Original Article **http://doi.org/10.61489/30053447.1.16**

Effects of Computer-Assisted Multiple-representations on Problem Solving and Experimentation Abilities in Learning General Physics at Arba Minch University

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Abstract

This study was designed to test the effectiveness of Computer-Assisted Multiple Representations (CAMR) in tutorial and laboratory classes. The experimental group consisted of 34 physics students, and the control group contained 45 chemistry students for design one (i.e. pre-test and post-test control group design) targeting the problem-solving ability as one dependent variable. In addition, the same 34 physics students were selected for design two (one group only pretest and posttest design) targeting experimentation ability as the other dependent variable. The result in design one showed a statistically significant mean difference in favor of the experimental group that was obtained based on a performance test. The result was also indicated that male students performed better than the female students. Design two indicated a significant mean difference between the simulation performed by CAMR, and conventional physical experiments that were obtained based on the practical test. However, no significant difference was observed between male and female students with respect to CAMR and conventional physical experiments. With regard to correlation, performance tests and assessment scores were significantly correlated under design one, but not under design two. The quantitative results were also supported by the evidence from qualitative analysis. The study finding implies that teaching organized knowledge assisted by computers is essential for the effective performance of problem-solving and experimentation tasks and activities.

Key words: Computer-Assisted, Multiple representations, basic models

1. Introduction

Developing conceptual understanding and procedural fluency are two important competencies in learning mathematics and science (Laswadi *et al*, 2016). However, students who learn to recite definitions and formulas that are common in traditional instruction (TI), show limited proficiency in solving problems and understanding situations in experimentation in which those concepts and procedures could be used. Currently, the main focus of research attention is a shift from a novice problem solver to an expert problem solver/a physicist/ to acquire competence in interpreting and using different representations, and in coordinating multiple representations such as a graph, a picture, a free-body diagram, and a formula (Walsh, Howard, & Bowe, 2007; Cock, 2012). What hinders students' competence in problem-solving and experimentation mainly depends on students' prior knowledge (Heuvelen, 1991; Trumper, 2003) which plays a role in developing conceptual understanding and procedural fluency.

Hestenes (1996) suggested that to address misconceptions directly models and models with multiple representations provide students with conceptual tools for diagnostic and eliciting purpose and create an environment of activities and discourse to think and reason critically about physical phenomena. According to Wetzels, Kester, & Van Merriënboer (2010) engaging the learner to actively build external representations might promote organization and integration processes that foster the development of mental models. Constructivist views contend that students learn best in tasks, building comprehension with relevance to their own interests and prior knowledge (Rapp, 2005). Constructivist learning environments, including CAMR, are designed to provide students with opportunities to construct conceptual understandings and abilities in activities of problem-solving and experiments.

The theoretical basis of the current research which tries to effectively change existing practices in physics classrooms is cognitive schema theory which receives special attention as an important theoretical perspective. Kotsaro & Smyrnaiou (2017) discussed such association between constructionism and modeling approaches through performing computer-assisted multiple representations. Finally, they recommended that it would be helpful to integrate other theoretical approaches of new technologies in teaching science starts from kindergarten and secondary schools, even in higher education. Beyzen, Bayrak, & Aykutlu (2017) pointed out that physics is generally considered to be difficult and teaching in a physics classroom should be carried out in accordance with the constructivist teaching approach. Moreover, students' previous knowledge and the incorrect information they acquire during the teaching of the subject results in misconceptions (Kubsch *et al.,* 2020), in order to prevent this and provide meaningful and permanent learning, students' previous notions (such as misconceptions) should be questioned and addressed.

Regarding what is required for effective problem solving are beliefs centered on one's learning and knowledge (Reddy, 2019). As teachers, we should choose appropriate tools to fulfill the needs and interests of individual students. Computer application in problem-solving and experimentation activities through virtual reality allows the expression of abstract reality, the presentation of abstract visual experiences that can induce students' imagination and enhance the creative concepts to develop various feasible, unique, and novel creative concepts (Hu, Wu, & Shieh, 2016). In this regard, Kaymakci (2016) has investigated the reasoning learning model so that the number of the analogical in the textbooks should be increased to enrich meaningful learning for students' transition levels between concrete and abstract operational terms.

Park (2016) reported that engaging learners in model-based learning through doing computer-assisted multiple representations can help them develop their scientific literacy-deepening their scientific knowledge through generating, evaluating, and revising their thinking. Hakyolu & Bekiroglu (2016) elucidated the role of collaborative interaction in the knowledge-argumentation association. The result of the investigation (Duran, 2016) about the student-centered approach made suggestions which become relevant for the current study. When students are given enough time and encouragement, most students ask questions and try to answer questions asked of them. Hence teachers should encourage their students to ask questions and allow sufficient time for them to think about questions posed. What is important in student-centered learning is that all students should be able to think about the question and express their opinions, Students opinions should be respected and if mistakes are committed appropriate feedback should be given. There has been an increasing movement towards the introduction of student-centered, however, students find it challenging when there is a sudden transition from traditional didactic practicals to full student-centered learning activities (King *et al,* 2016).

Several researchers (McDermott, 1998; 2013; diSassa, 1998; Hammer, 1996; 2000; Minstrell, 1992; and Redish, 1994; 1999) indicated students rarely express their conceptual knowledge explicitly in problem-solving and experimentation activities performed in a teacher-dominated approach characterized by the presentation of facts and skills, with the assumption of that students will see the underlying structures in the content.

On the basis of the research literature (Degene, 2007) added traditional methods and instructional strategies of teaching science are not compatible with attaining conceptual learning. It can be implied that cognitive skills such as problem-solving and experimentation will be affected in the same way. These setbacks in our classroom practices could be the reasons for lower achievement results obtained by students who sat for the Ethiopian secondary school leaving certificate examination administered and reported in 2022 by the Ministry of Education (MoE). Therefore, the problems to be addressed in this study were:

- unsuccessful association of physics concepts/principles in doing problem solving and experimentation, and
- Skill gaps in problem solving and experimentation (Heuvelen, 1991; Trumper, 2003) observed for the first year physics students as it also was evident in our existing instructional practice as a member of Arba Minch University.

Thus, the following research questions were posed to guide the study.

1. Will students being taught by CAMR score a statistically significant result in problem-solving and experimentation in mechanics compared to students being taught by TI?
2. Will CAMR bring statistically significant results for female students in problem solving and experimentation in a mechanics course compared to other students?
3. Will formative assessment results of classroom activities correlate with achievement test results?

CAMR is a student-centered method that would be helpful to encourage students to practice problem-solving and experimentation based on basic models in mechanics through doing multiple representations for effective interactive engagement.

2. Methodology

This study employed a non-equivalent pre-test and post-test control group in design one targeting problem-solving as a dependent variable and within one group comparison in design two targeting experimentation ability as the second dependent variable. Quantitative data were collected by performance tests for problem-solving and experimentation. Qualitative data were collected by conceptual test activities and focus group interviews.

The participants were first-year physics students (N = 34, M = 10, and F = 24) as experimental group, and first-year chemistry students (N = 45, M = 13 and F = 32) as control group were used in design one and the same experimental group was used in design two. It was unfortunate to get a second section in physics which was why I was forced to select chemistry students who were registered for the course. Two teachers for the experimental and control groups participated in design one and the researcher and laboratory assistant in design two.

The current study focuses on CAMR that was employed in teaching Newtonian mechanics courses along with distinct stage-by-stage cyclic learning episodes as shown in Fig 1.

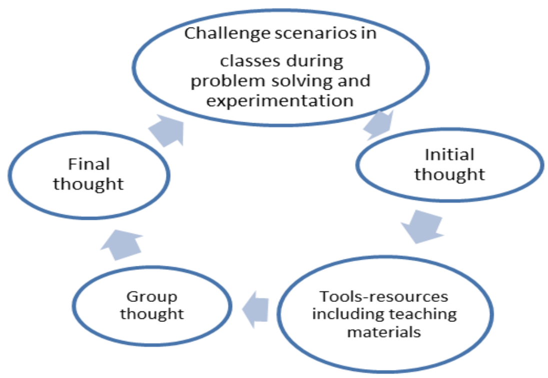


Figure 1: Stage-by-stage episodes of CAMR and each arrow corresponds with assessment and feedback (Adopted and modified from Al-arfaj, 2011)

The illustration depicts stepwise or stage by stage instructional process.

Stage 1 Challenging scenario focuses on topics about fundamental principles in mechanics.

Stage 2 The initial thought focuses on abstraction/idealization of the real world model building during problem-solving and experimentation. The process consists of creating models in different forms such as (i) conceptual (ii) assumption based propositions (includes estimate quantities and make assumptions and approximations) (iii) graphical (v) mathematical;

Stage 3 Tools (computer modeling), resources and teaching materials help to realize creating models;

Stage 4 The group thought focuses on generating hypothesis and generalizations. This process consists of model building with multiple representations in a small group discussion;

Stage 5 The final thought focuses on using models to construct meaning. The process consists of reflection and evaluation to make concrete the explanation and prediction made about real physical phenomena in the system and checking for connections, revising hypotheses, and generalizations.

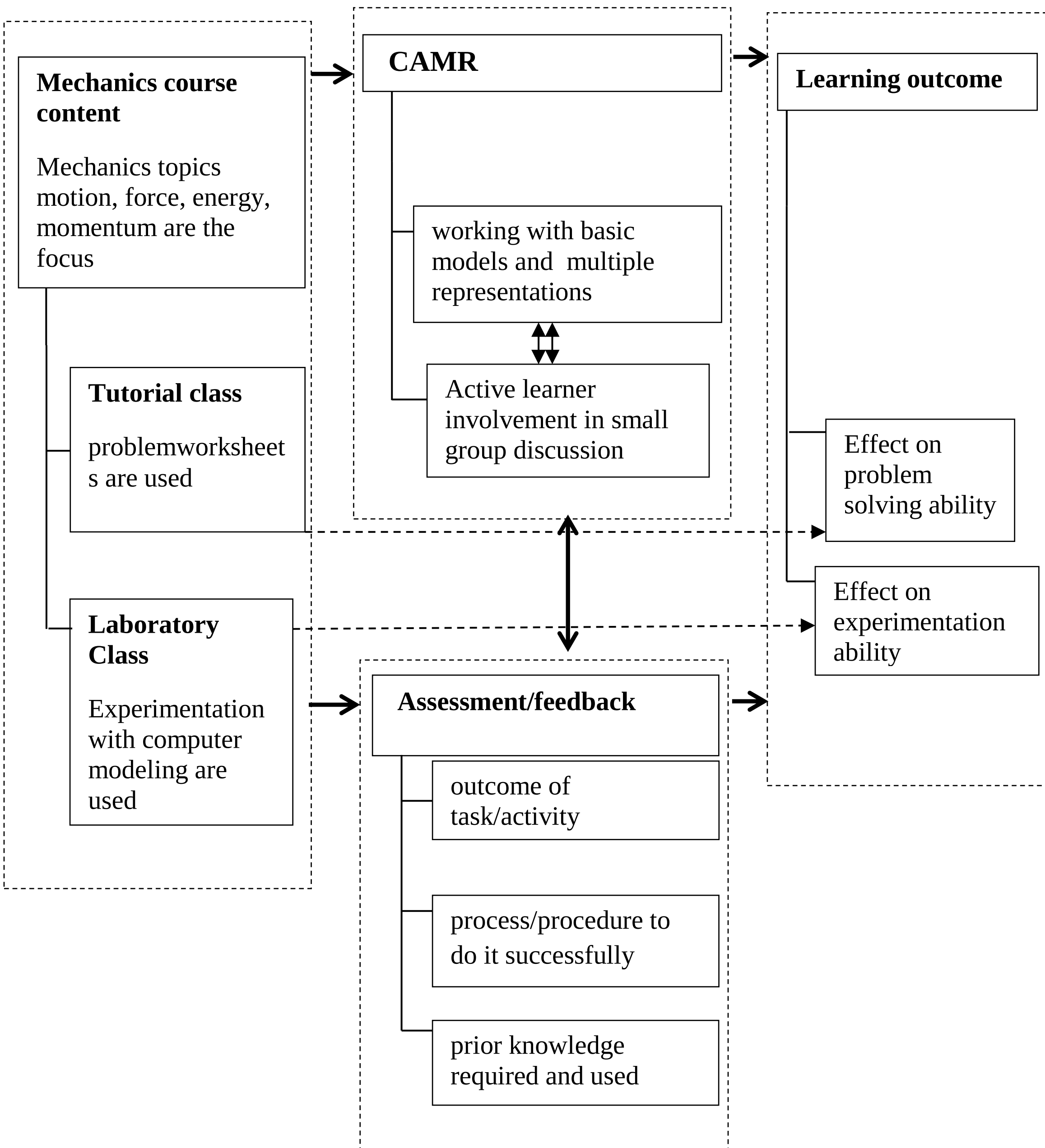


Figure 2: Conceptual framework

The function of each part of the conceptual framework in Fig. 2 arises from the curriculum itself, but more integration and organization of the parts is sought in this study. The sequence of chapters goes first with motion and followed by force, energy, momentum and extra that shows the learning progression in mechanic course. The projections of the real world in topics like motion, force, energy, and momentum within mechanics are possible with the help of basic models. Basic models can be expressed and defined with multiple representations such as scale models (show spatial relationships), conceptual models (symbolic representation with underlying structures), analogue models (a physical system as a model for another) and extra. Formative assessment and feedback help both teachers and students monitor progress and remedial measure on the identified errors, and mistakes committed and misconceptions will be subjected to more clarification and explanation.

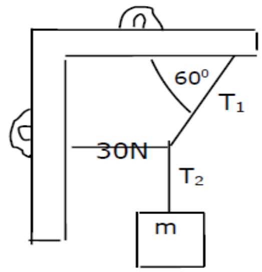
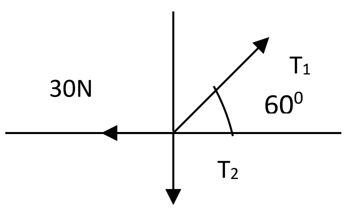
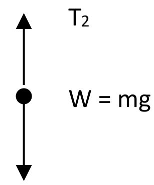
Sample lesson I

The lesson focuses on the given problem solving activity in the worksheet to be performed by CAMR stage-by-stage episodes. This activity was set for students to challenge their knowledge base on the first condition of equilibrium that they learned it in the lesson of Newton's first law. The problem-solving format (displayed in sample examples) guided the learner forward looking model-based strategies. Learners were guided to build models (predicted relations of variables) in different representations to describe events and processes in the context of the problem with the knowledge of basic models in mechanics.

The instructors of both the experimental and control groups set chapter-based problem worksheets. The problems for the treatment group were selected with the potential to engage the learner in a thoughtful course of actions through undertaking multiple representations based on basic models in mechanics.

Scientific argumentation and meaningful learning could be attained at the end of the CAMR cyclic stages. The assessment and feedback were practiced based on prescribed scoring procedures to come to the conclusion of the cyclic stages of CAMR.

Table 1: CAMR applied in problem solving activities

<table>
<tr><td rowspan="2">Question: For the systems to be in equilibrium, find the unknown tensions and masses.

(1) Pictorial Representation
__Coordinate axes : x & y coordinate axes
__Symbols for quantities: T-tension; W-weight</td><td>List of known information:
F = 30N
$\theta = 60^0$</td></tr>
<tr><td>Identify unknown:T_1 = ?; T_2 = ? & m = ?</td></tr>
<tr><td colspan="2">(2) Physical representation:
2.1 object description
-The block can be represented by point mass (center of mass = C.M)
-The strings are ideal ones since they are massless & inexpensive
-The weight is a force vector through the C.M.
2.2 Force diagram: For the junction point of the three strings and for the block.

(i)

(ii)</td></tr>
<tr><td colspan="2">(3) Conceptual model: The system under several forces model
Conceptual model was the system with balanced interaction forces. Students in small group applied 1st condition of equilibrium using force diagrams above where both $\sum F_x = 0$ and $\sum F_y = 0$ holds true for every part of the system.</td></tr>
<tr><td colspan="2">(4) Mathematical Representations & Solution: Mathematical model was used as part of modeling in order to identify variables, formulate equations, and analyze possibilities.
<u>Step 1</u> for the junction point, $\sum F_x = 0 \rightarrow 30N = T_1 \cos 60^0 \rightarrow T_1 = 60N$,
$\sum F_y = 0 \rightarrow T_2 = T_1 \sin 60^0 = (60N)(0.87) = 52N$
<u>Step 2</u> for the block, $\sum F_y = 0 \rightarrow W = T_2 = 52N \rightarrow mg = 52N \rightarrow m = 5.2$ kg
This was the solution for the first question and the same problem solving strategy was utilized for the rest two questions.</td></tr>
<tr><td colspan="2">(5) Evaluation: Answer sheets of small group of students for these homework questions were assessed according to the scoring rubrics to check the correctness of the answers.</td></tr>
</table>

Sample lesson II

The lesson focuses on the given experiment on friction to be performed based on CAMR stage-by-stage episode. The lesson objective is for students to be able to: (i) mention the physical principles used in the experiment; (ii) to deal with basic models; (iii) use physical principles and basic models to explain the experiment; and (iv) refine the modeling when it is needed.

For the first twenty minutes of the laboratory session, conceptual test activities were set to challenge students' knowledge base about friction in the work sheet. One of the conceptual questions was the following. The same constant force (P) is applied to three identical boxes that are sliding across the floor. The forces are in different directions, as shown in the diagram given below:

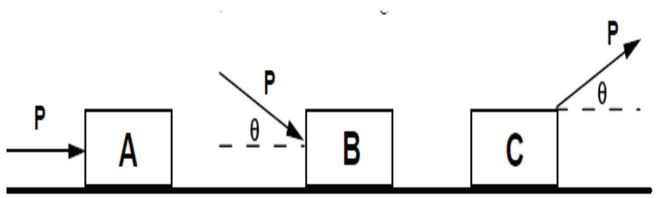


Figure 3: Forces in Different Directions

On which of the three boxes is the frictional force the largest or smallest? Or, is the frictional on each box the same? Explain using appropriate free-body diagrams and Newton's second law. The instructor as well as the technical assistant has to give timely feedback on the performance of students and corrections are made based on the feedback until the conceptual understanding is up to the required level for them to perform the experiment effectively. Once again, CAMR is used to perform simulation experiments with the help of built-in instructions for computer simulations available in the software package and softcopy of the detail manual for the computer simulations was also available. Model building was the process in which the learner used a large number of different representations to describe events and processes in the simulated situations with the knowledge of basic models in mechanics.

The students in small groups were working interactively through discussion over the experimental investigation as part of the group thought activity. The degree of interactivity of the learner in simulation experimental activities was maximized through the available instruments and teaching materials such as written lab manuals, handouts, computers, and lab reporting format. The investigation was performed by doing multiple representations using computer software. Finally, they should check the value of the coefficient of static friction is greater than the coefficient of kinetic friction.

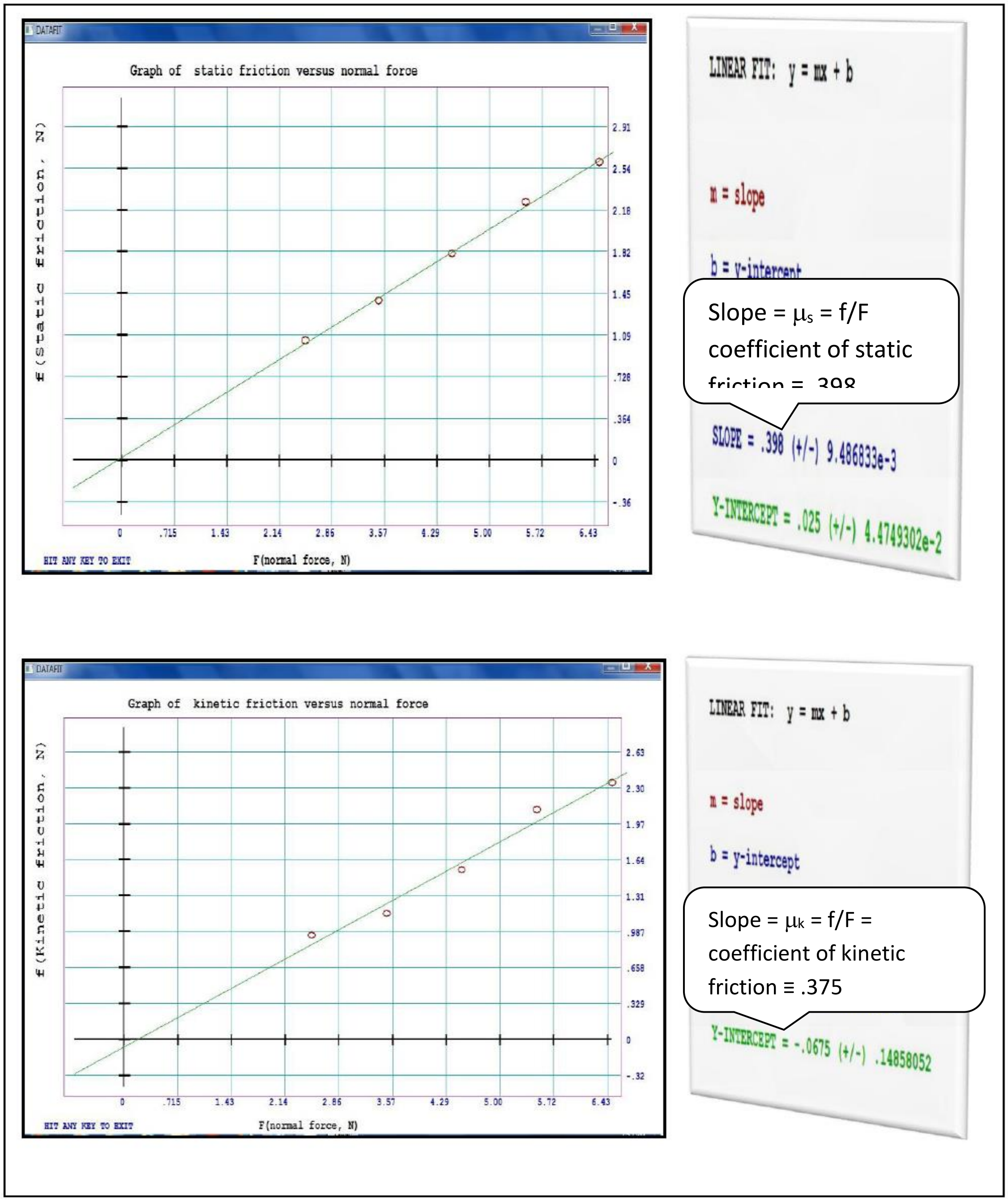


Figure 4: Graphical results for determination of coefficients of static & kinetic friction

The instruments for data collection are: (i) performance test to measure both dependent variables, namely problem-solving and experimentation. The performance test for problem-solving contained items scored out of 48 points of experimental performance on six simulation and physics experiments, separately each scored out of 18 points in line with scoring rubrics prepared for such purpose. (ii) conceptual questions (with 4 items) during problem-solving (iii) follow-up interview during experimentation was recorded (iv) written documents for certain worksheet questions and laboratory reports as part of the assessment and feedback were considered.

During the first week of the intervention period, inter-rater correlation coefficients were calculated in order to establish the reliability of the scoring rubrics for problem-solving and experimental performance. Based on scores from two assessors, the researcher, and an experienced staff member, the problem-solving had a calculated value of Kandull's tau .64, and the experimental got a calculated value of Kandull's tau .741. Both turned out to be significant at p=0.01 level indicating stability of the scoring rubrics. The performance tests for both problem-solving and experimentation were administered at post-test. Content validity as an indicator of the relevance of performance assessment tests in problem-solving and experimentation was established through decisions made together with subject instructors. Basically, the problems were taken from standard books and the experiments were standard experiments known worldwide. The researcher and the experienced teacher rated the test and there were inter-rater reliability between the two scores with calculated values of Pearson's correlation (r) equal to .78 and .809, respectively. Conceptual test activities were also used to collect data during tutorial and experimentation laboratory classes which were also taken from the text book. Moreover, focus group interview was also used to obtain qualitative data.

3. Results of the study

The teaching method and gender as factors of the independent variable and the interaction between them were found to have a statistically significant effect on the dependent variable known to be the problem-solving performance post-test (α = .05).

Table 2: Two-Way Analysis of Variance (Two-Way ANOVA) on problem solving performance test

Source	Sum of squares	df	Mean Square	F	Sig.	η^2
Method	809.649	1	809.649	22.271	.000	.236
Gender	540.067	1	540.067	14.856	.000	.171
Interaction	307.243	1	307.243	8.451	.005	.105
Error	2617.507	72	36.354			

The result of the *ANOVA* analysis in Table 2 indicates there was a statistically significant main effect for the teaching method, $F(1,72)$ = 22.27, $p<$ .05, indicating that the intervention was effective. The actual difference in mean scores between the groups was large (partial eta-squared = .236 = 23.6 % of the variability of the subjects' scores in the problem-solving performance test can be accounted for teaching method). Thus, the CAMR teaching method produced more learning improvement (M = 8.47) than traditional lecture teaching method (M = 3.66). There was a statistically significant main effect for gender, $F(1,72) = 14.86$, $p < .05$. The actual difference in mean scores between the gender groups was large (partial eta-squared = .171 = 17.1% of the variability of the subjects' scores in the problem-solving performance can be accounted for gender). The interaction effect between method and gender was statistically significant, $F(1,72) = 8.45$, $p < .05$. The effect size was medium (partial eta-squared = .105). The third significant factor which is labeled "interaction" means that the effect of the teaching method was not the same for female and male students. The independent *t*-test revealed a statistically significant difference between the mean performance test score for male students (M = 17.8) and female students (M = 6.3) in the CAMR group, $t = 3.39$, $df = 30$, and $p = .002 < .05$.

Table 3: Two-Way Analysis of Variance (Two-Way ANOVA) on experimentation performance test scores

Source	Sum of Squares	df	Mean Square	F	Sig.	η^2
Method	40.33	1	40.33	10.89	.002	.266
Gender	$1.8X10^5$	1	$1.8X10^5$	.00	.998	.000
Interaction	.075	1	.075	.02	.89	.001
Error	111	30	3.7			

In the same way, for design two, the result of the *ANOVA* analysis in Table 3 showed the main effect of the teaching method which was statistically significant $F(1,30) = 10.89$, $p < .05$. Thus, the CAMR teaching method applied to simulation experiments produced more learning advantage (M = 16.41) than traditional lecture method applied on the conventional physics experiments (M = 13.76). Partial η^2-eta squared was .266 (26.6 % of the variability of the subjects' scores in the experiment can be accounted for teaching method and considered large in magnitude). Gender was not the main effect, $F(1,30) = .00$, p > .05 and the interaction effect was not statistically significant, $F(1, 30) = .02$, $p > .05$. Therefore, there was no statistically significant difference observed by gender for experimentation ability which could be due to the application in the small groups.

As shown in Table 3, there was no significant correlation between scores of problem activities and post-test scores, r = -.256 and p = .156< .05. The problem-solving activities were not always subjected to a timely formative assessment and feedback. There was a statistically significant correlation between scores of experimentation performance test and scores of assessment of experimentation activities with p = .028 < .05. It means, there is dependence of experimentation performance post-test scores on scores of the lab reports as one increased the other increased too.

The correlation coefficients between the post-test scores and formative assessment scores of problem-solving and experimental activities were also calculated. Correlations between the post-test and scores of problem-solving activities were found as r = -.256 and p-value .156. On the other hand, the correlations between post-test and scores of experimentation activities were found as r = .531* and p-value .028.

When we see the excerpt of the record of a small group of students, who were engaged to solve the following question taken from the textbook, we describe constant-acceleration motion with the variables and parameters v_{xi}, v_{xf}, a_x, t and $x_f - x_i$ of the equations:

$$\text{(i) } v_{xf} = v_{xi} + a_x t$$

$$\text{(ii) } x_f - x_i = \frac{1}{2}(v_{xi} + v)$$

$$\text{(iii) } x_f - x_i = v_{xi}t + \frac{1}{2}a_x t^2$$

$$\text{(iv) } v^2_{xf} = v^2_{xi} + 2a_x (x_f - x_i)$$

The first doesn't involve $x_f - x_i$, the second does not contain a_x, the third omits v_{xf}, and the last leaves out t. So to complete the set there should be an equation not involving v_{xi}, but it is derived from the others. Students of the small group were engaged to solve the problem. They searched the set of equations from (i) to (iv) as mentioned in the question somewhere in the textbook. According to the records of the discussions which were going on among students along with the teacher, students finally understood the problem and obtained additional equations not involving v_{xi}.

$$x_f - x_i = v_{xf}t - \frac{1}{2}at^2 \tag{1}$$

This new equation was found important to solve the previous question students were in charge in a simple way. To consolidate the knowledge they gained homework questions were assigned for the small groups of students to solve in line with the problem-solving strategy. The format guided them to follow steps of forward-looking model-based strategy. They were also told to make necessary preparations for projectile motion to be discussed in the next tutorial session.

Let us see the work of a small group of students in measuring the acceleration of motion along air track where the manual and the built-in instruction described the procedure in detail. Accordingly, they collected the data in table form and the analysis was made to determine g (the acceleration due to gravity). The graph was drawn with a slope = m = 1/2 a = 1/2 g sinθ. The students had used data analysis software in the software package to obtain the graphs indicated in figure 5.

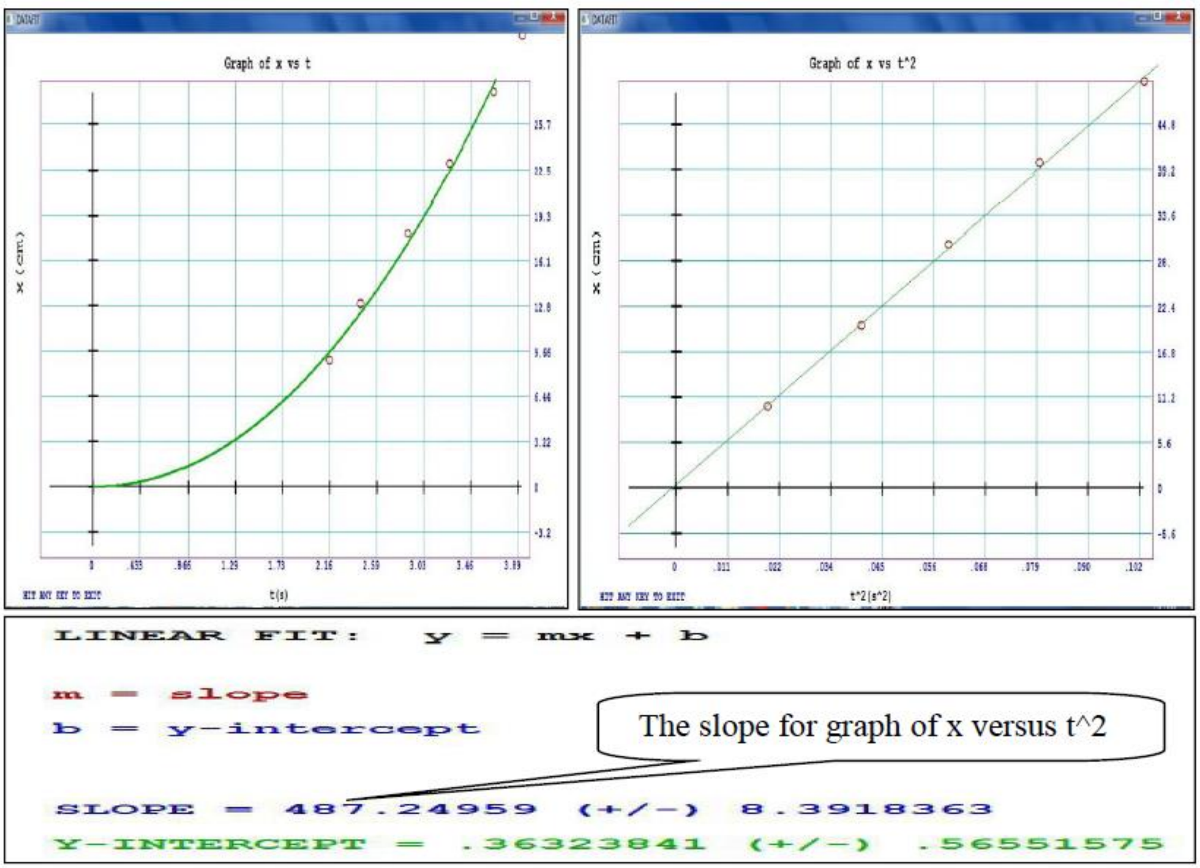


Figure 5: Example of graphs drawn by students that show x-t and x-t2 graphs

The software can easily calculate the slope of x vs t^2 graph and equate it with 1/2 a = 1/2 g sinθ. The slope of the graph was calculated to be 487 cm/s^2 or the same to say $9.74 m/s^2$ = g sinθ which helped them to estimate the value of g. The students were also encouraged to use a standardized laboratory reporting format in computer-based experiments.

The conclusion of the lesson involved making remarks either from the students' or the instructors' side in order to substantiate the outcomes of problem-solving and experimentation activities. That was done in order to advance meaning-making and meaningful learning which could be ensured as students work to understand and apply scientific models. The computer model was designed in such a way that the students were engaged interactively to think and justify based on basic models. The truth is that not every model has to fit every phenomenon but the controversy (discontent) that occurred has opened up opportunities for students to be able to build the appropriate models for that specific phenomenon. The final evaluation stage was meant to verify the correctness of stage-by-stage progressions in experimentation and problem-solving which could be done in group discussions and oral presentations to be supported by assessment and feedback practices.

There was, therefore, valid evidence that the CAMR teaching method was important. The result of focus group discussions indicated what students experienced in group work, weekly activities, and peer assistance were helpful in bringing learning gains in the course. A significant percentage of the students replied that they had a better understanding of basic models, laws, principles, and multiple representations in mechanics they used in problem-solving. The instructor was interviewed to cross-check the importance of CAMR for the reported learning gains and the response attuned to the report obtained from the students.

The content analysis indicated that students made significant progress in problem-solving performance. Every time the students strictly followed the CAMR, they understood the problem by searching the basic model in mechanics. The basic models were used to make multiple representations. Students in significant numbers thought that group work, laboratory reports, computer utility, weekly activities, and peer assistance as features of CAMR were helpful in learning the course. It was also revealed that due to the implementation of CAMR in teaching, students responded as they obtained a considerable understanding of laws and principles, basic models, and multiple representations in mechanics. They also responded that they gained practical skills in designing laboratory experiments, finding trends in data, working cooperatively, and oral presentations.

4. Discussion

Lin & Singh (2015) found that for the quantitative problem involving strong alternative conceptions, simply guiding students to work through the solution of the analogous problem was not enough to help most students. However, additional scaffolding supports directly helped students examine and repair their knowledge elements involving alternative conceptions. The reason is that misconceptions, unless treated with appropriate teaching methods, could limit students' performance in problem-solving and experimentation as demonstrated in this study. Thus, active learner involvement in small group discussion through working with basic models and multiple representations, as elements of CAMR, can bring students' conceptual understanding to the level they can perform problem-solving and experimentation for better results.

The result obtained based on design one showed CAMR teaching method brought about better performance scores in problem-solving which is consistent with prior research works (Ornek, 2009; Vesenka et al., 2002). The application of CAMR in design two also brought a significant experimental performance for the effectiveness of CAMR and for students' conceptual development gains as well. Computer simulation in-line with the assessment methods is effective in both computer-based and hands-on activities (Ekmekci & Gulacar, 2015). Similarly, learners who are taught using computer simulation were happy with the approach used by Kibirige & Tsamago (2019).

Duran (2016) argues that the inquiry-based learning approach as a constructivist learning approach can contribute to students' use and development of critical thinking skills in problem-solving and experimentation activities. In addition, Raiz, Marcinkowski, & Faisal (2020) reported the effect of discovery learning on students' conceptual understanding and they found that the new approach significantly improved their conceptual understanding during laboratory activities. Brewe, Kramer & O'Brein (2009) pointed modeling instruction impacts students in a significant, positive manner in learning introductory physics courses. There is therefore supportive evidence about the effectiveness of CAMR when it is applied in problem-solving and experimentation that is revealed in this study. The overall impact of the intervention as reported by both the students and the teacher and revealed by conceptual test results and focus group interview was positive since it was helpful for students' learning.

5. Conclusion

This study confirmed that the CAMR teaching method is practical and effective in bringing about better outcomes in problem-solving and experimentation performances in mechanics courses. It was also found that male students achieved better than female students in problem-solving, but no significant difference was observed in experimentation performance. There was a significant correlation between experimentation performance tests and formative assessment scores of experimentation activities, but no significant correlation was obtained for problem-solving activities.

6. Implications

The finding of the study implies that teaching organized knowledge is essential for the effective performance of problem-solving and experimentation tasks and activities. In general, there is no one best strategy for all classroom situations, thus future research should focus in order to test new effective teaching strategies.

Declaration of competing interest

The author declare that there is no conflict of interest in this study.

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