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Impact of Project -based Learning on Students' Critical Thinking Skills in Kinematics in Mbale District, Uganda

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Abstract*:* This study explored the influence of project-based learning (PBL) on students' critical thinking skills. The participants were fifty 10th-grade students from a purposively selected school in Mbale District, Eastern Uganda. Participants were randomly distributed to the experimental and control groups using cluster sampling. A mixed-method research approach was adopted. The pretest-posttest non-equivalent quasi-experimental design was used. The experimental group used the PBL approach while the control group followed the conventional approach. A kinematics survey test with eight essay questions and focus group interview prompts were data collection tools. The questions were open-ended to adequately measure students' critical thinking skills in kinematics. The survey test was validated by experts and piloted ($\alpha=0.88$). Data was analyzed using independent samples t-tests and effect size. Though both groups' mean scores increased, the independent sample t-test *(t(50)=12.22, df.=48, p=0.00)* revealed that students from the treatment group exhibited proficiency in critical thinking skills relative to their counterparts from the control group. Therefore, this study recommends that science educators should adopt PBL to improve students' life and career skills.

Keywords: Critical thinking; Kinematics; Project-based Learning; 10th-grade students.

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Introduction

The current era, dubbed "Industrial Revolution 4.0," necessitates students to grasp 21st-century skills for work and life. The 21st-century skills that educators should emphasize in learning science and mathematics include critical thinking, problem-solving, creativity, collaboration and communication skills (Partnership for 21st Century learning, 2015). One of the main skills to be attained by students is critical thinking. Critical thinking skills must be engrained in every student to adapt to the increasingly complex challenges, as well as the growth of science and technology, which are restructuring the current society. Critical thinking refers to a mental process encompassing rational contemplative thinking to produce decisions based on a dilemma encountered by an individual (Putra, Sulaeman, Supeno, & Wahyuni, 2021). Critical thinking abilities are inevitable to make better decisions during the learning process. Students who think critically can construe, scrutinize, evaluate, explain, infer and self-regulate their thoughts (Shaw et al., 2020). When students are confronted with an issue, critical thinking skills motivate them to study the situation and consider viable solutions. Students can use critical thinking to think creatively, work on a problem with others and communicate successfully. Critical thinking is vital to teaching, and teachers who apply it are likely to help learners improve their conceptual and procedural knowledge and understanding (Ma, Zhang & Luo, 2021).

Presently, there is a global agreement on the necessity of developing students' critical thinking in science education because it is essential for scientific reasoning. Scientific reasoning demands incessant decision-making and critical thinking is the process of making logical decisions about what to believe and what to do (Baloyi, 2017). A student in science must be able to identify or frame a question, search for and select information from reputable sources, make inferences, plan and execute experiments and present reports. Therefore, critical thinking appears to play a major part in science learning and physics, in particular. Surprisingly, Dewey emphasized over a century ago that science education should foster reflective thinking, which is presently referred to as critical thinking (Miettinen, 2000). More recently, education reforms have declared unequivocally that higher-order thinking skills are an important component of science learning (NGSS, 2013). Students at all educational stages must know, comprehend and apply knowledge and think critically to be scientifically literate. In line with this, different countries have changed their curricula to empower students with higher-order thinking skills (Rodrigues & Oliveira, 2008). The physics curriculum in Uganda's secondary schools is no exception. For instance, the physics curriculum in Uganda attempts to encourage effective learning and the acquisition of metacognitive skills so that students may adjust to their changing roles in society (Science Teachers' Initiative, 2020).

Nonetheless, a teacher's teaching style has a significant influence on the growth of essential skills in students. Secondary school students in Uganda continue to learn physics through conventional techniques like the lecture method, which results in passive and irrelevant learning (Komakech & Osuu, 2014). Moreover, Physics teachers frequently emphasize expository learning and students are rarely given opportunities to express their opinions on the issues being covered. Consequently, students are often unable to succeed in physics questions or problems that require higher-order thought (UNEB, 2019). This trend is likely to impede students' ability to make a living after school, particularly in the twenty-first century. The education ministry reports that Uganda's secondary school education has failed to produce graduates with the requisite skills and information to enter the workforce or pursue higher education (MoES, 2008). Therefore, it is central to use instructional tactics that engage students in everyday problems and improve their thinking skills. One of the instruction methods that encourage students to think critically and apply physics concepts is the Project-Based Learning (PBL) technique.

PBL is a student-centered, teacher-facilitated learning strategy (Bell, 2010). Through this method, students seek out information by posing questions that excite their innate curiosity. The starting point of a project is an investigation. Students create a question and are directed through the research process by the teacher. PBL method employs "projects" as a vehicle for boosting students' inspiration and displaying and explaining what they have learned. PBL activities customarily involve gathering data, interrogating specialists on the topic, performing experiments, evaluating data and reporting outcomes. Such activities are possible in PBL because students are actively participating in the information-seeking process in authentic scenarios. PBL classrooms are substantially different from conventional learning milieus because they are independent of isolated, content-based, teacher-centered courses. During PBL, the teacher determines the topic that students studies, cultivates the students' desire to learn and fosters the development of a driving question. Students are given the freedom to make decisions that are important to them (Larmer & Mergendoller, 2010). Students conduct in-depth research, review their findings and receive feedback from the teacher and their peers. Students then give a presentation to a select audience on their results. Moreover, students have some autonomy in working cooperatively with their peers over a long period to generate realistic products or presentations under the supervision and facilitation of their teachers.

PBL is one of the most effective techniques for improving science education and enabling students to apply their scientific knowledge and skills to solve issues in their daily lives, as well as become science-literate persons (Bell, 2010). Furthermore, PBL fosters individual learning, allows students to make connections between school and life, stimulates lifelong learning, and promotes self-control. Extensive research in different contexts and settings shows that PBL has improved students' academic achievements (Jarrar, 2020), fostered favorable attitudes toward science (Yalçin, 2017), improved teamwork by allowing students to learn from each other as well as themselves (Cortázar et al., 2021), and enhanced students' critical thinking abilities (Heba & Khataibeh, 2021; Astra, Rosita & Raihanati, 2019). Despite the benefits of PBL, little research has been done in Uganda and in kinematics in particular on how PBL influences the learning of physics concepts and hence the growth of students' critical thinking abilities. This is because the majority of studies were conducted in developed nations with distinct contexts. Thus, this study sought to establish the influence of the PBL on the 10th-grade students' critical thinking abilities in kinematics.

Methodology

Research Design

This study adopted the mixed research methods. It employed the pretest-posttest non-equivalent quasi-experimental design, having experimental and control groups. This design was employed to avoid disrupting the school's academic program by randomly assigning students to the two groups (Cohen & Morrison, 2007). In other words, intact classes at the chosen school were used for the study. Students in the experimental group were taught using the PBL technique whereas the control group experienced the conventional instructional method. The design of this study is shown in Figure 1.

Experimental	P_1	X	P_2
Control	P_1	--	P_2

Figure 1: Research design Description

P_1: Pretest in both experimental and control groups.

X: Treatment using Project-based learning method.

P2: Posttest in both experimental and control groups (Cohen et al., 2017).

The pretests P_1 were given to both the experimental and control groups before the intervention (*Figure 1*). The pretest was used to assess if the students in both groups had similar critical thinking skills in kinematics. For four weeks (April 06 to April 29, 2022), the experimental group received the intervention (X), whereas the control group did not. After an intervention, both groups completed a post-test (P2). The items of P_1 and P_2 were similar. The goal of the post-test was to see if the intervention had any effect on the students' critical thinking skills in kinematics.

Teaching in the Experimental Group

The researchers used PBL to teach the kinematics lesson to the students in the experimental group. They began the project by showing students the Mars Exploration Rover Animation. Students were asked the driving question. The students were divided into four groups, each with six members. Students were given complete freedom to come up with whatever project they wanted to answer the driving question. Thus, the students chose the egg drop project. In this project, students agreed to design and build a container that would protect a raw egg from breaking when it fell from a height of 4 meters. *Students brainstormed to get initial design ideas.* They were encouraged to conduct research into whatever they believed would assist them in completing their suggested project. The students were given a rubric to assist them to understand the project's criteria and how it would be graded. Furthermore, the researchers delivered inquiry-based lessons. The students applied the kinematics ideas they had learned to make egg protectors, which they then presented to their target audience. As indicated in Table 1, the instructional plan for the PBL which lasted for four weeks.

Table 1: The plan for the Project-Based Learning

School: Gold			
Class: Senior three (10th-grade).			
Topic: Kinematics		Unit: One	No. of lessons: 10
Objective: Students should be able to apply concepts learned to solve a problem.			
Competences: Collaboration, Critical thinking, Communication.			
Driving question: How can you drop a raw egg on the ground without breaking it?			
	Day 1	Day 2	Day 3
Week 1	Pretest	Introduction of the project.	Determination of velocity of a tennis ball based on measurements of displacement and time.
Week 2	Determination of the acceleration of a tennis ball.	Freefall	Force and Newton's laws of motion.
Week 3	Momentum	Conservation of linear momentum	Change in momentum and impulse.
Week 4	Group project design and construction of the device.	Test of egg drop device and review.	Posttest

Teaching in the Control Group

The conventional teaching style of lecture and rote memorization was used to teach kinematics to students in the control group. Students were taught by another physics teacher with over fifteen years of expertise. Students received a posttest after four weeks.

Population and Sampling Techniques

The population of the study consisted of all the 10th-grade students in Mbale District in the academic year 2022. The district consisted of 42 secondary schools. *The* study sample consisted of fifty 10th-grade students from school A which was chosen through purposive sampling because the school's physics performance was among the worst in the district. Students were randomly assigned to the experimental and control groups using the cluster sampling technique. There were 24 students in the experimental group and 26 in the control group.

Instruments

The survey test consisting of 8 essay-type items to assess students' critical thinking skills in kinematics was adapted (NJCTL, 2021). The survey test was validated by six physics experts with vast experience in teaching and examining physics at the Uganda National Examination Board (UNEB). This helped to make the test items clear and understandable to the students' academic level. Furthermore, this was confirmed by five 10th-grade students who were outside the study sample. The survey test was piloted on 25 senior three students outside the study sample and the overall Cronbach alpha was 0.88, which indicated a good internal consistency of the test. Critical thinking indicators such as analysis, evaluation and inference were used to score each item (Anwar, *Senam & Laksono*, 2017). Each item received a score of four points. The distribution of questions for tests of critical thinking skills is shown in table 2.

Each item had a maximum score of four points. Table 2 shows a sample rubric for critical thinking skills.

Statistical Treatment of Data

Homogeneity and Shapiro-Wilk normality tests were conducted using SPSS (version 20). The independent samples t-test and effect size were conducted to test whether or not a substantial statistical disparity exists between the experimental and control groups' mean scores of students' critical thinking skills for the pre-and post-test. Furthermore, the focus group interviews were videotaped and the conversations were transcribed verbatim in a text file. The transcriptions were analyzed using the procedures outlined (Lesh & Lehrer, 2000). The transcriptions were then read multiple times and the analysis was fine-tuned for clarity. The transcriptions were coded anonymously, and the attitudes of students towards physics in the two groups were compared.

Table 2: A sample Rubric for the Survey test of Critical Thinking Skills in Kinematics

Critical thinking indicator.	Question	Answer
Evaluation	A student reasons that when a small ball of mass m, rolling with a velocity v collides elastically with a larger stationary ball of mass M, the small ball stops moving, and the larger ball rolls away with velocity v. Do you agree with this student's reasoning? Explain why you agree or disagree.	No. I do not agree with the student's reasoning. Explanation If the small ball collides with a larger ball, due to the law of conservation of momentum, the larger ball must have a much smaller velocity, for its final momentum to equal the initial momentum of the small ball. In this case, for an elastic collision, the small moving ball will bounce off with the same speed in the opposite direction. The larger ball will not move at all. For the moving ball to stop and the stationary ball to move with the velocity of the moving ball an elastic collision of identical masses is required.
Analysis	Your sister is in a serious condition and has been admitted to the hospital. Doctors have recommended that she can only eat an egg to sustain her life. Bringing the egg to her by vehicle takes too long and is too unsafe. It is also deemed too dangerous to land an airplane. Therefore, the egg will be dropped from the airplane in space. You are part of a group selected to save the life of your sister. How will you drop the egg to reach the ground without breaking or cracking?	Materials: Cotton, sponge, clothes, empty box, toilet paper, and inextensible strings. Procedure: The egg is enclosed in soft materials such as cotton, clothes, sponge, or toilet paper to provide a cushion and then placed in a box. When the egg container lands on the ground, the cushion extends the time of impact, thus reducing the force, according to Newton's second law. Also, a parachute is made for the egg container to reduce the velocity at which the egg drops. Since the egg is falling at a slower speed, the force of the impact will be much less once it hits the ground. Less force means that the egg will have a chance to survive.

Table 3: Test of Homogeneity on the Survey Data

Instruments	Data	Significance value	Criteria
Survey Test	Pretest	0.14	Homogeneous
	Posttest	0.29	Homogeneous

Findings and Discussion

This study sought to establish the influence of the PBL on the 10th-grade students' critical thinking abilities in kinematics. Data was collected using a survey. Critical thinking indicators such as analysis, evaluation, and inference were used to score each item. Each item had one indicator with a score of four points. This section presents and discusses the findings of the study in the context of the research question.

Research Question: What is the effect of using PBL on the 10th-grade students' critical thinking skills in kinematics?

To answer the research question, the study tested the following null hypothesis: The PBL strategy does not affect the 10th-grade students' critical thinking skills in kinematics.

Findings Related to the Homogeneity Test on the Pretest and Post-test Survey Data

Levene's test was conducted on the survey data. The results of Levene's test are presented in Table 3 which reveals p=0.14 (0.14>0.05) for the pretest and p=0.29 (0.29>0.05) for the posttest. This means that the pretest and posttest data had similar variance.

Findings Related to the Normality Test on the Pretest and Post-test Survey Data

The Shapiro-Wilk normality test was conducted on the survey data. Table 4 shows the results.

The table indicates that the p-value for both pretest and posttest is greater than 0.05 in both groups. This implies that the data were fairly normally distributed and an independent sample t-test was used to test the hypothesis.

Table 4: Test of Normality on the Survey Data

Instruments	Groups		Significance	Results
Survey test	Experimental	Pretest	0.36	Normal
		Posttest	0.18	Normal
	Control	Pretest	0.17	Normal
		Posttest	0.16	Normal

Table 5: Results of Students' Critical Thinking Skills in a Pretest Survey

Pretest	N	Mean	Std. deviation	t	df.	Sig. (2-tailed)
Experimental	24	8.25	2.74	-0.24	48	0.82
Control	26	8.46	3.52			

Table 6: Results of Students' Critical Thinking Skills in a Posttest Survey

Posttest	N	Mean	Std. deviation
Experimental	24	23.63	1.53
Control	26	17.81	1.81

Table 7: Results of the Independent Samples t-test on the Post-test Survey Data

	t	df	Sig. (2-tailed)	η	Effect size, η^2
Survey test	12.22	48	0.00	0.87	0.76

Findings related to groups' Pretest Scores on the Survey Test

To find out whether or not the students' critical thinking skills were the same, a pretest was administered to the experimental and control groups before intervention. The mean, standard deviation, and independent sample t-test for the pretest survey data are presented in Table 5.

Table 5 shows that the experimental group's mean critical thinking skill score was 8.25 (S.D= 2.74), while the control group's score was 8.46. (3.52). Moreover, *t*he independent samples t-test showed no significant statistical change in the mean scores for pretest scores on students' critical thinking abilities (t(50)= -0.24, p=0.82). The results suggest that before treatment, students in both groups had almost the same level of critical thinking abilities.

Findings related to groups' posttest scores on the survey test.

Table 6 shows a difference in the average scores of students' critical thinking skills with the experimental group being 23.63 (S.D= 1.53) while the control group is 17.81 (S.D=1.81).

Moreover, the results of the independent samples t-test are shown in Table 7 which revealed that the average scores of students' critical thinking skills in the two groups were significantly different (t(50)=12.22, df.=48, p=0.00, η^2 =0.76). The difference was in favor of students from the experimental group who were taught using the PBL approach. Thus, the null hypothesis that "The PBL technique does not affect the 10th-grade students' critical thinking skills in kinematics" was rejected.

Findings Related to the Sub-indicator of Critical Thinking Skills

Table 8 indicates that students in the experimental group (Mean= 3.07, S.D= 0.42) outperformed their peers in the control group (Mean= 2.20, S.D= 0.36) in terms of inference indicator of critical thinking. Furthermore, the difference in their mean score was statistically significant (t(50)=7.88, p=0.00, η^2=0.56).

Findings Related to the Analysis sub-indicator of Critical Thinking Skills

Table 9 indicated that students in the experimental group (Mean= 2.96, S.D= 0.66) outperformed their peers in the control group (Mean= 2.29, S.D= 0.55) in terms of analysis indicator of critical. Furthermore, the difference in their mean score was statistically significant (t(50)=3.91, p=0.00, η^2=0.24).

Table 8: Students' scores in the Inference indicator of critical thinking skills

Groups	**N**	**Mean**	**S.D**	**T**	**df**	**Sig.**	**η**	**Effect size, η^2**
Experimental	24	3.07	0.42	7.88	48	0.0	0.75	0.56
Control	26	2.20	0.36					

Table 9: Students' scores in the Analysis indicator of critical thinking skills

Groups	**N**	**Mean**	**Std. Deviation**	**T**	**df**	**Sig.**	**η**	**Effect size, η^2**
Experimental	24	2.96	0.66	3.91	48	0.00	0.49	0.24
Control	26	2.29	0.55					

Table 10: Students' Scores in the Evaluation Indicator of Critical Thinking Skills

Groups	N	Mean	S.D	T	df	Sig.	η	Effect size, η^2
Experimental	24	2.71	0.67	2.90	48	0.01	0.39	0.15
Control	26	2.21	0.53					

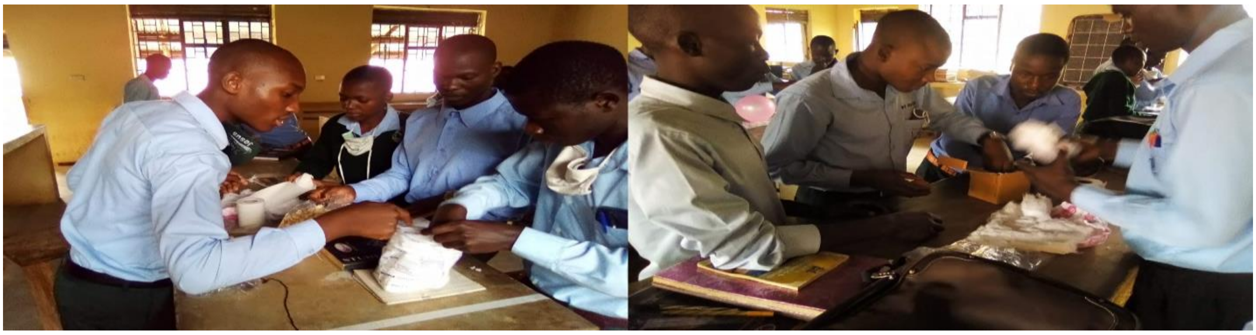

Figure 2: Students in groups are using different materials to construct their egg protectors

Figure 3: Different groups have completed their egg containers

Findings related to the Evaluation sub-indicator of Critical Thinking Skills

Table 10 revealed that students in the experimental group (Mean= 2.71, S.D= 0.67) is better than their peers' in the control group (Mean= 2.21, S.D= 0.53) in terms of evaluation indicator of critical thinking. Furthermore, the difference in their mean score was statistically significant (t(50)=2.90, p=0.01, η^2=0.15).

Experimental Group's Activities during the Project

Students were engaged in research on some of the concepts of kinematics. They applied the kinematics concepts to construct the egg container and presented it to the audience. The following pictures depict some of the activities exhibited by the students in the experimental group.

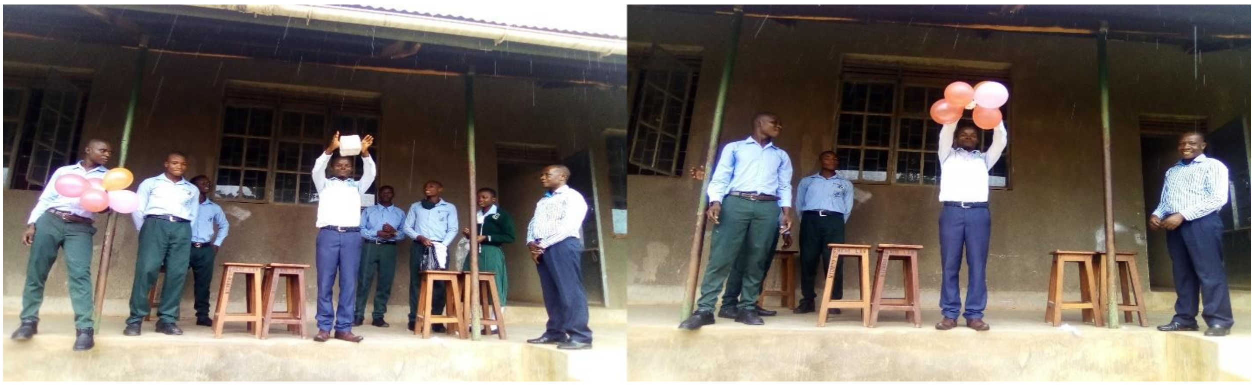

Figure 4: Teachers are launching the egg containers in the presence of students

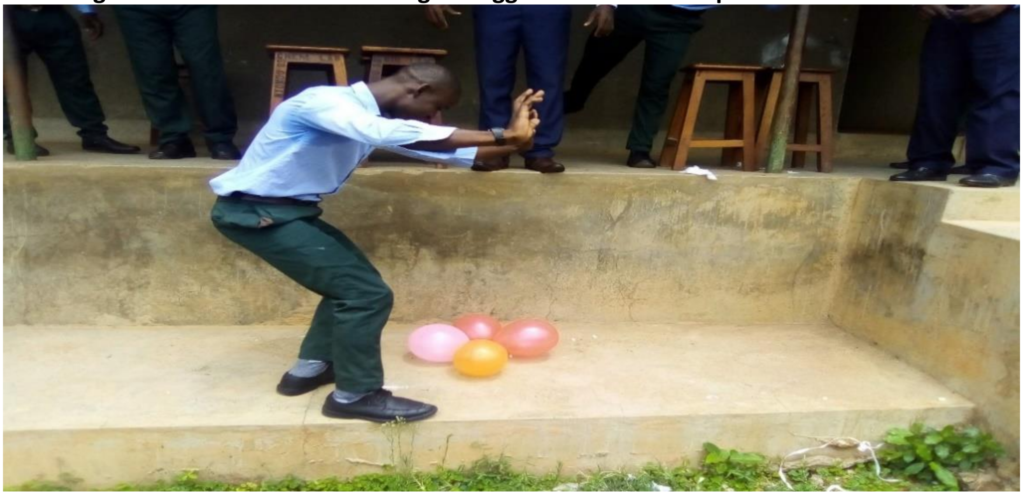

Figure 5: A student expressing excitement after their egg container successfully landed on the ground

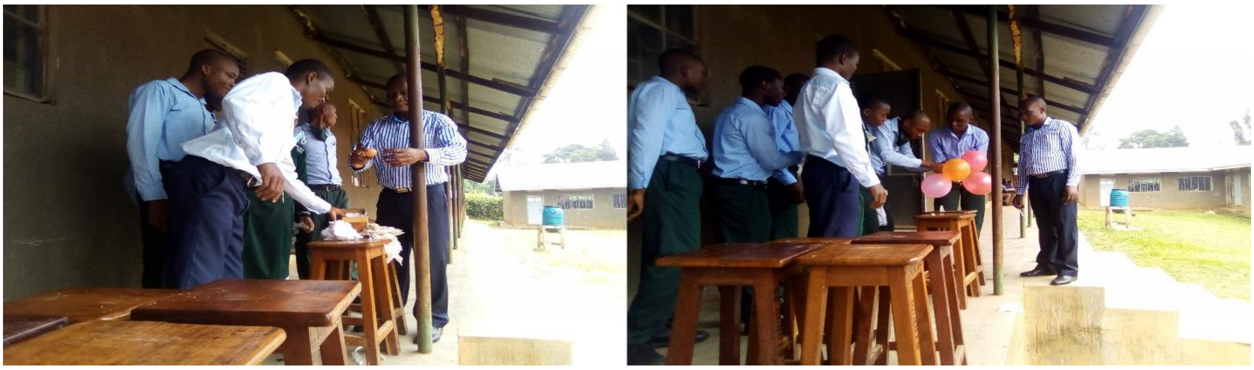

Figure 6: The teachers and students open egg containers to inspect the egg

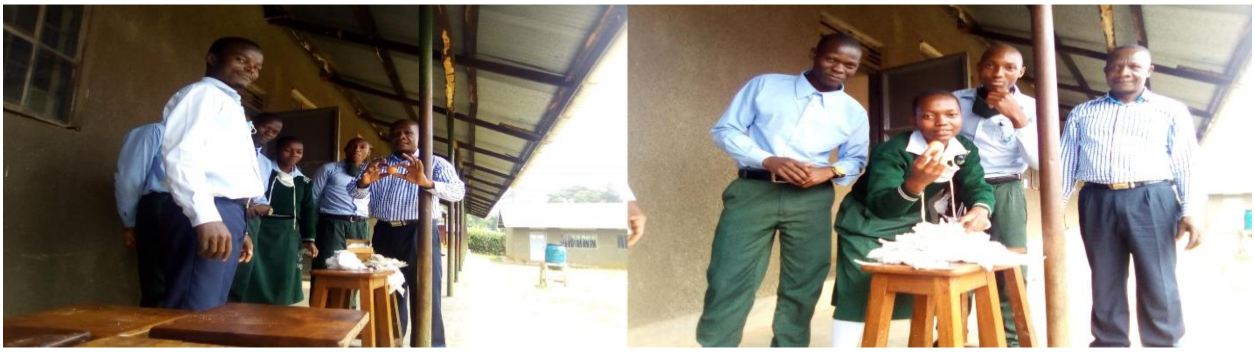

Figure 7: The teacher (Left photo) and student (right photo) display the eggs that had survived

Figures 1 to 6 revealed that students in the experimental group collaborated with peers, analyzed different materials and selected only those that would reduce the force for the egg to survive after the impact. They also displayed creativity during the construction of their egg containers, indicators of critical thinking capabilities.

Findings Related to the Focus Group Interview Based on the Survey Test

The variations in students' critical thinking abilities were also discovered during focus group interviews. The focus group interview was premeditated to complement the survey test by exploring the students' verbal critical thinking abilities. The focus group interviews were videotaped and the conversations were transcribed verbatim in a text file. The transcriptions were analyzed using the procedures outlined (Lesh & Lehrer, 2000). Transcriptions were then read multiple times and the analysis was fine-tuned for clarity. Transcriptions for the following question were coded incognito, and the critical thinking skills of the two groups were compared. In this study, students who took part in the focus group interview were identified using codes. The sampled experimental group's focus group participants were A1 and A2, while the control group's focus group participants were B1 and B2. Below are sample transcriptions of four students:

Question: Your sister is in a serious condition and has been admitted to the hospital. Doctors have recommended that she can only eat an egg to sustain her life. Bringing the egg to her by vehicle takes too long and is too unsafe. It is also deemed too dangerous to land an airplane. Therefore, the egg will be dropped from the airplane in space. You are part of a group selected to save your sister's life. How will you drop the egg to reach the ground without breaking or cracking?

> A1 (Experimental): Wrap the egg in soft tissue like toilet paper or a sponge. Place it in the middle of a box stuffed with cotton. When the egg container is dropped to the ground, the cotton absorbs some impact. The cotton will increase the time of impact leading to a decrease in the force exerted on the egg. Therefore, the egg will not break.

> A2 (Experimental): Enclose the raw egg in cotton and place it in a container filled with clothes or papers. Create a parachute for the egg container. When the egg container is released from the air aircraft, the parachute will aid in lowering the speed due to air resistance. The egg container reaches the ground at a small speed. According to Newton's second law, when the container lands on the ground, the cotton will increase contact time and lower the force. Therefore, the egg will experience a small force and will not break.

It is clear from the preceding responses that students in the experimental group had better critical thinking skills. They effectively reasoned, demonstrated how parts might lead to a whole, came to conclusions and presented solutions.

> B1 (Control): The egg can safely reach the ground by wrapping it in a massively soft material such as cotton and a balloon. It is then released to land on the ground because soft materials absorb shock as it minimizes the reaction on the ground.

B2 (Control): The egg is well wrapped in a sponge and then thrown to another sponge placed on the ground. This will prevent the egg from breaking.

Although students in the control group suggested solutions to the problem, they lacked coherence in their procedures. In addition, their reasoning was not effective since they failed to connect parts to the whole in the given scenario. This may have been due to the teacher's application of the conventional approach, which resulted in students' inadequate critical thinking skills.

Generally, both quantitative and qualitative results revealed that PBL improved students' critical thinking skills based on kinematics concepts. Based on the findings, it is likely that students' active engagement in lessons and answering the questions during and between the group discussions contributed to the development of their critical thinking skills. Students' capacity to connect assertions and evidence improves as a result of discussions and their critical-thinking skills increase as a result. The current study's findings, which suggest that PBL improves students' critical thinking abilities, are consistent with those of prior studies (Cortázar et al., 2021; Alawi & Soh, 2019; Heba & Khataibeh, 2021).

When the two students' groups were compared on sub-dimensions of critical thinking, it was clear that students in the experimental group outperformed their peers in the control group. Students in the experimental group substantially improved their analysis, evaluation and inference indicators of critical thinking compared to their counterparts in the control class who were taught using the conventional approaches. Jirana, Suarsini and Lukiati (2020) conducted a study in which they used the PBL approach to stimulate critical thinking skills and creativity as a preservice biology teacher. Results of the study revealed that students improved their analysis, evaluation, synthesis, application and use of data to develop critical thinking. The PBL strategy employs inquiry to find solutions to multidimensional problems. Likewise, the study by Duran and Dökme (2016) found that using an inquiry-based learning technique increases students' critical thinking skills in the areas of analysis, evaluation, inference, self-regulation, interpretation, and interpretation sub-dimensions.

Conclusions and Recommendations

Based on the results, it was concluded that the PBL approach improved 10th-grade students' critical thinking skills in kinematics. The impact was visible in both groups' posttest results, with the experimental class's critical thinking skills outperforming the control group. The additional qualitative findings from focus group discussions supported the quantitative results.

The project-based learning is consistent with current Uganda's competency-based curriculum being implemented in the lower secondary school curriculum with inherent students' higher-order thinking skills. These results have far-reaching ramifications in physics education and for physics educators. Therefore, the researcher suggests that educators use the PBL approach to teach physics and other scientific disciplines. This will consequently benefit students in improving their 21st-century skills, particularly in critical thinking. In other words, when kinematics principles are taught utilizing a project-based learning approach rather than the conventional approach, students' scientific conceptual and procedural knowledge deepens and broadens, and can apply them in new but challenging contexts. The researchers recommend replication of this research in other contexts to compare and contrast the findings.

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