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Energy Conservation and Students Collaborative Skills Analysis Through Car Experiments in Junior High School

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ABSTRACT

Many studies develop laboratory activities or worksheets on specific topics and on one of the 21st-century skills, but not on energy or collaboration. This research aims to provide comprehensive insights into the experiment on energy materials and students' collaboration skills during the experiment. The method of this research was the experiment-based practicum learning (EBPL) method. This study found that to pass through the loop successfully, a car must meet the 5gR rule. Although the law of conservation of energy states that the total mechanical energy at the bottom must equal the sum of the kinetic and potential energy at the top, in real life there is a decrease in the top of the loop due to non-conservative forces such as friction and air resistance. Moreover, the average across all measured indicators of student collaboration skills is 84.5%, which is categorized as a very high level. In conclusion, the hands-on laboratory experiment combined with tracker video analysis successfully engaged students in collaborative scientific practices and fostered the development of essential teamwork competencies.

Keywords : Energy; Students' Collaboration Skills; Laboratory Experiment; Science

I. INTRODUCTION

Understanding key physics concepts, particularly the laws of energy, such as Kinetic Energy, Potential Energy, and Mechanical Energy, is essential for developing scientific literacy and is a basic requirement for studying advanced science [1]. These energy concepts are crucial for analyzing how real-world systems function. However, these ideas are often taught using abstract models and mathematical formulas. This approach commonly results in students having difficulty and developing persistent misconceptions when instruction is based on traditional teaching methods that make students passive listeners [2].

Modern educational standards also emphasize the need to teach 21st-Century Skills alongside academic content. Among these skills, the ability to collaborate is important. Collaboration enables students to work effectively in teams, clearly communicate their ideas, and solve complex scientific and engineering challenges, which are necessary in professional fields. The science laboratory activity is an ideal, practical, and social setting for developing collaboration skills [3]. The primary challenge for science educators is to find teaching

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methods that successfully ensure students deeply understand complex topics like energy while simultaneously and intentionally cultivating and assessing necessary collaborative skills.

Conventional methods for teaching science, which typically involve a teacher delivering lectures followed by simple, fixed-procedure laboratory exercises, are often ineffective in two major ways. First, regarding conceptual understanding, these approaches fail to provide students with the necessary hands-on, investigative context required to build a strong, practical grasp of energy conservation and transformation. Consequently, the learning achieved is often superficial and short-lived. Second, concerning the development of skills, even when students work in groups, traditional lab formats usually lack the structured collaborative tasks and reliable assessment tools needed to evaluate teamwork. This means that the development of essential collaborative skills happens merely by accident rather than being a planned and measurable outcome of the instruction [4].

The previous research about experiment-based practicum learning method has been conducted. Haerani et al. [5] conducted a study to develop the experiment-based physics worksheet in science and how such experimental-based worksheet could contribute to developing students' science process skills. Similarly, Basir et al. [6] employed magnetic induction and force practicum tools and proved its effectiveness in improving science process skills. Additionally, Fayanto et al. [7] in their study of guided experiment implementation investigates the impact on students' engagement and motivation with controlling self-regulation. However, in current educational research concerning teaching models there is no successful combination of the assessment of difficult academic topics like understanding Mechanical Energy and within one teaching approach.

Although existing research provides valuable insights, many studies develop laboratory activities or worksheets on specific topics and one of the 21st-century skills, but not on the topics of energy and collaboration skills. This study offers a new perspective by implementing experiment-based practicum learning methods in improving students' collaboration skills. Furthermore, previous research by Basir et al. [6] focuses on a physics subject, such as force and science process skills. By filling these gaps, this research aims to provide comprehensive insights in the experiment of energy material and students' collaboration skills while doing the experiment. Understanding how experiments conducted in the topic of energy are crucial for enhancing teaching strategies and fostering collaboration skills among students in science learning.

This research analyzes the result of the experiment with the title "It's Race Day" in energy material using tracker analysis. In addition, we also investigated the effect of students' collaboration skills after doing the experiment. The result of this study can provide an overview to the stakeholders in the field of science education including teachers, researchers, and others on the practicum learning of energy topic.

II. METHOD

The method of this research was experiment-based practicum learning (EBPL) method on energy material which was conducted in class 9th grade students at junior high school level. This method is based on the idea that students actively build their own knowledge through experience [8]. Instead of just confirming known principles, the EBPL requires students to design, carry out, and analyze their own experiments to discover scientific rules. This deep involvement in the experimental process for example, measuring the energy variables in a roller coaster-like, forces students to directly deal with abstract concepts, leading to a strong change in their understanding. Moreover, the EBPL model is designed to naturally promote collaboration [9]. It demands that students share responsibility, handle equipment together, divide up the work for data collection, and reach a collective agreement on their findings. This structured dependence ensures that collaboration is essential for successfully completing the task, making the practicum an excellent setting for intentionally assessing teamwork skills.

The collaboration skills were determined using questionnaires which were developed by Faize et al. [10]. The students choose the answer that best matches their experience or opinion when working together to complete the experiment. Each statement has five options: Never, Rarely, Sometimes, Often, and Always. The statements consisting in the questionnaire are all positive statements. Student responses were analyzed using a Likert scale. The scale is from one to five sequentially followed the options.

Percentage of each instrument item numbers obtained by the formula:

$$Percentage = \frac{Total\ score\ of\ students'\ answer}{Ideal\ score} \times 100\%$$

The percentage of students will be categorized based on [11], as shown in Table 1.

Table 1. Students Response Categorization

Percentage (%)	Category
80 – 100	Very High
60 – 79	High
40 – 59	Enough
20 – 39	Low

(Source: Ref [11])

This practicum activity is a part of energy material lesson, specifically discussing kinetic energy, potential energy, and mechanical energy. Energy cannot be created or destroyed, it is always conserved and can change from one form to another. Kinetic energy is energy in moving objects. Moreover, potential energy is the energy of objects due to their position and/or shape. While mechanical energy is the sum of kinetic energy and potential energy. Table 2 shown the core and supplement outcomes based on Cambridge syllabus.

Table 2. Syllabus Outcome

Core	Supplement
State that energy may be stored as kinetic, gravitational potential, chemical, elastic (strain), nuclear, electrostatic and internal (thermal)	Recall and use the equation for kinetic energy $E_k = \frac{1}{2}mv^2$
Describe how energy is transferred between stores during events and processes, including examples of transfer by forces (mechanical work done), electrical currents (electrical work done), heating, and by electromagnetic, sound and other waves	Recall and use the equation for the change in gravitational potential energy $\Delta E_p = mg\Delta h$
Know the principle of the conservation of enegy and apply this principle to simple	Know the principle of the conservation of energy and apply this principle to

Core	Supplement
examples including the interpretation of simple flow diagrams	complex examples involving multiple stages, including the interpretation of Sankey diagrams

There are several equations will apply to the calculation of energy, including
Kinetic energy

$$E_k = \frac{1}{2}mv^2 \qquad (1)$$

Potential energy

$$E_p = mg2R \qquad (2)$$

Mechanical energy

$$E_m = E_k + E_p \qquad (3)$$

Note:
Ek : Kinetic energy (J)
Ep : Potential energy (J)
Em : Mechanical energy (J)
m : mass of the object (kg)
v : velocity or speed (m/s)
g : gravitational force (m/s^2)
R : radius to the loop (m)

This practicum conducted by 6 groups with 4–5 students in each group. The practicum was carried out in 2–3 lesson hours (70–105 minutes) to complete. Each object used in the experiment was tested at least three times to obtain reliable and valid results. Since there are four objects used by students in the experiment, this means that students conduct the experiment at least 12 times.

Preparing the Materials

This research needs several tools and materials which are a camera, tripod, toy car, toy car's track, digital balance, tape measure, and tracker analysis. These materials are shown in Figure 1.

(a) (b) (c) (d)

Fig. 1. Tools and Materials (a) Track (b) Toy car (c) Measuring tape and (d) Analytical Balance

The toy car track used must have a launcher and be able to form a loop. This is done so that the cars launched have the same energy and maintain the same condition for all the objects. The loop is useful for explaining in more detail the energy contained in toy cars.

Variables

The experiment contains three kinds of variables which are independent, dependent, and controlled. Those variables are detailed in Table 3.

Table 3. Experiment Variable

Variable	Details
Independent	Mass of the car
Dependent	Kinetic energy, potential energy, and mechanical energy
Control	Height of the loop and track length

Procedures

The development of the experiment was started from September─November 2025. After several trials, the experiment was completely developed. The flowchart of the experiment work is shown in Figure 2.

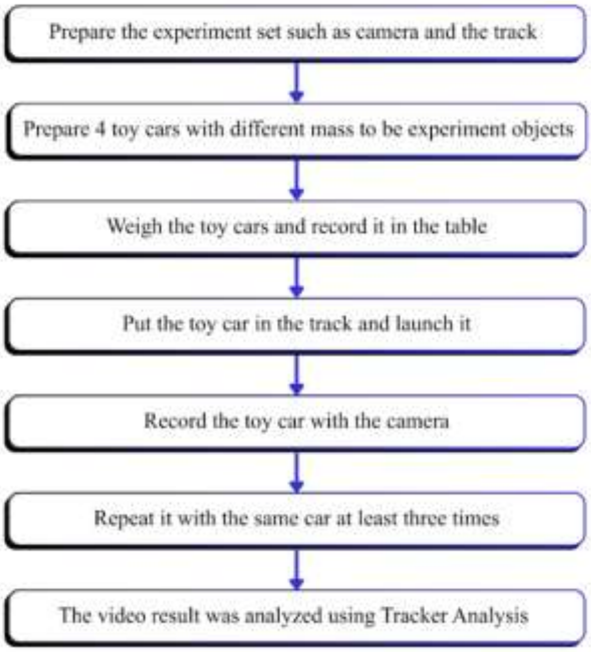

Fig. 2. Flow chart of energy experiment work steps

The outcomes of the observation are recorded in the student worksheets distributed by the teacher. The student worksheet functions as a pedagogical tool, supplying material and procedural instructions for the students. The worksheet consists of 10 pages consisting of a cover containing experiment title and group identity; the next page contains precautions, objectives, introduction, tools and materials, theory, variables, hypothesis, procedures, data analysis in table and graph, calculation, questions, discussion, and conclusion. The first two pages of the worksheet can be seen in Figure 3. The contents of the worksheet have been judged and assessed by two experts. This is important to do before implementing with students to establish content validity, reduce individual bias, and improve the credibility and reliability of the instrument to ensure the items are relevant, clear, and aligned with the intended learning objectives [12].

Fig. 3. Experiment Worksheet

III. RESULTS AND DISCUSSION

Energy Transformations

The experiment used in this study was implemented the law of conservation of energy. The law of conservation of energy states that energy is always conserved and can change from one form to another. During each transformation of energy, the total amount of energy remains constant, which means that loss of potential energy equals to the gain of kinetic energy and vice versa.

To calculate the energy produced in each trial using different mass, the toy car mass, radius to the loop, gravitational acceleration, and track length must be determined. The results of each measurement are shown in Table 4.

Table 4. Measurement Result

No.	Measurement	Result
1.	Mass of the car	7.74 gram; 10.74 gram; 13.74 gram; 16.74 gram
2.	Radius to the loop	10.5 cm
3.	Gravitational acceleration	9.8 m/s2
4.	Track length	82 cm

To get the precise velocity of the toy car in each point, this study used Tracker Video Analysis software as seen in Figure 4. Beside velocity, Video Tracker Analysis also can determine the precise acceleration, time, even kinetic energy.

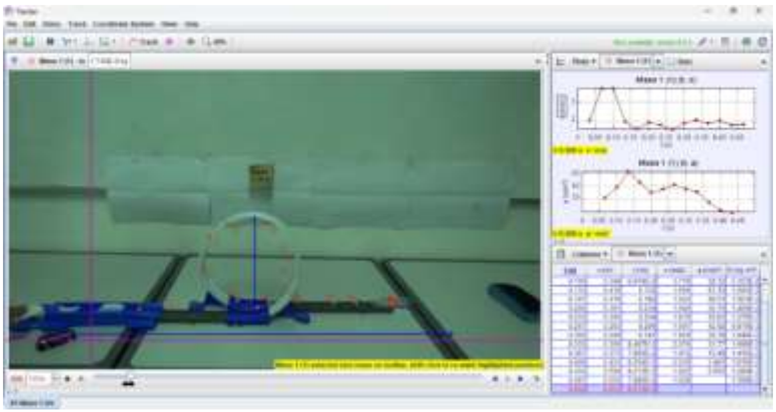

Fig. 4. Analysis on tracker analysis

Furthermore, the illustration of the science principle in the experiment can be seen in Figure 5. There are 3 points in this experiment.

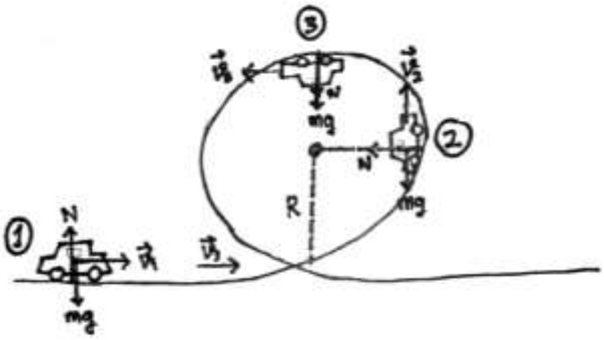

Fig. 5. Science principle in the experiment

The velocity of a toy car when it is launched from the launcher and is still on a flat surface can be likened to v_1. While the velocity of a toy car when it is on top of the loop can be likened to v_3. In addition to kinetic, potential, and mechanical energy, this experiment also applies Newton's laws. Point 1 in the illustration implement the Newton's first law and kinetic energy. The First Newton's Law is implemented in this situation because the toy car remains silent before it has been launched. It can be said in mathematical way as $\sum F_y = 0$ with $N = mg$.

The scientific principles used in point 2, as shown in the illustration, are Newton's second law and mechanical energy. The Second Newton's Law stated that the acceleration of an object is directly proportional to the net force acting on it and inversely proportional to its mass. In mathematical way it can be expressed as $\sum F_x = ma$ with $N = ma_{sp}$ so that $N = m\frac{v^2}{R}$.

Moreover, the analysis of point 3 relies on Newton's second law for analyze the acceleration in that point. So,

$$\sum F_y = ma_{sp}$$
$$mg = m\frac{{v_3}^2}{R}$$
$$g = \frac{{v_3}^2}{R}$$
$${v_3}^2 = gR$$

so that without friction $v_3 = \sqrt{gR}$ and with friction $v_3 > \sqrt{gR}$.

The Critical Velocity

A key objective of this experiment was to evaluate the "Critical Velocity" (v_3) required at the apex of a vertical loop to prevent the toy car from losing contact with the track. According to the principles of circular motion, the car stays on its path when the sum of downward forces consist of Gravity (mg) and Normal Force (N) equals the required centripetal force ($\frac{mv^2}{R}$). The "critical limit" occurs at the moment the car is about to fall, where N drops to zero and gravity alone maintains the circular acceleration. Mathematically, this simplifies to v_3 = gR. For the experimental loop radius of 0.105 m, the theoretical minimum speed at the top is approximately 1.01 m/s.

To achieve this critical velocity at the top, the car must begin at the bottom with a significantly higher initial speed (v_1) to compensate for the climb against gravity. By applying the Law of Conservation of Energy, the total mechanical energy at the bottom ($\frac{1}{2}mv_1{}^2$) must equal the sum of kinetic and potential energy at the top ($\frac{1}{2}mv_3{}^2 + mg2R$). Substituting the critical velocity into this energy balance yields the "5gR rule", which establishes a theoretical safety margin of approximately 2.26 m/s for the starting velocity. This threshold ensures the car has a sufficient "energy budget" to reach the height of the loop while maintaining enough speed to stay pinned to the track (Klobus, 2011).

$$K_1 = K_3 + P_3$$
$$\frac{1}{2}mv_1{}^2 = \frac{1}{2}mv_3{}^2 + mg2R$$
$$v_1{}^2 = v_3{}^2 + 4gR$$
$$v_1{}^2 = gR + 4gR$$
$$v_1{}^2 = 5gR$$
$$v_1 = \sqrt{5gR}$$

Experimental results validated these principles, though real-world variables introduced notable deviations. As shown in Table 5, cars that failed to complete the loop, such as Car 4, consistently exhibited velocities at the apex below the 1.01 m/s threshold. Notably, despite having an initial velocity higher than the theoretical 5gR, car with mass 4 failed because its larger mass increased the normal force at the entry of the loop, resulting in higher work done by friction. This indicates that while mass cancels out in ideal formulas, it significantly affects energy decay in practice, requiring a higher safety margin for heavier vehicles to complete the circular path [13].

Table 5. Experimental Trial Data

No.	Mass of The Car (kg)	Velocity at Bottom (v_1) (m/s)	Velocity at Top (v_3) (m/s)	Loop Status
1.	0.00774	4.29	2.06	Success
2.	0.01074	3.99	1.22	Success
3.	0.01374	3.56	1.35	Success
4.	0.01674	3.31	0.00	Failed

Mechanical Energy Conservation Analysis

The experimental results demonstrate a dynamic exchange between Kinetic Energy (K) and Gravitational Potential Energy (P) as the toy car traverses the track. At the starting position (Point 1), the car's energy is entirely kinetic. As the car ascends the loop, its velocity decreases as K is converted into P.

The data in Table 6 shows that while the types of energy shift, the total Mechanical Energy remains relatively constant, although with a decrease at the top of the loop. This reduction is attributed to non-conservative forces such as friction and air resistance [14].

Table 6. Mechanical Energy Comparison

Car	Point	Height (m)	Velocity (m/s)	Potential Energy (J)	Kinetic Energy (J)	Mechanical Energy (J)
1	Bottom (1)	0.00	4.29	0.00	0.07	0.07
	Top (3)	0.21	2.06	0.02	0.02	0.04
2	Bottom (1)	0.00	3.99	0.00	0.09	0.09
	Top (3)	0.21	1.22	0.02	0.01	0.03
3	Bottom (1)	0.00	3.56	0.00	0.09	0.09

Car	Point	Height (m)	Velocity (m/s)	Potential Energy (J)	Kinetic Energy (J)	Mechanical Energy (J)
4	Top (3)	0.21	1.35	0.03	0.01	0.04
	Bottom (1)	0.00	3.20	0.00	0.09	0.09
	Top (3)	0.21	0.00	0.03	0.00	0.03

Student Collaboration Skills

Student collaboration skills in this research was determined by a questionnaire. The questionnaire consists of five indicators with seventeen statements. A total of 25 students filled out the questionnaire after the experiment was conducted. The experiment implementation can be seen in Figure 6.

Fig. 6. Experiment implementation

Furthermore, Table 7 shows the percentage of students' response and its category in each indicator. The high performance across all indicators suggests that the interactive, hands-on nature of laboratory experiments, particularly when combined with analytical tools such as tracker video analysis creates authentic contexts where collaboration is both necessary and naturally reinforced [15]. These findings contribute to the growing body of research demonstrating that laboratory-based inquiry activities effectively foster the development of collaborative competencies in secondary students.

Table 7. Student's Collaboration Skills Relate to the Experimental Activity

No.	Indicators	Percentage of Student Collaboration Skills (%)	Category
1.	Communication	80.0	Very High
2.	Team support	89.0	Very High
3.	Learning orientation	85.6	Very High
4.	Participation/roles	86.1	Very High
5.	Conflict resolution	81.6	Very High
	Average	84.5	Very High

There were 80% of students responded in the communication indicator. This happened them in the very high group. This result aligns with research highlighting the critical role of dialogue in laboratory environments. To create good collaboration within a group, good communication is also necessary. The communication in the experimental activity including share ideas, criticism, and negotiating ideas with others. Previous studies have shown that laboratory work creates a unique discourse where students become active participants in meaning-making through their own linguistic patterns and terminology [16]. Research on physics laboratory work has demonstrated that students naturally engage in physics discussions when given environments that position them as actors rather than passive observers. Figure 7 dispresents details of the statements regarding communication.

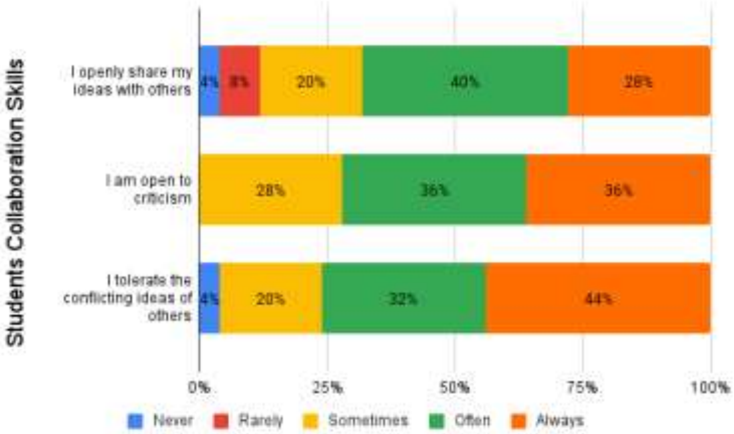

Fig. 7. Students' collaboration skills in communication

The second indicator is team support. The average student response in team support is 89%, which is categorized as very high and represents the highest-performing indicator in this study. This demonstrates how the hands-on, experimental activity of investigating the energy involved in the toy car, the effectiveness of structured laboratory experiences, can developing mutually beneficial cooperation and interdependence. Research on collaborative learning in STEM education demonstrates that group work consistently produces better performance, greater productivity, and more supportive relationships compared to individual or competitive working arrangements [17]. When students work together in laboratory settings, they naturally develop mechanisms for supporting one another's learning [18]. The high team support scores in the present study suggest that the experimental activity effectively promoted peer modeling and cognitive elaboration processes through which students verbalizing and elaborating on their own ideas while working to resolve incompatibility with peers [19]. Figure 8 displays the statements regarding their team support.

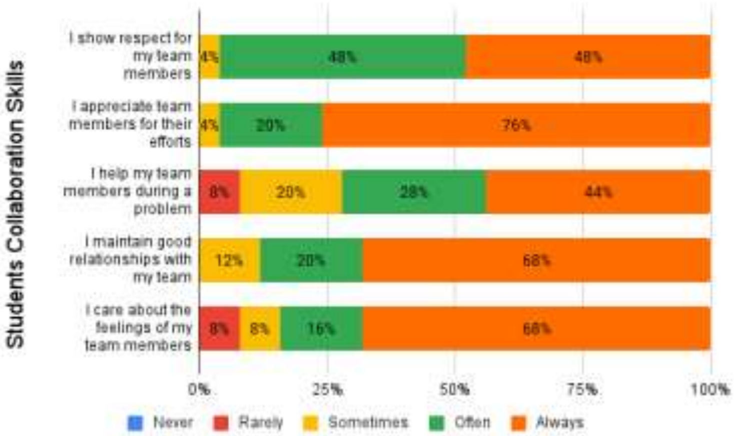

Fig. 8. Students' collaboration skills in team support

The third indicator analyses the students' opinions about the learning orientation. This study shows that the indicator is 85.6% , categorized as a very high category. This suggests that the experiment using toy car complete the loop is evident, especially when grasping the idea of energy conservation, indicating strong intrinsic motivation and goal-directed behavior during the collaborative activity. This finding reflects the capacity of inquiry-based laboratory work to engage students' curiosity and drive toward understanding. The active investigation approach provides students with opportunities to develop independent thinking while simultaneously functioning as collaborative team members [20]. Figure 9 displays the statements regarding the learning orientation.

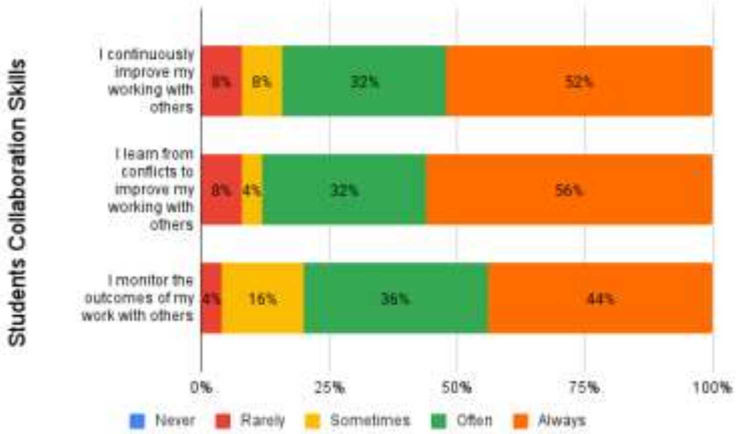

Fig. 9. Students' collaboration skills in learning orientation

The fourth indicator analyses the students' response towards participations or roles of the students in the experiment activity. The average percentage is 86.1% in the very high category, indicating that students understood and effectively executed differentiated responsibilities within their collaborative groups. Effective role structures in group work should emphasize different students taking responsibility for different components of the scientific dialogue that advances collective thinking, rather than assigning merely managerial duties [21]. The relatively high performance in this dimension suggests that either the experimental structure inherently promoted role differentiation, such as through different phases of the experiment requiring different competencies or that students naturally distributed tasks effectively. Figure 10 displays the statements regarding the participations or roles among team members.

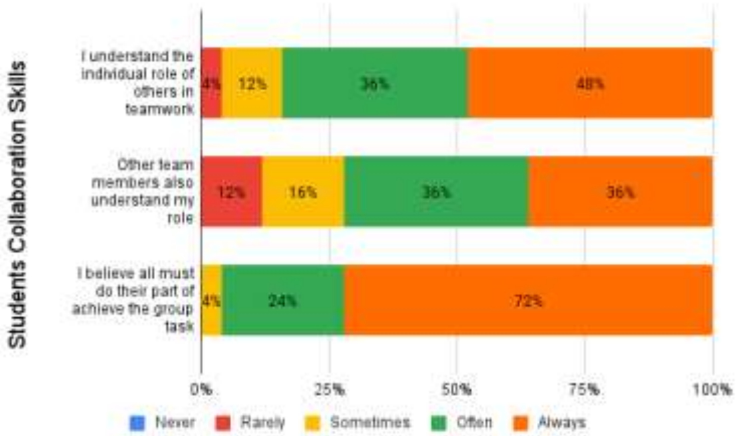

Fig. 10. Students' collaboration skills in participation/roles

The last indicator is conflict resolution. The average score is 81.6%, the lowest of the measured indicators yet still firmly in the very high category. This dimension reflects students' ability to constructively resolve differences of opinion and maintain collaborative relationships when perspectives differ. Conflict management literature shows that a collaborative approach which characterized by active listening, respectful communication, and open-minded problem solving promotes team cohesion and goal achievement [22]. The development of these skills during laboratory activities has implications beyond academic achievement, as conflict resolution competencies are essential for success in the 21st century workplace and collaborative environments. The presence of strong conflict resolution skills indicates that students are able to maintain productive working relationships despite the cognitive demands and potential frustrations inherent in collaborative experimental work. Figure 11 displays the statements regarding the conflict resolution.

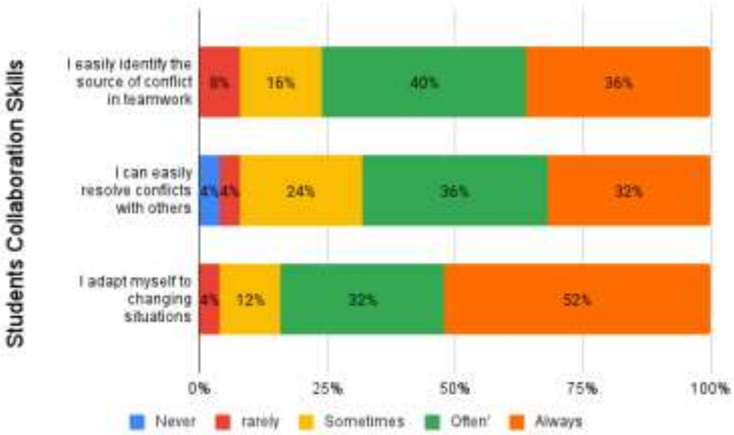

Fig. 11. Students' collaboration skills in conflict resolution

Overall, the energy practicum activity using toy cars received very positive responses from students. The collaboration score of 84.5% proves the effectiveness of this activity. The consistency of students' answers in various indicators also reinforces the evidence that the material on substances and their changes can be conveyed well through this practice.

IV. CONCLUSION

This research investigated the effectiveness of the "It’s Race Day" energy experiment utilizing tracker analysis as a pedagogical tool for secondary students, with particular emphasis on measuring students' collaboration skills development during laboratory work. The experimental analysis using tracker video technology successfully demonstrated energy transformation processes and enabled precise measurement of critical velocity parameters during the race car motion. Through collaborative data analysis, students observed the conversion of potential energy to kinetic energy and identified critical velocity thresholds affecting car performance, providing concrete evidence of fundamental energy principles. Simultaneously, the findings demonstrate that students achieved notably high performance across all measured collaboration indicators, with an overall average of 84.5% classified as very high. These results indicate that the hands-on laboratory experiment combined with tracker video analysis successfully engaged students in collaborative scientific practices and fostered the development of essential teamwork competencies. The consistency of high performance across all five indicators suggests that laboratory-based inquiry activities create authentic contexts where multiple collaboration skills develop simultaneously and naturally reinforce one another through the investigative process.

Despite these encouraging findings, several considerations are worth discussing. Measuring collaboration skills through observational data reflects the behavior exhibited by students during a single experimental session; longitudinal assessments would strengthen our understanding of whether these skills persist and can be applied to other contexts. Furthermore, understanding the relationship between the development of collaboration skills and conceptual learning outcomes in the energy and motion unit would provide more complete evidence regarding the pedagogical effectiveness of this approach. Future research may explore whether the use of analytical tools such as tracking software specifically enhances collaborative processes compared to traditional experimental analysis methods. Nevertheless, this study provides substantive evidence that laboratory-based inquiry combined with video analysis technology constitutes an effective strategy for developing secondary students' collaboration skills, with important implications for science education practice.

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REFERENCES

[1] J. W. Jewett, "Energy and the Confused Student I: Work," *Phys. Teach.*, vol. 46, no. 1, pp. 38–43, Jan. 2008, doi: 10.1119/1.2823999.

[2] S. Sripathi and B. Shadreck, "Bridging the Gap in Physics Education: Investigating Misconceptions and Pedagogical Strategies in Chongwe District's Secondary Schools," *ASET Journal of Management Science*, vol. 4, no. S01, May 2025, doi: 10.47059/ajms/v4si01/01.

[3] R. D. Agustina, R. P. Putra, Y. Cesariyanti, and N. M. Putri, "Collaborative Skill Improvement Analysis in Real Laboratories Based on Discovery Learning for Undergraduate Physics Education Major," *KnE Social Sciences*, pp. 1003–1012, 2024.

[4] G. Grote and S. W. J. Kozlowski, "Teamwork doesn't just happen: policy recommendations from over half a century of team research," *Behavioral Science & Policy*, vol. 9, no. 1, pp. 59–76, 2023.

[5] H. Haerani, A. Muhammad, and K. Khaeruddin, "Development of experiment-based physics worksheets in science in developing students' science process skills," *Jurnal Penelitian Pendidikan IPA (JPPIPA)*, vol. 9, no. 1, pp. 292–298, 2023.

[6] M. Basir, A. Setiawan, and D. T. Chandra, "Design and Construct of Magnetic Induction and Force Practicum Tools to Improve Science Process Skills," *Jurnal Penelitian Pendidikan IPA*, vol. 10, no. 9, pp. 6516–6524, 2024.

[7] S. Fayanto, "Guided Experiment in Basic Electronics Simulations: Its Effect on Student Engagement and Motivation with Controlling Self-Regulation.," *International Journal of Education in Mathematics, Science and Technology*, vol. 13, no. 5, pp. 1177–1188, 2025.

[8] N. K. Dewi and R. V. Listyarini, "Development of green chemistry-based practicum module for senior high school to promote students' environmental literacy," *Jurnal*

Pendidikan Sains Indonesia (Indonesian Journal of Science Education), vol. 10, no. 3, pp. 641–653, 2022.

[9] U. O. Matilda and A. O. Helen, "Effect of formative classroom assessment on students' academic achievement in junior secondary school basic science in Egor local government area of Edo state," *Journal of Education and Practice*, vol. 10, no. 15, pp. 184–189, 2019.

[10] F. A. Faize, M. Akhtar, M. A. Dahar, and M. Aqeel, "Development and Validation of the 21st Century Collaboration Skills Scale for High School Students," *Psychol. Rep.*, p. 00332941251390440, 2025.

[11] Riduwan, *Dasar-Dasar Statistika*. Penerbit Alfabeta, 2016.

[12] A. Kuswidyanarko, M. Jannah, and R. Rohana, "Student worksheet development on the math division material based on the PMRI Approach for Fifth-Grade Elementary School Students," *Jurnal Ilmiah Sekolah Dasar*, vol. 5, no. 4, pp. 708–721, 2021.

[13] W. Kłobus, "Motion on a vertical loop with friction," *Am. J. Phys.*, vol. 79, no. 9, pp. 913–918, 2011.

[14] D. Ponikvar and G. Planinsic, "Conservation of mechanical and electric energy: simple experimental verification," *Eur. J. Phys.*, vol. 30, no. 1, pp. 47–56, 2009.

[15] A. Malik and M. Ubaidillah, "Multiple skill laboratory activities: How to improve students' scientific communication and collaboration skills," *Jurnal Pendidikan IPA Indonesia*, vol. 10, no. 4, pp. 585–595, 2021.

[16] J. Andersson and M. Enghag, "The relation between students' communicative moves during laboratory work in physics and outcomes of their actions," *Int. J. Sci. Educ.*, vol. 39, no. 2, pp. 158–180, 2017.

[17] F. Rusk and W. Rønning, "Group work as an arena for learning in STEM education: Negotiations of epistemic relationships," *Education Inquiry*, vol. 11, no. 1, pp. 36–53, 2020.

[18] D. Herro, C. Quigley, J. Andrews, and G. Delacruz, "Co-Measure: developing an assessment for student collaboration in STEAM activities," *Int. J. STEM Educ.*, vol. 4, no. 1, p. 26, 2017.

[19] D. Fung, "Achieving individual and collaborative success: An investigation of guided group work and teacher participation in junior secondary science classrooms," *Int. J. Educ. Res.*, vol. 111, p. 101908, 2022.

[20] L. T. Jacalan and A. A. Castillo, "Effect of Inquiry-based learning approach on the students' performance in Physics," *International Journal of Science and Management Studies (IJSMS)*, vol. 6, no. 3, pp. 230–233, 2023.

[21] Y. Chang and P. Brickman, "When group work doesn't work: Insights from students," *CBE—Life Sciences Education*, vol. 17, no. 3, p. ar52, 2018.

[22] M. M. Lacey, S. G. Campbell, H. Shaw, and D. P. Smith, “Self- selecting peer groups formed within the laboratory environment have a lasting effect on individual student attainment and working practices,” *FEBS Open Bio,* vol. 10, no. 7, pp. 1194–1209, 2020.