



Students' Gender Proficiency in Multiple Representational Format and Mathematical Reasoning in Senior School Physics Problem-Solving

Funke Susan Apata^{1*}

¹Faculty of Education, National Open University of Nigeria, Abuja–Nigeria

*Corresponding email: fapata@noun.edu.ng

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ABSTRACT

This study investigated multiple representation formats and mathematical reasoning to unravel physics concepts and laws in problem-solving. Four hundred and sixty (460) students from forty-six (46) co-educational schools in Kwara State- Nigeria, participated in the study. Using a random sampling technique 230 males and 230 females were selected. The two instruments used are Physics Multiple Representational Test and the Physics Mathematical Reasoning Test. Two research questions and two hypotheses guided the study. Results of the analyses through frequency count, percentages, and t-test revealed a low mean value for mathematical reasoning and the representational format of students. The male recorded a higher mean value in multiple representation formats and mathematical reasoning than their female counterparts. It concluded that students' mathematical reasoning and multiple representational formats in problem-solving were low, and the female students were the most affected when it comes to low performance. The study recommended a curriculum review to accommodate an introductory course on multiple representations. Also, an innovative program that enhances mathematical reasoning and promotes the relationship between mathematics and physics is in the curriculum. Extracurricular activities that could stimulate female interests in representational format and mathematical reasoning, should be introduced in schools.

Keywords: Gender Proficiency, Multiple Representation Format, Mathematical Reasoning, Physics, Problem-Solving.

INTRODUCTION

Physicist unravels the implications of the laws through quality problem solving for formative and summative assessment in the physics classroom. Ayudha, C.F.H & Setyarsih, W (2021) asserted that problem-solving is the most crucial skill physics educators should have. Researchers proposed several strategies that could be employed while solving a problem in physics. They include (i) analyzing the given problems, (ii) developmental features of a situation, (iii) identifying the problem to solve as the subject matter, (iii) finding the basic actions that are adequate to the given problem, (iv) precise definition of formulas that are adequate to solve the problem, and (v) thinking of all possible special and normal cases of a problem (Jonassen, D.H, 2011; Ledesma, E.F.R, 2012).

Despite the evidence that problem-solving strategies are universally recognized and crucial for physics performance, and despite the efforts of researchers, educators, and physicists to improve these skills, accessible results reveal students' underachievement in physics (Musasia, A.M, et al., 2016; Reddy, M., & Panacharoensawad, B., 2017). According to Haratua, T. M. S. & Sirait, J (2016) students' problem-solving strategies are insufficient to tackle problems successfully. Ngadimin, et al (2021) asserted that physics disciplines are more than just materials and formulas. The reason might be physics is full of visual representations such as experiments, formulas and computations, graphs, and explanations of concepts (Ornek, F., et al, 2008). Hasanah, D. S. (2021) stated that physics as an exact science requires students and educators to have high analytical skills. Hence, this is a challenge for the world of physics education to develop the students not only in their cognitive abilities but also in their psychomotor and affective abilities (Fadlina & Ritonga, S., 2021).

Researchers found that scaffolding supports can help people develop problem-solving skills (Bao et al., 2011; Lin & Singh, 2011). In a similar vein, Lucas, L.L (2014) reported using representations to solve physics problems makes the process easier. Literature showed that multiple representations are an approach that encourages comprehension of concepts and addresses physics problems (Dewati et al., 2019b; Prahani et al., 2016).

Kohl, P. B & Finkelstein, N (2017) opined that students who have grasped a physics idea will have little trouble expressing their comprehension in multiple representations. Similarly, Mason, A & Singh, C (2011) found that experts typically begin by visualizing the problem and performing the conceptual analysis and planning steps before moving on to the implementation, while novices may look for plausible formulas without regard to their applicability. Also, educators can assess students' mental representations, allowing them to create the skills needed to produce a more coherent understanding of how students handle physics problems. According to Lucas, L.L (2014), tangible representations in physics problem solving provide students with the skills they need to acquire a more coherent understanding of how they solve physics problems. It also improved qualitative and quantitative reasoning skills. Hence, literature abounds on the effect of multiple representational formats in problem-solving for learning gains.

Additionally, in the early study Kohl, P. B & Finkelstein, N (2017) reported that good use of multiple representations is considered key to learning physics. For instance, Chiou, G. L & Anderson, O. R (2010) found a relationship between students' mental models and their explanations of heat conduction. Also, Fredlund et. al. (2012) investigated the potential of different representations in supporting students' understanding of the properties of light in an interactive learning session. Additionally, representations proficiency is regarded as a problem-solving tool in a conscious, skilled, and interconnected manner (Justi, R., et al, 2009). Stieff, M & DeSutter, D (2021) stated that representational proficiency is leverage for conceptual change and improving student learning outcomes in science, especially physics. Jonassen, D.H (2011) asserted that problem-solving entails mental representation and some

manipulation. Hence, adopting appropriate means such as written language, diagrams, sketches, graphs, equations, and manipulations can help students understand physical quantities and concepts in better form that ease problem-solving.

Tenzin, D (2019) reported despite students' outstanding attitudes about understanding the material of physics, the mathematical nature of physics still challenges the students' performance in problem-solving. Empirical evidence has revealed being able to describe complicated and abstract topics in many ways improves students' problem-solving abilities (Ibrahim, B. & Rebello, N.S, 2013; Bollen, L., et al, 2017; Klein, P., et al., 2018; Maries, A & Singh, C., 2018; Susac, A., et al., 2019).

Adetula, L.O (2010) asserted that physics is based on elementary, secondary, and tertiary theories Simple mathematical inferences and logical linkages disseminate the primary, whereas the inductive-deductive scheme propagates the secondary. The tertiary theories are also for the deductive mathematical framework. Physicists base their physical theories on mathematical assumptions and axioms using these ideas. According to Ornek, F., et al (2008), physics covers many fundamental and derived formulations with inductive and deductive approaches, making geometry and algebra skills advantageous. Similarly, Pospiech, G (2007) said that mathematical representations such as geometrical objects, diagrams, algebraic formulas, and verbal explanations each have a unique purpose in quantifying and visualizing physical processes.

Furthermore, Apata, F. S (2016) explained that most of the problems in physics require mathematical cognition, making it critical for students who want to do well in physics to have a strong background in mathematical reasoning. Lim, C. S & Hwa, T. Y (2006) described mathematical reasoning as a mental operation aided by mathematical knowledge and a desire to solve problems. According to Ezugwu, A. E, et al (2020), numerical reasoning is the ability to think with numbers. Furthermore, researchers defined mathematical reasoning as the ability to answer a problem using appropriate mathematics and algorithms (OECD, 2019; OECD, 2016b; OECD, 2015). According to Chukwunenye, J.N, et al (2019), numerical thinking is the ability required to apply arithmetic operations alone or in sequence. Mathematical reasoning can also be a tool that can solve a variety of problems (United Kingdom Committee on Education, UKCE).

In an Early study, Sherin, B. L (2001) maintained that students must understand how to interpret mathematical structures in physical terms to perform well in physics. For instance, the Malaysian Mathematics Curriculum aspires to build the human capital that can think mathematically and use mathematics in real-life situations, according to the Ministry of Education Malaysia (MOE, 2004). Also, in a previous study, Karadag, Z (2009) discovered that the mathematical thinking skills that aroused the most in problem-solving were analyzing, conjecturing, and reasoning. Hence, mathematical reasoning is a necessary skill for addressing physics problems.

The promotion of gender equity, women's empowerment, and the elimination of gender disparity in primary and secondary education at all levels are some of the aims of the United Nations' millennium statement of September 2000 (United Nations, 2000). According to global data, women hold little under 20% of postgraduate physics positions, with the high reduction in women's representation occurring between high school and university (UNESCO, 2018). An early study showed that gender differences could affect the capacity to think mathematically, but also the process of acquiring mathematical information, according to researchers (Brandon, P., et al, 1985).

Dewi, N. R., et. al., (2019) revealed male students' mathematical thinking ability achievement is comparable to female students in a test of mathematical thinking conducted at a university in Central Java-Indonesia. According to Arhin, A. K. & Offoe, A. K (2015), there is no substantial gender difference in mathematical reasoning or physics achievement. In Ghana, Tetteh, H. N. K., et al (2018) discovered that male students win science and mathematics quizzes (Brilliant Science and Mathematics Quiz), and female students also win over their male counterparts. Female pupils outperformed their male counterparts in mathematical achievement, according to Ajai, J. T & Imoko, B. I (2015). Female physics students outperformed their male counterparts when exposed to cooperative learning, according to Apata (2020). Therefore, studies on gender revealed inconsistency in the performance of male and female students.

Problem of Research

Physics contains a broad spectrum of fundamental and derived formulations that gain meaning through exact relations among physical quantities. It is a subject for scientific and technological advancement in a nation. Despite its relevance to human activities and growth, students considered it abstract, and difficult to comprehend. Hence, these had led to perennially low achievement in the subject (Reddy, M., & Panacharoensawad, B., 2017). Poor instructional strategies used in teaching, non-proficient in mathematics, lack of interest, low ability; negative self-concept, anxiety, maladjustment, environmental influences such as poor classroom conditions, curricular inadequacies, peer groups, a lack of home support, poor problem-solving skills, poor understanding of the concept of physics, and a lack of motivation are the causes of poor academic performance among senior school students (Apata, F. S., 2016). Given the empirical evidence for their strength, only a few researchers have focused on gender in representational format and mathematical reasoning proficiency as problem-solving induced factors in senior secondary school. Therefore, this study will cover the gaps by assessing students' multiple representational and mathematical reasoning in problem-solving as it relates to gender.

Research Focus

The main aim of this study is to find out how students in senior school physics use multiple representational formats and mathematical reasoning in solving questions. The specific objectives are to:

1. Investigate the students' representational format in solving physics problems.
2. Determine the students' mathematical reasoning when solving physics problems.
3. Examine the impact of gender on students' representational format in solving physics problems.
4. Determine the impact of gender on the students' mathematical reasoning when solving the problem in physics.

To realize the stated objectives, two research questions (i) and (ii) were answered:

- (i) What is the level of the multiple representational formats in physics problem-solving among the students?
- (ii) What is the level of mathematical thinking in physics problem-solving among students?

and the two hypotheses (a) and (b) were tested:

- a) There is no significant difference between the multiple representational formats of male and female students in solving problems in physics.
- b) There is no significant difference between the mathematical reasoning of male and female students in solving problems in physics.

METHODOLOGY OF RESEARCH

General Background of Research

This study was conducted in Kwara State of Nigeria. The time for the study was 13th November 2021 to March 24th, 2022. The research is descriptive.

Subject of Research

The research is descriptive. The population for the study was made up of SSII physics students in Kwara State. The study's participants were SSII physics students from Kwara State. The study involves SSII classes because they were not involved in external examinations. A total of 46 co-educational secondary schools that met the study's criteria were selected. The following are the criteria:

- (i) A minimum of five males and five girls must be present in the SSSII physics class.
- (ii) Minimally, four sets of physics students must have written WAEC and NECO for the Senior School Certificate Examination (SSCE).

Intact classes of physics students participated at the SSS II level. Five male students and five female students from each participating school were involved in the study, through a random and stratified sampling technique. The selection is before the marking exercise commences. The sample size was four hundred and sixty (460) students.

Instrument and Procedures

Two relevant instruments, "Physics Multiple Representational Test" and "Physics Mathematical Reasoning Test," were adapted from Ibrahim, B & Rebello, N.S (2012) and WAEC past questions respectively. The test items were from the topics the students had covered, based on the scheme of work and the teachers' attestation.

The "Physics Multiple Representational Test" has two sections. Section A provides the biographical data of students, which includes name, school, and gender. Section B contains five questions from the optics and mechanics sections of the syllabus. The students had already learned the topics. The adapted questions were prepared by the table of specifications, according to Bloom's Taxonomy. The "Physics Multiple Representational Test" aims to explore proficiency in physics representational format through the following:

1. Draw a diagram (s) that represents your understanding of the problem through a chart, graph, sketch, free-body diagram, picture, or arrows.
2. Label the diagram (s) with symbols of physical quantities given in the problem.

The second instrument, the "Physics Mathematical Reasoning Test," has two sections. Section A is for the biographical data of students. Section B contains five adapted questions prepared using a table of specifications by Bloom Taxonomy. The essay questions covered (i) waves and (ii) mechanics which the students had learned. This instrument assessed students' mathematical reasoning through the following:

- i. Identify the physics concepts that you think are relevant to solving the problem.
- ii. Briefly explain how you will use the key concepts in your procedure for solving the problem and evaluating if your answer is correct.
- iii. Identify the equations that you would need.
- iv. Express the necessary mathematical processes, such as (i) recognition of constants and (ii) variable classification needed to arrive at the final answer with the appropriate unit.

Students were allowed to use any method to solve the questions. Also, none of the test items in the "Physics Multiple Representational Test" is in a diagrammatic format. Due to investigating whether the students recognize the importance of multiple representational and reflect them in their workings. The marking guide for the instrument used rubrics based on the process that led to the answers.

For ethical reasons, permission was granted by the Kwara State School Board before administering the instruments at the selected schools. The purpose of the study was explained to the schools' principals and students. The researcher told them their results and personal information would be kept private. Also, recommendations shared with the school board will improve physics education. The study was accepted by all 460 students, resulting in a 100 percent success rate.

The instruments were subjected to validation by physics educators and measurement evaluators in the department. A reliability test with a test-retest method revealed 0.76 and 0.82 reliability indexes for the Physics Multiple Representational Test and the Physics Mathematical Reasoning Test, respectively.

Data Analysis

Data were analyzed using descriptive statistics (frequency count and percentages) and a t-test.

RESULTS AND DISCUSSION

Level of physics students' performance in representational format, using frequency counts and percentages

Table 1. Level of physics students' performance in the representational format

Score Range	Frequency	Percentage (%)
0 – 49	359	78
50 – 69	101	22
70 < above	0	0

Table 1 shows the levels of students in representation physics problem-solving. The table showed that the general performance of the students in representation is low. These are evident from the frequency and percentage of students within the score ranges of 0 – 49, 50 – 69, and 70<, as 359 (78%), 101 (22%), and 0 (0%), respectively.

Level of physics students' performance in mathematical reasoning using frequency counts and percentages

Table 2. Level of Physics Students' Performance In Mathematical Reasoning

Score Range	Frequency	Percentage (%)
0 – 49	329	72
50 – 69	121	26
70 <	10	2

Table 2 reveals that the performance in mathematical reasoning is low, with 72% of the students' scores being within the range of 0–49, 26% being within 50–69, and 2% being in 70<.

Based on the analysis of hypothesis testing about the representational formats of male and female students in solving problems in physics, the results show there is no significant difference between the representational formats of male and female students in physics.

Table 3. T-test of Representational Formats of Male And Female Students In Physics Problem-Solving.

Variable	N	Mean	SD	SE	DF	t-cal	P
Male	230	28.3478	17.29934	1.14068	458	3.644	.000
Female	230	22.9217	14.51345	.95699			

Significant at 0.05 alpha levels

From the data shown in Table 3, the mean score of male physics students is higher in representational formats (mean = 48.18; SD = 17.29934) than that of female physics students (mean = 22.9217; SD = 14.51345). This difference is significant ($t = 3.644$; $df = 458$; $P 0.05$). The null hypothesis which states that there is no significant difference between the representational formats of male and female students in physics is rejected.

Based on the analysis of hypothesis testing about the mathematical reasoning of male and female students in solving problems in physics, the results show there is no significant difference between the mathematical reasoning of male and female students in physics.

Table 4. T-Test of Mathematical Reasoning of Male And Female Students In Physics Problem-Solving.

Variable	N	Mean	SD	SE	DF	t-cal	P
Male	230	40.7217	18.07072	1.19155	458	6.207	.000
Female	230	31.4609	13.61946	.89804			

Significant at 0.05 alpha levels

Table 4 shows that male physics students obtained a higher mean score in mathematical reasoning (Mean = 40.7217; SD = 18.07072) than their female counterparts (mean = 31.4609; SD = 13.61946). The t-test indicated that there was a significant difference ($t = 6.207$; $df = 458$; $P 0.05$). The null hypothesis which states there is no significant difference between male and female physics students in their mathematical reasoning was rejected.

The findings revealed that the general performance of the students in representational format is low. Thus, it implies that many students were not proficient in multiple representations in solving physics problems. The result is in agreement with Saniter, A (2003); Nieminen, P., et al (2010); Theasy, Y., et al (2018); Rahim, N. S. A, et. al (2019), and Munfaridah, N., et al. (2021). A study carried out by Saniter, A. (2003) showed that even at the university level, students have been failing to connect the meanings of formulas to phenomena and experiments. In a related study Nieminen, P., et al (2010), found only 11% of the learners produced coherent and scientifically correct representations after a teaching sequence. In another study, Theasy, Y., et al (2018) found that in the graphical representation, students tend to have difficulty in determining the exact position of variables on the axis in, Work and Energy Problems Solving. Rahim, N. S. A., et al (2019) remarked in a study conducted in Malaysia that the use of representations by students in solving problems is

interpreted by the minimal scores obtained. Munfaridah, N., et al (2021) revealed that the group of "returning students" did not show significant growth in their representation ability of electricity topics, unlike the group of "new students." Hence, from the findings of this study, it can be inferred physics curriculum in secondary schools does not contain lessons that teach students the use of multiple representations in problem-solving. However, the findings of Sa'dijah, C., et al (2021) differ from the present work which revealed Indonesia students' skills in generating different representations to solve word problems.

Table 2 shows that physics students' performance in mathematical reasoning is low. The findings are consistent with those of Liu, P. H., & Liu, S. Y (2011), Herman, T. (2018), and Brahmia, S.W., et al. (2021). A study carried out by Liu, P. H., & Liu, S. Y (2011) found lack of understanding of development in mathematics and physics among the students had narrowed their views and further affected their preferences in mathematics and physics. In another study, Herman, T. (2018) shows that students generally still have problems with reasoning and further stress that students still run into constraints when dealing with the reasoning in general. Brahmia, S.W., et al. (2021) found despite mathematical reasoning being taught in prior mathematics courses, the pretest and posttest scores revealed that the knowledge is not applied. These findings suggest that physics educators should develop novel teaching ways to motivate students to reason in mathematics to close the problem-solving gap.

Findings on mathematical thinking and gender revealed that male students performed better than their female counterparts. The result is at variance with Long, Y. C & Jiar, Y. K (2014); Arhin, A. K & Offoe, A. K (2015); Tetteh, H. N. K., et al (2018) and Dewi et al. (2019). A study carried out by Long, C. Y & Jiar, Y. K (2014) found no significant difference in mathematical thinking and physics achievement by gender. In another study carried out by Arhin, A. K & Offoe, A. K (2015) indicated that in gender, there was no significant difference in mathematical thinking and physics achievement. In a study conducted by Tetteh, H. N. K., et al (2018) in Ghana's science and mathematics quizzes (Brilliant Science and Mathematics Quiz), male students emerge as winners and sometimes female students also emerge as winners over their male counterparts. In another study, Dewi et al. (2019), found that male and female students performed equally in mathematical thinking achievement tests at a university in Central Java, Indonesia. The reason for this result might be due to the wrong teaching methods of the teachers.

Findings on gender representational format revealed a mean score of the male is higher than their female counterparts. Finding agrees with Nieminen, P., et al., (2013) and Munfaridah et al. (2021). In a study conducted by Nieminen, P., et al., (2013), males significantly outperformed their female counterparts in force concept, pre-and post-test representational consistency, and pretest scientific reasoning. In another study, Munfaridah, N., et al. (2021) found female students had slightly higher error rates on graphical questions. The researcher stressed further; that those female students have difficulties with electric

circuit diagrams. This result might be that the female students are not too inclined in the psychomotor domain.

CONCLUSIONS

It concluded that students' mathematical reasoning and multiple representational formats in problem-solving were low, and the female students were the most affected when it comes to performance. The study recommended a curriculum review to accommodate an introductory course on multiple representations. Also, an innovative program that enhances mathematical reasoning and promotes the relationship between mathematics and physics is in the curriculum. Extracurricular activities that could stimulate female interests in representational format and mathematical reasoning, should be introduced in schools.

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