STEAM, and Digital

Mind Mapping (DMM) was associated with improved students' conceptual mastery of Newton's laws. Students achieved a medium N-gain of 0.610, and the independent-samples t-test indicated a significant difference in conceptual mastery between the experimental and control groups. The Cohen's d value of 1.6 indicated a large effect of the integrated intervention. Qualitative findings from student interviews further supported the quantitative results, showing that students could explain Newton's laws and describe their learning experiences involving investigation, STEAM-based activities, reasoning, clarification, evaluation, and reflection. These findings suggest that the integrated approach provided a coherent learning experience that supported students' conceptual understanding beyond formula-based learning. However, the study did not separately examine DMM's contribution through systematic analysis of the development and quality of students' mind maps. Future research should therefore examine the evolution of DMM products from initial to final versions to provide deeper evidence regarding students' conceptual development.

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