

Multiple Representations: An Approach to Teaching Selected Physics Topics

*Aduo Frank¹, Isaac Litukgma Njofuni²

¹Department of Science, Adankwaman Senior High School, Central Region, Ghana

²Department of Integrated Science Education, University of Education, Winneba

DOI: <https://dx.doi.org/10.51584/IJRIAS.2025.1009000104>

Received: 10 September 2025; Accepted: 16 September 2025; Published: 25 October 2025

ABSTRACT

This study investigated the impact of using multiple representations in teaching selected physics topics, specifically sound and waves, to senior high school students in Ghana. An action-research design was employed with an intact class of 30 form two students purposively sampled. Various representational formats including visual, text, graph, diagrammatic, and mathematical representations were incorporated during lessons. The main data collection instruments were achievement tests and classroom observation over five lessons. Findings revealed that students demonstrated improved skills in diagrammatic, graphical, verbal, and mathematical representations, with a notable enhancement in their cognitive achievement on physics concepts relating to sound and waves. The intervention engaged students actively in classroom discourse, promoting higher motivation, interaction, and participation. Quantitative analysis showed significant gains in students' ability to correctly solve physics problems using multiple representations compared to pre-intervention results. The study concluded that employing multiple representations supports conceptual understanding and problem-solving skills, counteracting the limitations of traditional lecture-based teaching that often leads to rote memorization and low engagement. The use of diverse representations facilitated students' development of science process skills such as graph drawing and diagrammatic reasoning. Recommendations include integrating multiple representations consistently in physics curricula, encouraging collaborative learning, and providing teacher training on implementing these strategies. The findings underscore the pedagogical value of multiple representations and provide a basis for adopting similar approaches to improve science education outcomes in Ghana and beyond.

Keywords: multiple representations, physics education, cognitive achievement, representational competence, physics problem-solving.

INTRODUCTION

The presentation of any system or process with representations such as diagrams, tables, equations, texts, graphics, animations, sounds and videos as two or more is expressed as multiple representations (Ainsworth, 2006; Rosengrant, Etkina, & Van Heuvelen, 2007).

According to Wanbugu and Changeiywo (2008), physics is classified as a difficult subject, not popular, avoided by students and with poor performance in schools. This detrimental performance in physics is as a result of many factors; lack of appropriate teaching materials and qualified teachers, traditional teaching methods, lack of mathematics skills, student epistemologies and misconceptions (Onah, & Ugwu, 2010; Ojo, 2001; Zewdie, 2014; Elby, 2001).

Researchers such as Ainsworth (1999), Dolin (2001), and Russell and McGuigan (2001) argue that, for effective learning of science concepts, there is a need for students to understand different representations of scientific concepts and processes, capable of combining them into one another, as well as understand these representations co-ordinate in representing scientific knowledge. Employing multiple representations in teaching and learning can provide many contexts for learners to understand a concept (Cock, 2012). Students

of Physics find themselves to do multitasking and often realised they are not ready for it. This perception, however, negatively impacts students' achievement. One important factor which is behind this poor performance as revealed by many studies is the traditional instructional approach which is mainly used. This method of teaching is ineffective for teaching different physical principles (Wieman & Perkins, 2005; Elby, 2001; Jimoyiannis, & Komis, 2001).

Multi-representational learning environments are used by a wide range of learners in a number of domains and asserted to be of numerous benefits for their use. The use of multiple representations in learning can provide many contexts for learners to understand a concept (Cock, 2012). According to Kohl, Rosengrant, and Finkelstein (2007), the use of multiple representations affects learners' performance in problem-solving and can be used as a way to solve abstract problem during problem-solving.

Statement of the Problem

lecturing teaching approach to teaching physics is a contributing factor behind low performance in physics. Presentation of concepts through lecturing approach may lead to loss of interest and enthusiasm in learning as student tend to forget what they easily learn. When students are asked to solve physics problems, a big number of them do not develop the necessary conceptual understanding, but try to memorise only mathematical formulas (Elby, 2001). This leads to the students developing negative attitude towards the learning of physics, consequently affecting students' academic performance in physics.

In this regard, teachers have to employ various teaching methods in order to optimise the achievement of students by involving them in learning activities, and if not, students tend to memorise what they are taught without conceptual understanding. Recent studies suggest that students learn more when they are able to learn from multiple modes of representation in that, multiple modes of instruction require greater cognitive involvement (Ainsworth, 1999, 2006; Gunel, Hand, & Gunduz, 2006).

Few studies have focused on the occurrence of science learning while focusing on the modes of representation (Hand, Gunel, & Ulu, 2009; McDermott, 2009). There are numerous representational formats present in the physics teaching syllabus but only few are used with little impact on students' learning. There was therefore the need to identify various representational formats available in the Teaching Syllabus for Physics (Senior High School 1-3) and conduct a study on the impact of these multiple representations on teaching selected physics topics, specifically, sound and waves.

Purpose

The purpose of this study sought to identify various representational formats present in the Physics Teaching Syllabus and examine effects of these multiple representations on form two physics students' learning achievement.

Research Question

The research questions that guided the study were as follow:

What representational formats are available in the Teaching Syllabus for Physics (Senior High School 1-3) in Ghana.?

What are students' cognitive achievement in sound and waves when they are taught using the representational teaching approach?

Significance of the Study

The findings and recommendations of this study be of great benefit to physics students and teachers who teach physics in Ghanaian schools.

The findings of this study could be very important to the various stakeholders of education, since this study focused on the effects of multiple representation-based environments in physics classroom, its results would help physics educators who seek alternative pedagogical instructions in classroom settings.

Furthermore, teachers' awareness of students' understanding of the multiple representations and kind of learning supported by multiple representation-based environments will enable teachers to better choose and utilise appropriate type of methods, manipulations, or activities to meet the needs of students.

Finally, the study also extends existing theory about the role of the teacher and student in constructing multiple representations in teaching, learning and assessment.

Review of Related Literature

Multiple Representations

The presentation of any system or process with representations such as diagrams, tables, equations, texts, graphics, animations, sounds and videos as two or more is expressed as multiple representations (Ainsworth, 2006; Rosengrant et al., 2007). Representations can be either internal or external and are effective in moulding, amplifying and generating mathematical ideas (Johnson & Lesh, 2003). External representations such as concrete objects and manipulatives, and visual aids such as diagrams are designed and used to make abstract mathematical concepts more approachable to learners (Gravemeijer, 2002). According to Cuoco (2001), learners develop their internal representations of mathematical concepts based on the external representations' teacher selects to introduce them.

Moreover, they are effective not only upon enabling increasing students' comprehensions, but also their performances (Scaife & Rogers, 1996; Ainsworth, 2006). It could be stated that multiple representations will smooth the transform of information from one form to another for students. In the process of learning, it could be stated that addressing to students with richer representations by increasing the variety of external representations that affect the cognitive configuration gives more effective results. Because it is evident that there is a need for consciously-structured external supporting within the process of the concept instruction (Lappi, 2007) and (well-designed) two representations are better than one representation (Bransford & Schwartz, 1999; Ainsworth, 2006). In this sense, attention could also be paid to the common finding of different studies (Zou, 2000; Mutimucuo, 2003) regarding the fact that multiple representation is an effective strategy for students' learning and drawing their attention. Within the scope of this study, it is aimed to discuss the efficiency of learning environments, which highlighted with the multiple representations for the sound and waves topic in senior high school physics subject.

Kinds of Representations Adopted by Students during Problem Solving in Physics

Lehrer and Schauble (2000) stated that during the problem-solving process, students use several kinds of representations as one way of making their thinking visible and communicating their ideas. Generally, students combine both conceptual reasoning (i.e., related to verbal representation) and equations (i.e., related to mathematical/symbolic representations). We always need text, formulas, symbols, graphs, and/or figures to learn physics. Overall, the outcomes of the review show that when students use representations in multiple formats during the learning process, their conceptual understandings of physics concepts as well as problem-solving skills are enhanced (Chiou & Anderson, 2010; Fredlund, Airey, & Linder, 2012; Ibrahim & Rebello, 2013; Kuo, Hull, Gupta, & Elby 2013; Kohl & Finkelstein, 2006; Meltzer, 2005). My experience in learning physics as a student and teaching physics as a professional teacher has made me to realise that problem solving in physics is supported by selecting equations followed by explaining the meaning of the equations to examine whether the solution is correct.

Kuo et al. (2013) argued that such an approach, combining equations and verbal representation, can help students in the problem-solving process. In their case study, they explored how students blended conceptual and mathematical reasoning in the problem-solving process. It was found that students used either a symbolic form-based explanation of the velocity equation or a blended processing. Based on these results, the

researchers argued that blending conceptual and symbolic reasoning has the potential to support student learning.

Representational Competence Among Students

When focusing on student use of multiple representations, especially in the sciences, student difficulties are associated with both understanding the representations themselves as well as how to reason using representations while learning and during problem solving. Focusing on physics, the difficulties with graphing become more pronounced as the need to use them appropriately becomes more critical (Woolnough, 2000; Wu & Krajcik, 2006). Student difficulties are associated with interpretation of the axes, understanding the gradient and failing to understand why two different graphs that look the same, but have different variables, don't necessarily represent similar situations.

Interestingly, student understanding is sensitive to context, for example, many are unable to answer graphical questions which include the same level of mathematics which they have already demonstrated proficiency in, in another context (Britton, New, Sharma, & Yardley, 2005). Such inconsistency is part of how students negotiate tenuous understandings as they co-construct conceptual knowledge in physics. Experience also suggests that some students simply lose confidence when a question includes a graph, or requires them to use a graph, leading to a higher level of stress and incorrect answers (Engelbrecht, Harding, & Potgieter, 2005). There has been a range of investigations into student difficulty with other representations key to physics including equation-based (Bieda & Nathan, 2009), diagram-based (Pollock, Thompson, & Mountcastle, 2007) and word-based representations (Dufresne, Gerace, & Leonard, 2004). Thus, it was concluded that, for students to succeed within the scientific discipline, they do not need to simply be competent with one representational format, rather to shift their tenuous and often inconsistent understandings, towards those that are more scientifically congruent. This implies that students need to choose and use appropriate individual representations and integrate between them when needed. Consequently, while continued research into individual representations is immensely valuable, the field of multiple representation research has continued into broader descriptions of representational use, grouping representations as modes and even investigating inter-modal and multi-modal use.

Gilbert (2004) suggested that different representations could be grouped into five modes including concrete, verbal, symbolic, visual, and gestural and that visualisation describes making meaning out of representations. Representational competence focuses on the domain specific constellation of representations. Studies in representational competence isolate representation use specific to a domain and then investigate scaffolding student attainment of such representational use (Kohl & Finkelstein, 2005; Kohl & Finkelstein, 2006). Representational competence begins with using representations authentically and being able to extract information from given representations but has been extended to cross-representational use where multiple modes of representation in Gilbert's model (2004) are used in student answers and instructional materials (Hand & Choi, 2010; Stieff, Hegarty, & Deslongchamps, 2011).

METHODOLOGY OF THE STUDY

Population

Population according to Neuman (2006), is a set of all units that the research covers, or to which it can be generalised. Population is a group to which the Researcher would like the result of the study to be generalised. The accessible population for this study was all form two Agricultural science students enrolled in physics as one of their electives.

Sample and Sampling Techniques

Singleton and Strait (2010) defined sample as the selected elements (object or people) chosen for a study. In this study, purposive sample type was used to select an intact class of 30 form two Agricultural Science students. The whole class was chosen for the study because there was a need for all students in the class to be

exposed to multiple representation for deeper understanding of physics concepts particularly sound and waves. Moreover, the study was conducted during normal lessons and all the students had to be involved.

Instruments and instrumentation

According to Frenkel and Wallen (2003), instrumentation refers to the whole process preparing to collect data. It entails not only the selection or design of the instrument but procedures and conditions under which the instrument will be administered. It helps to keep track of what is being observed and how to report for data collection. In this study, class observation and achievement test were used during lessons.

Achievement Test

In this study, the achievement test used comprised of two tests namely pre-intervention test and post-intervention test (Appendix A). This was done to assess students' academic achievements and the effectiveness of the representation lessons after successful treatment of the selected topics.

Observation

In gathering the qualitative data, students' observation checklist was developed (Appendix B). An observation checklist is listing of specific concepts, skills, processes or attitudes and it is designed to allow the observer to quickly record the presence or absence of specific qualities or understanding (Saskatchewan, 1994). Hence after careful planning on what behaviour to look out for, the Students' Observation Checklist (SOC) was developed by the Researcher. According to Johnson, Johnson and Holubec (1998), there are two types of observation procedures: Formal Observation Form which is used to record how often target actions take place and Informal Observation which is a teacher's impressions of what is happening in the classroom.

Validity and Reliability of Instruments

The Researcher assessed content validity through the use of professionals in the field of science (Physics) education. The Researcher also discussed with his supervisor, other lecturers and colleagues on whether the instruments accurately represent the concept of the study. Their ideas were well considered and appropriately incorporated.

Reliability according to Cohen, Manion and Morrison (2008), means that scores from an instrument are stable and consistent; scores should nearly be the same when researchers administer the instrument multiple times and also scores need to be consistent. In determining the reliability of the instrument for this study on students' achievement test, the Cronbach's alpha reliability was determined to be 0.79. This was in line with Gall, Borg and Gall's (2007), suggesting that, the coefficient of reliability values above 0.75 is considered reliable, hence the instruments used for collecting the data was reliable.

Data Collection Procedure, Discussion and Analysis

The Student Observation Checklist which is an Informal Observation Form was used to gather data in this study. During the observation, data was gathered about the kinds of representation formats frequently used in the sound and waves lessons. In using the Students' Observation Checklist, some skills were acquired by students in adopting the following representational formats as seen from table 1 below.

Table 1: Students' Observation Checklist on representational format used and skills acquired

Kinds of representation observed and skills acquired	Lessons				
Mathematical representation; students were able to use basic mathematical operations in solving sound and wave					

problems					
Graphical representation; students acquired graphing skills which enabled them to determine wave properties from a graph					
Verbal representation; students grasping spoken words and written notes on sound and waves lessons					
Diagrammatic representation; students drawing productive diagrams in solving sound and waves related problems					
Visual representation; students observed animation of some types of waves motion					
Demonstration; students volunteers demonstrating mode of vibrations in pipes.					
Practical; students through practical approach determining end correction of a closed pipe using resonance tube experiment					
Models; students describing wave and some terminologies associated with waves using models					

√ representational format observed; * representational format **not** observed

From Table 1, it is observed that not all the representational formats were observed and adopted by students in all the five lessons. Representations such as model was used in only lessons 1 and 2. Again, it is seen from the table above that demonstration and practical representation were only observed in lesson 4 and 5. The table above also reveals that visual representation was observed in lesson 1 and 4 only.

However, Students' Observation Checklist from the table above shows that representations such verbal, mathematical diagrammatic and graphical representation were and observed fully utilised in all the five representation lessons. Based on this, the Researcher based on these four representational formats employed in all the lessons to quantitatively determine the cognitive achievement of students.

QUANTITATIVE ANALYSIS

Depending on the correctness of the answers to the questions in the tests, students' responses to achievement test questions were classified as "correct", "partially correct" and "incorrect" for each representation. The response to four representations namely, mathematical, diagrammatic, graphical and verbal given by the students to test items were analysed and presented below in tabular forms.

Table 2: Students' Responses to Pre-Intervention Test

Representational format	N	Correct	Partially correct	Incorrect
Mathematical	30	4(13.3%)	6(20%)	20(66.7%)
Diagrammatic	30	3(10%)	5(16.7%)	22(73.3%)
Graphical	30	2(6.7%)	9(30%)	21(70%)
Verbal	30	5(16.7%)	6(20%)	19(63.3%)

Note: 'N' represents total number of students

Data from Table 2 showed that few students 4(13.3%) demonstrated good mathematical concept in wave lessons as correct. Twenty percent of students comprising of 6 students partially got the mathematical representation of the wave question right. As many as 20(66.7%) of the students got the mathematical representation of the wave concept wrong.

Ten percent of the students consisting of 3 students were able draw correct diagrams in wave achievement test. Few students, 5(16.7%) of the students were partially able to draw correct diagrams. Majority of the students about 73.3% drew incorrect diagrams.

Few students, 2(6.7%) of the students expressed correct graphical representation of the wave question.

Few students, 2(6.7%) exhibited correct graphical representation. Thirty percent of students partially had the question pertaining to representation correct. Twenty-one students comprising of 70% got the question pertaining to graphical representation incorrect

Minority of the students about 30% of the students were able to use verbal representation partially correct. Twenty-one students comprising 70% of the students could not use graphical representation correctly to answer the wave question.

Few students, 5(16.7%) were able to answer correctly question pertaining to the use of verbal representation. Few students, 6(20%) partially got the verbal representation part of the questions correct. Majority of the students, 19(63.3%) got the wave question pertaining to verbal representation incorrect

Table 3: Students' Response To Post-Intervention Test

Representational format	N	Correct	Partially correct	incorrect
Mathematical	30	27(90%)	2(6.7%)	1(3.3%)
Diagrammatic	30	26(86.7%)	2(6.7%)	2(6.7%)
Graphical	30	28(93.3%)	1(3.3%)	1(3.3%)
Verbal	30	29(96.7)	0(0%)	1(3.3%)

Note: 'N' represents total number of students

Data from Table 3 showed that majority 27(90%) of students demonstrated good mathematical concept in wave lessons as correct. Few students 2(6.7%) partially got the mathematical representation of the wave question right. Only one student comprising 3.3% of the students got the mathematical representation of the wave concept wrong.

Quite a number of students 26(86.7%) were able to draw correct diagrams in wave achievement test. Very few students, 2(6.7%) were partially able to draw correct diagrams. Very few students 2(6.7%) were unable to demonstrate their diagrammatic representational skills, hence drawing wrong diagrams.

As many as 93.3% of the students exhibited correct graphical representation in the wave achievement test. Only two students, one having a challenge with the graphical representation hence scoring partially correctly whilst the other unable to employ graphical representation at all in his answer thereby getting it wrong.

Almost all the students 29(96.7%) were able to exhibit correct verbal representational skills except one student who got the wave question pertaining to the verbal representation incorrect.

Demographic Description of Respondents

Demographic description may be referred to as how people are classified into groups using common characteristics such as race, gender, income level or age. Demographic information provides data regarding research participants and is necessary for the determination of whether the individuals in a particular study are a representative sample of the target population for generalization purposes (Lee & Schuele, 2010). The profile of the respondents in this study is looked upon in terms of age and gender. All the respondents were male students

Age of Respondent

Age (Years)	Frequency	Percent (%)
17	2	6.7
18	8	26.7
19	16	53.3
20	4	13.3
Total	30	100

Majority of the students are between the ages of 18 (26.7.3%) and 19 (53.3%) years. 6.7% of them are 17 years of age while 13.3% are 20 years. Hence majority of the students fall within the standard age for their academic level.

Summary of the key findings

Research question one

What representational format is available in the Teaching Syllabus for Physics (Senior High School 1-3) in Ghana.?

The research question was answered by the representational formats available in the Teaching Syllabus for Physics (Senior High School 1-3) in Ghana.

The representational formats available are as follows: (1) practical (2) models (3) diagram (4) visual (5) verbal (6) mathematics (7) graph and (8) demonstration and (9) physical representation

In reference to page 13 of the physics syllabus, verbal representation is used to describe the charging and discharging of process of a capacitor via spoken words and written notes.

On page 38 of the physics syllabus, students are to demonstrate mode of vibrations in pipes and explain end correction using demonstration.

In reference to page 17 of the physics syllabus, model of an atom is described using model representation

On page 23 of the physics syllabus, practical representations were used to perform an experiment to determine the latent heat of fusion of ice by the methods of mixtures.

In reference to page 10 of the physics teaching syllabus, visual representation is used to trace rays of light through a triangular prism to determine its refractive index. Diagrammatic representations are used to draw and discuss the operation of electric motor and moving coil galvanometer in reference to page 33 of the physics teaching syllabus.

Graphical representations are used to interpret graphical representation of linear motion and interpret graphical representation of simple harmonic motion found in page 3 and 21 of the Physics Teaching Syllabus.

In reference to page 1 of the physics teaching syllabus, physical representation is used to measure physical quantities with various measuring instrument and also describe certain physical objects

One representation format that are mainly used in the physics teaching syllabus is the mathematical representation. On page 1 of the physics teaching syllabus, some basics mathematical concepts are outlined. Similarly, mathematical representation is used to solve simple progressive wave problems.

Research question two

What are students' cognitive achievement in sound and waves when they are taught using the representational teaching approach?

As many as 90 % of the students demonstrated good mathematical concept with very few students about 6.7% not getting the mathematical skills correctly.

Majority of the students about 86.7% were able use the diagrammatic representation correctly.

As many as 93.3% of the students exhibited good graphical representational skills whilst only 3.3% of the students got it incorrect

Almost all the students comprising of 96.7% got the verbal representation skills correct after exposed to representation teaching strategy whilst 16.7% of the students got the verbal representation skills right prior to the intervention.

On the basis of the summary of major findings, multiple representations teaching had great cognitive achievement on students' performance.

CONCLUSIONS

The multiple representations teaching approach provided an equal support for every student to eventually achieve an enhanced conceptual understanding of the sound and waves concepts taught. On the basis of the findings, it is concluded that the use of graphs, charts, models, animations and mathematical representations enabled students to increase their participation in lessons, intense student-student interactions, increased teacher-student interactions coupled with the high levels of motivation during lessons, become active learners and solve mathematical problems correctly. Results from this study also indicated that majority of the students enjoyed the interactive lessons with multiple representations and thus, they were motivated more to participate actively in the lessons, and were also eager to be present in the next lesson. Students have also shown positive attitude towards learning in representation lessons. Among these attitudes were: Students were very punctual and regular during representation lessons; their attention span was also very high during representation lessons; Students' enthusiasm was very high. Students performed better when they were taught sound and waves topics using representation strategy: and high level of students' enthusiasm. This study therefore concluded that, multiple representation teaching had positive effects on students by enhancing their understanding of concepts in Physics.

Suggestions:

For Teachers & Schools:

Integrate multiple representations (charts, diagrams, graphs, equations, models, animations, and practical demonstrations) consistently in Physics lessons.

Encourage group work and peer-to-peer discussions to make students more responsible for their own learning.

Train students to use diagrammatic and mathematical representations effectively, beyond rote memorization of formulas.

For Stakeholders (Curriculum Planners, GES, MoE):

Incorporate computer-assisted instructional tools and digital simulations in Physics curricula to sustain student interest and engagement.

Provide professional development workshops for teachers on how to design and implement multi-representational lessons.

For Future Research:

Replicate the study with a larger and more diverse sample to strengthen generalizability.

Extend the research to other subjects (e.g., Mathematics, Biology, Chemistry) to explore the effectiveness of MRs across disciplines.

Conduct longitudinal studies to evaluate the long-term effects of multiple representations on conceptual understanding.

REFERENCES

1. Ainsworth, S. (1999). The functions of multiple representations. *Computers & Education*, 33, 131-152.
2. Ainsworth, S. (2006). Deft: a conceptual framework for considering learning with multiple representations. *Learning and Instruction*, 16(3), 183–198.
3. Bieda, K. N., & Nathan, M. J. (2009). Representational disfluency in algebra: Evidence from student gestures and speech. *ZDM*, 41(5), 637-650.
4. Bransford, J. D. & Schwartz, D. L., (1999). Rethinking transfer: A simple proposal with multiple implications, *Review of Research in Education*, 24, 61-100.
5. Britton, S., New, P., Sharma, M., & Yardley, D. (2005). A case study of the transfer of mathematics skills by university students. *International Journal of Mathematical Education in Science and Technology*, 38(13).
6. Chiou, G. L., & Anderson, O. R. (2010). A study of undergraduate physics students' understanding of heat conduction based on mental model theory and an ontology-process analysis. *Science Education*, 94(5), 825-854.
7. Cock, M. De. (2012). Representation use and strategy choice in physics problem solving. *Physical Review Special Topics -Physics Education Research*, 8(2). <http://doi.org/10.1103/PhysRevSTPER.8.020117>
8. Cohen, L., Manion, L., & Morrison, K. (2018). *Research methods in education* (8th ed.), New York: Routledge.
9. Cuoco, A. (2001). The roles of representations in school mathematics. National Council of Teachers of Mathematics.
10. Dufresne, R. J., Gerace, W. J., & Leonard, W. J. (2004). Solving physics problems with multiple representations. University of Massachusetts.
11. Elby, A. (2001). Helping physics students learn how to learn. *American Journal of Physics, Physics Education Research Supplement*, 69 (7), 54-64.
12. Fraenkel, J. R., & Wallen, N. E. (2003). *How to design and evaluate research in education* (5th ed.). New York: McGraw-Hill.
13. Fredlund, T., Airey, J., & Linder, C. (2012). Exploring the role of physics representations: An illustrative example from students sharing knowledge about refraction. *European Journal of Physics*, 33(3), 657- 666.
14. Gall, M. D., Borg, W. R., & Gall, J. P. (2007). *Educational research: An introduction* . USA: Longman Publishers.

15. Gilbert, J. K. (2004). Models and Modelling: Routes to more authentic science education. *International Journal of Science and Mathematics Education*, 16(2).
16. Gravemeijer, K. (2002). Preamble: From models to modelling. In K. Gravemeijer, R. Lehrer, B. Van Oers, & L. Verschaffel (Eds.), *Symbolising, modeling and tool use in mathematics education*, Dordrecht: Kluwer academic publishers, 30, 7-22
17. Gunel, M., Hand, B., & Gunduz, S. (2006). Comparing student understanding of quantum physics when embedding multimodal representations into two different writing formats: Presentation format versus summary report format. *Science Education*, 90(6), 1092-1112.
18. Hand, B., & Choi, A. (2010). Examining the impact of student use of multiple modal representations in constructing arguments in organic chemistry laboratory classes. *Research in Science Education*, 40(16).
19. Hand, B., Gunel, M., & Ulu, C. (2009). Sequencing embedded multimodal representations in a writing to learn approach to the teaching of electricity. *Journal of Research in Science Teaching*, 46(3), 225-247
20. Ibrahim, B., & Rebello, N. S. (2013). Role of mental representations in problem solving: Students' approaches to nondirected tasks. *Physical Review Special Topics - Physics Education Research*, 9(2), 1-17.
21. Jimoyiannis A., & Komis, V. (2001). Computer simulations in physics teaching and learning: a case study on students' understanding of trajectory motion. *Computers & Education*, 36, pp. 183-204.
22. Johnson, D., Johnson, R., & Holubec, E. (1998). *Cooperation in the classroom*. Boston: Allyn and Bacon.
23. Kohl, P., & Finkelstein, N. (2005). Student representational competence and self-assessment when solving physics problems. *Physical Review Special Topics-Physics Education Research*, 1(1).
24. Kohl, P., & Finkelstein, N. (2006). Effect of instructional environment on physics students' representational skills. *Physical Review Special Topics-Physics Education Research*, 2(1).
25. Kohl, P. B., Rosengrant, D., & Finkelstein, N. D. (2007). Strongly and weakly directed approaches to teaching multiple representation use in physics. *Physical Review Special Topics –Physics Education Research*, 3(1), 1–10. <http://doi.org/10.1103/PhysRevSTPER.3.010108>
26. Kuo, E., Hull, M. M., Gupta, A., & Elby, A. (2013). How students blend conceptual and formal mathematical reasoning in solving physics problems. *Science Education*, 97(1), 32-57.
27. Lappi, O. (2007). Conceptual Change in Cognitive Science Education - towards Understanding and Supporting Multidisciplinary Learning. The European Cognitive Science Conference, May 2007, European Cultural Center of Delphi, Delphi/Greece.
28. Lee, M., & Schuele, C. (2010). Demographics. In N. Salkind (Ed.), *Encyclopedia of research design*. (pp. 347-348). Thousand Oaks, CA: SAGE Publications.
29. Lehrer, R., & Schauble, L. (2000). Developing ModelBased Reasoning in Mathematics and Science. *Journal of Applied Developmental Psychology*, 21(1), 39-48.
30. McDermott, M., & Hand, B. (2009). The impact of embedding multiple modes of representation within writing tasks on high school students' chemistry understanding. *Instructional Science*, 1-30. Retrieved from <http://www.springerlink.com/content/cq626h8847351u60/>
31. Meltzer, D. E. (2005). Relation between students' problem-solving performance and representational format. *American journal of physics*, 73(5), 463-478.
32. Mutimucio, I., (2003). Multiple representations of energy processes in mechanical energy systems, Research and quality of Science Education, ESERA Conference, Netherlands, <http://www1.phys.uu.nl/esera2003/programme/pdf%5C164S.pdf>. 21 March 2007.
33. Neuman, W. L. (2006). *Social Research Methods: qualitative and quantitative approach* (7th ed.). Whitewater: Pearson.
34. Ojo, M.O. (2001). Problems of teaching Science and Mathematics in Nigeria. A paper presented at the Train-the Trainers workshop for Science and Mathematics teachers in Colleges of Education in Six Geo-political zone of Nigeria. Onah, D.U., & Ugwu, E.I. (2010). Factors which predict performance in secondary school physics in Ebonyi north educational zone of Ebonyi State, Nigeria. *Advances in Applied Science Research*, 1 (3): 255-258

35. Pollock, E. B., Thompson, J. R., & Mountcastle, D. B. (2007). Student Understanding of The Physics and Mathematics Of Process Variables In P-V Diagrams. Physics Education Research Conference, 951, 168-171, : AIP Publishing.
36. Rosengrant, D., Etkina, E., & Van Heuvelen, A., (2007). An Overview of Recent Research on Multiple Representations. Physics Education Research Conference, AIP Conference Proceedings, 149-152.
37. Russell, T., & McGuigan, L. (2001). Promoting understanding through representational: Redescription: An illustration referring to young pupils' ideas about gravity. Paper presented at the Proceedings of the Third International Conference of the ESERA, Thessaloniki, Greece; Aristotle University of Thessaloniki, (p. 600).
38. Saskatchewan Education (1994). Curriculum and Instruction Branch, Shuttleworth, Martyn. Qualitative Research Design. Retrieved on January 14, 2015 from <http://www.experiment-resources.com/qualitative-research-design.html>
39. Scaife, M., & Rogers, Y., (1996). External cognition: How do graphical representations work? International Journal of Human-Computer Studies, 45(2), 185-213.
40. Singleton, A. R., & Strait, C. B. (2010). Approches to social research (5th ed.). New York: Oxford University Press.
41. Stieff, M., Hegarty, M., & Deslongchamps, G. (2011). Identifying representational competence with multi-representational displays. Cognition and Instruction, 29(1), 123-145.
42. Wanbugu, P. W., & Changeiywo, J. M. (2008). Effect of mastery learning approach on Secondary school student's physics achievement. Eurasia Journal of mathematics, Science & technology education,, 4(3), 293-302.
43. Wieman, C., & Perkins, K. (2005). Transforming Physics Education. Published in Physics Today, 58 (11), 36.
44. Woolnough, J. (2000). How do students learn to apply their mathematical knowledge to interpret graphs in physics? Research in Science Education, 30(3), 259-267.
45. Wu, H. K., & Krajcik, J. S. (2006). Inscriptional practices in two inquiry-based classrooms: A case study of seventh graders' use of data tables and graphs. Journal of Research in Science Teaching, 43(1), 63-95.
46. Zewdie, Z. M. (2014). An investigation of students' approaches to problem solving in physics courses. International Journal of Chemical and Natural Science, 2(1), 77-89.
47. Zou, X., (2000). The Use of Multiple Representations and Visualizations in Student Learning of Introductory Physics: An Example from Work and Energy Documents, Thesis (PhD), The Ohio State University

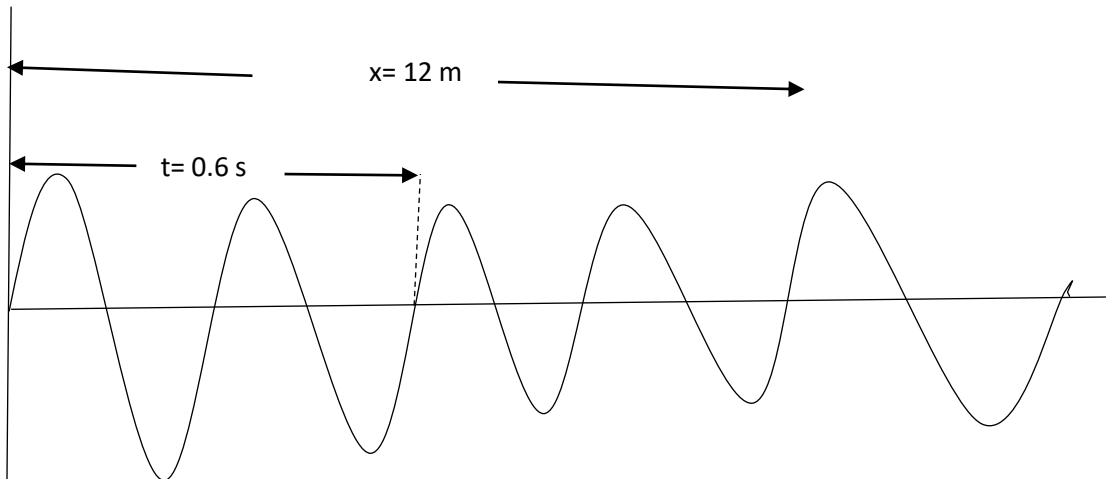
APPENDICES

Appendix A- Sound and waves Achievement Test

Pre-Intervention Test

Distinguish between transverse waves and longitudinal waves

The diagram below illustrates a wave form. Determine the speed of the wave



Post – Intervention Test

The equation, $y = 20 \sin (12\pi t + 16x)$, where y is in millimeters, x is in metres and t is in seconds represents a wave motion. Determine the

Amplitude

Frequency

Wavelength

Velocity

Draw and label a suitable diagram to illustrate in each case the mode of vibration of air column for the **third** harmonic in

An open pipe

A closed pipe

Appendix B- Students' Observation Checklist

Kinds of representation observed and skills acquired	Lessons				
Mathematical representation; students were able to use basic mathematical operations in solving sound and wave problems					

Graphical representation; students acquired graphing skills which enabled them to determine wave properties from a graph					
Verbal representation; students grasping spoken words and written notes on sound and waves lessons					
Diagrammatic representation; students drawing productive diagrams in solving sound and waves related problems					
Visual representation; students observed animation of some types of waves motion					
Demonstration; students volunteers demonstrating mode of vibrations in pipes.					
Practical; students through practical approach determining end correction of a closed pipe using resonance tube experiment					
Models; students describing wave and some terminologies associated with waves using models					