

## **Doppler Effect: The effect of educational design research activities on problem solving in the Vhembe District**

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### **Abstract**

The Doppler Effect is a topic included in the grade 12 physical science curriculum in South Africa. This topic provides the opportunity to integrate theory and the application of it in everyday experiences. Activities on the Doppler Effect were developed by using educational design research (EDR). It possesses an iterative design characteristic and was tested in 2 schools. Problems were documented and changes to the activities were made and tried out in 10 schools by 216 learners. These designed activities enable learners to predict, interpret and explain their observations and were developed to actively involve the learners in order to construct their own knowledge. As summative assessment, grade 12 learners have to sit for a common examination where the solving of problems is prevalent. The learners' performance was therefore tested by correlating the marks of the activity sheets with that of solving problems on this topic in a written test. The test is a common test written by the entire Vhembe district and only the section on the Doppler Effect was used. This study is framed by the Martinand's model and provides a theoretical framework for this study because it offer links between practice and theory which is important in the building, organization and the integration of scientific knowledge. An instructional manual was developed comprising of the final activities and was distributed amongst the district officials and teachers to assist them in the teaching of the Doppler Effect in the Vhembe district.

**Key words:** Educational design research, Doppler Effect, activities, physical science

### **Introduction**

Applications of the Doppler Effect are apparent in everyday life. The distinct change in the sound of a siren of an ambulance is heard; while the ambulance approaches the pitch of the siren is relatively high but as the ambulance passes and moves away the pitch suddenly drops. The Doppler Effect is used in speed traps by traffic officers to measure the velocity of detected vehicles. It is also applied in medicine. An echocardiogram produce an assessment of the direction of blood flow and the velocity of blood and cardiac tissue at any point in a human body using the Doppler Effect. The measurement of blood flow rate in veins and arteries based on the Doppler Effect is used for diagnosis of vascular problems like stenosis. In astronomy, the Doppler Effect has helped scientists in realising that the universe is expanding. This topic is included in the grade 12 physical science curriculum (Department of Education, 2003, p 41). The South African government stipulates policy on curriculum and assessment in the schooling sector by means of its National Curriculum Statement Grades R-12 (NCS). The NCS learning outcomes outlines that the learner should be able to explain,

interpret, evaluate scientific and the technological knowledge and apply it in everyday experiences. Although the curriculum encourage teachers to do practical work by integrating everyday activities in the classroom, the summative assessment of grade 12 learners are still a written examination where they have to solve problems. Therefore this study attempts to report on the effect of EDR activities that suggest that science is not detached from our daily life but also measure the performance of learners when solving problems on the Doppler Effect because this is required in their final examination.

### **Aim of the study**

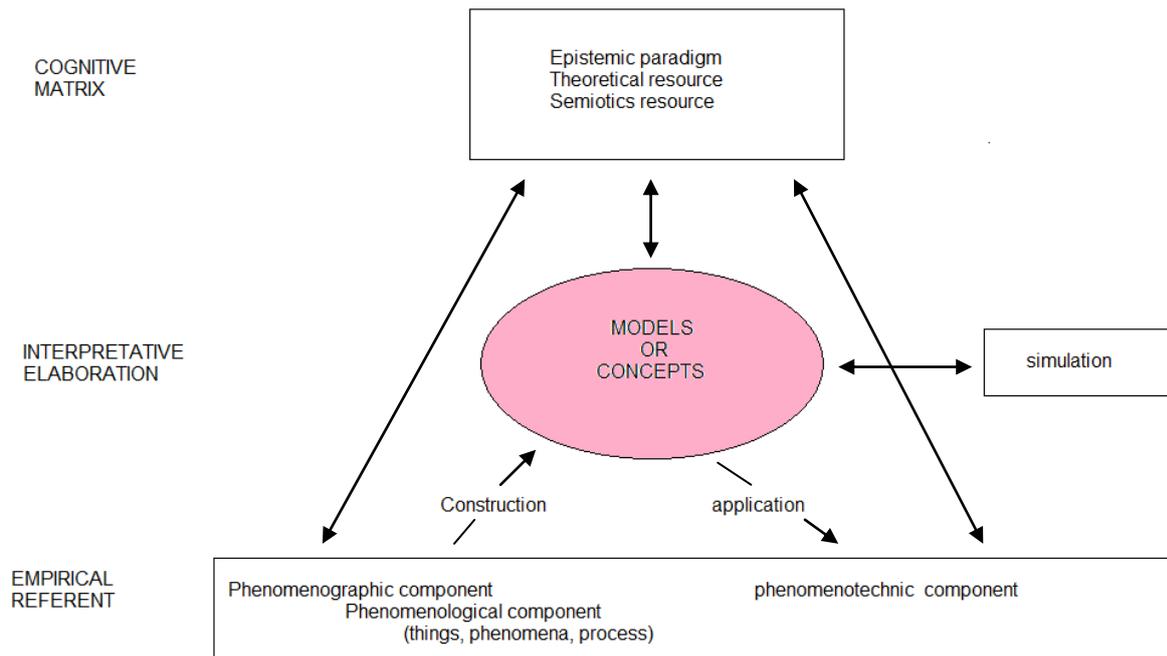
The aim of this paper is to determine the effect of educational design research activities on the Doppler Effect by correlating the marks of the activity sheets with that of solving problems in a written test.

### **Theoretical Framework**

*This study is framed by the Martinand's model (figure 1) as cited in Ganaras, Dumon & Larcher (2008). The Martinand's model has taken into consideration some constructivist views such as; the learners construct knowledge for themselves (Hein, 1996:1). Learners learn new concepts by constructing or building on their prior understanding (von Glasersfeld, 1983). Furthermore Erickson (2001) notes that learners are capable of constructing plausible conceptions while engaging with their physical and social worlds. In addition a constructivist perspective holds that learning occur when learners construct their own meanings in a unique way whilst interacting with their learning environment and building on their existing knowledge (Killoran, 2003; Ping, 2002).*

This model provides a theoretical framework for this study because it offer links between practice and theory which is important in the building, organisation and the integration of scientific knowledge (Ganaras *et al.*, 2008). In this study it will be used to analyse the dialectic link between experiments, models and theory that is experienced by learners during their construction of knowledge.

**Figure 1: Martinand`s science model**



*The empirical referent:*

The empirical referent consists of real objects and phenomena and also includes rules of action on these objects and phenomena. The empirical referent has been divided into three components as follows:

- i) Phenomenotechnic component; this is the experimental ability, knowledge of laboratory apparatus and laboratory safety rules.
- ii) Phenomenographic component; refers to the ability to describe objects and phenomena so that related information can be communicated.
- iii) Phenomenological component; corresponds to another description in terms of concepts, models and shared theories.

*The interpretive elaboration:*

This is what is created with the use of models and concepts in order to represent the empirical referent.

*The cognitive matrix:*

It consists of the epistemic paradigm and the theoretical resource (language, drawing, theories and symbols). Cognitive matrix is a set of theoretical and experimental knowledge of a learner's operational knowledge (Ganaras et al., 2008).

This scheme was used in the development of the EDR activities and analysis of the data. The learners in this study were in the final year of school and it is assumed that they should have cognitive matrixes which allow them to link the Doppler Effect phenomena and explain the empirical referent in using the developed EDR activities and theories. According to the theoretical framework, the empirical referent is divided into three components. The phenomenotechnic component includes the knowledge of the apparatus used in the

activities which are a slinky, eyedropper and bicycle. The phenomenographic component includes the description of an empirical referent in terms of the Doppler Effect concept, while the phenomenological component consists of the description of the same empirical referent in terms of concepts and notions, resulting from some past conceptualization (water waves, frequency, wavelength and speed of a wave etc).

### **Research Design**

A qualitative and quantitative approach was used when collecting and analysing the data. To establish the baseline questionnaires and interviews were used (Mupezeni, 2012). Activities were developed based on the baseline data and the evaluation of these involved determining the worthiness, merit or the quality (Johnson & Christensen, 2000) of the designed activities. Educational design research sometimes called design based research was used and it possesses an iterative design characteristic (Cobb, 2003).

A quantitative approach namely the explanatory research design (Creswell, 2005) was used to determine the correlation between the final products namely the marked activity sheets and the scores of the learners in a written test.

### **Research population and sample**

The Vhembe district in Limpopo Province has 27 circuits, only three circuits were purposefully chosen because of their proximity to each other which reduced transport costs during the distribution and collection of questionnaires. A total of 12 secondary schools in this district were chosen for trying out the designed activities. The sampling is therefore both purposeful and convenient. Two schools (one rural and another urban) were chosen for piloting the activities and 10 schools for evaluating the refined activities. Because of this limitation, generalisation is not justifiable. A total of 216 learners were used in the study and were taught by the selected teachers.

### **Methodology**

*The study aimed at producing high quality developed activities designed to solve an educational problem. The activities were use-inspired (van den Akker, 1999) and were specifically designed for the teachers and learners in grade 12.*

Systematic educational and instructional design processes are cyclical in character: analysis, design, evaluation and activities are refined in an iterative manner until a satisfying model was obtained. This study has used the Generic Design Research Model as described by Wademan (2005).

Description of the steps used in the Generic Design Research Model:

1. Problem identification

The challenges of teaching the Doppler Effect to Grade 12 learners in the Vhembe District were identified as the problem of the study (Mupezeni, 2012).

## 2. Preliminary investigation of problem, context and approaches.

The study has been done in three parts. The first part was to establish the baseline by distributing questionnaires to teachers and conducting an interview with the subject advisor. This was to establish the challenges faced by teachers and determining the teaching approaches they used. The second part involved the development of activities using Educational Design Research (EDR), the trying out of the activities and then the redevelopment of the activities. The third part comprised of the testing of the activities in 10 schools. After the evaluation of these activities an Instructional Manual on teaching the Doppler Effect was developed and distributed in the district.

## 3. Tentative products and theories

After analysis of the questionnaires information on the challenges which the teachers have when teaching the Doppler Effect were documented. A possible solution had to be found to address these challenges. The design-based activities were chosen as a possible solution because they integrate all three Learning Outcomes as required by the NCS as well as present knowledge and alternative teaching approaches. The researcher's goal was to come up with refined activities which could be used to assist teachers and learners in the topic Doppler Effect.

## 4. Refinement of problem, solution and method.

Both formative and summative evaluations were used. Formative evaluation was used to improve and to uncover shortcomings of the activities during their development. Summative evaluation was used to gain evidence for the effectiveness of the developed activities (Nieveen, 2007). The activities were initially tried out in 2 schools. Challenges faced in trying-out the activities were noted, for example some schools did not have the required apparatus. Changes were implemented and the activities were then modified. The final product was then tried-out in 10 schools.

## 5. Refinement of design theory

The researcher reflected on the performance of the learners and evaluated the effectiveness of the activities in solving the practical and the written tasks on the Doppler Effect. The evaluation was done to improve the activities and questions to a high quality product.

## 6. Problem resolution and advancing theory.

The challenges of teaching the Doppler Effect were identified. Activities were developed to assist the teachers and learners on the teaching and learning of the Doppler Effect in grade 12.

**An instructional manual** was produced after all necessary improvements were incorporated.

### ***Development of Doppler Effect activities***

The only activity suggested in the textbook "Focus on Physical Science grade 12" (Hendricks et al., 2007, p 54) for the Doppler Effect is a practical demonstration of a person riding a

bicycle while blowing a referee whistle. The class is observing when the bicycle is moving towards them and away from them.

An additional three activities were added and the one for the bicycle modified. A learner might not be able to blow the whistle steadily and so an electronic device (cell phone) was used. In order to link science with the everyday experiences of the learners another activity was designed for the learners to observe the change in sound frequencies when the vehicles pass by the road. The developed activities have incorporated the main ideas of three teaching approaches namely Mastery Learning Approach (MLA), Enquiry-based approach and the Activity, Student, Experiment, Improvisation (ASEI) and Plan, Do, See, Improve (PDSI) approach. The Mastery Learning Approach (MLA) is a teaching method where learners are given opportunities to demonstrate mastery of content which they were taught (Kibler, Cegala, Watson, Barker & Miler, 1981). The Enquiry-based approach is an approach that has improved problem solving skills and has been effective at increasing student attitude toward physics (Arion, Crosby, & Murphy, 2000). With this approach the role of the learner is active participation, asking probing questions and learning the concepts by hands-on approach (Luke, 2010). The Activity, Student, Experiment, Improvisation (ASEI) and Plan, Do, See, Improve (PDSI) approach is an approach which advocates a shift in the educator's thinking and practice from teacher centred to learner centred approaches. When teachers improvise, they demystify conventional experiments by scaling them down, thereby relating physics to everyday situations (Nui & Wahome, 2005).

For example, the learners had to demonstrate their knowledge of water waves which they were taught earlier (Mastery Learning approach) and the learners were to actually perform the experiments by themselves (Enquiry-based approach). The materials used for the activities were readily available within the learners' environment and were relating to the learners' everyday experiences.

### **Validity and reliability**

The test questions and activities were validated by a subject advisor and a senior science lecturer in the Faculty of Education. The lecturer was chosen because of his content knowledge of the topic and the fact that he conducted lesson observations at schools when their students do teaching practice. The test and the activities were pilot tested in the field to check on clarity of instructions of the activities and on the relevance of the questions with regards to the learning outcomes and syllabus. The pilot led to the conclusion that the test questions and activities were not too difficult, too long or too simple for the learners.

### **Data analysis**

Both the activity sheets and tests on the Doppler Effect were written by 216 learners, marked and analysed. The learners carried out the activities performing the experiments by themselves and the tests were used as a measure of learning gains. Therefore the scores from marked activity sheets and marked tests were compared to determine if there was any

correlation between the two. In order to find a relationship between the marked activities and the written tests, correlation analysis was carried out.

### **Analysis of activity sheets and test**

Statistical results show that there is a positive correlation between marked activities and written tests. There was a very weak positive correlation between learners achievement and learners centred teaching approaches.

The usual time allocated to the teaching of the Doppler Effect is five lessons of 270 minutes (4 x 60 minutes plus one single lesson of 30 minutes). The activities developed were tried out during two double lessons. The first lesson was a practical lesson; learners were completing activity sheets as they carried out the activities. The completed activity sheets were marked to quantify the effectiveness of this learner centred teaching approach. The marks were expressed in percentages.

The study used the theoretical framework as a lens to look at the development of EDR activities and how the practical links with the theory. The “phenomenographic component” (description of the Doppler Effect phenomena and lack of understanding of the concept) has led to the development of “model” or EDR activities which were used in schools by learners which in turn led to the “phenomenotechnic component” (knowledge of laboratory equipment and development of practical skills).

In the second lesson learners were given a written test on the Doppler Effect in which they were required to solve mathematical problems involving the Doppler Effect formula. The first learning outcome (DOE, 2003) requires that learners should use skills and solve problems in scientific, technological and everyday contexts. The given questions were typical of final examination questions to enable the learners to be familiar with the questions to ensure that learners have appropriate practice before they write their final examinations. The answers were marked out of 100.

### **Results**

The results of the marked activity sheets as well as the written tests for the 2 trial schools were recorded (see table 1).

**Table 1: Comparison on the learners` performance, in set activities and written test in 2 schools.**

Mark range	Design based activities		Written test	
	No of learners		No of learners	
	School 1	School 2	School 1	School 2
90-100	0	0	0	0
80-89	1	1	0	0
70-79	1	3	0	1
60-69	3	4	1	1
50-59	4	3	1	4
40-49	5	3	3	7
30-39	2	5	7	3
20-29	2	3	3	5
10-19	0	1	2	1
0-9	0	0	1	1
	<b>18</b>	<b>23</b>	<b>18</b>	<b>23</b>
% of learners who got marks above 30	<b>88.9</b>	<b>82.6</b>	<b>66.7</b>	<b>69.6</b>

The results in table 1 show that learners in both schools performed better in questions on activities (88.9% and 82.6%) than on the written test (66.7% and 69.6%).

Changes were made to the activities after the pilot like rephrasing of some questions and changing the equipment. For example, cafeteria trays were replaced by ripple tanks for better observation of created waves and eyedroppers were replaced by small plastic pipettes which were able to produce constant supply of droplets at a faster rate. Cell phones were used to supply a source of sound since some schools did not have portable sirens.

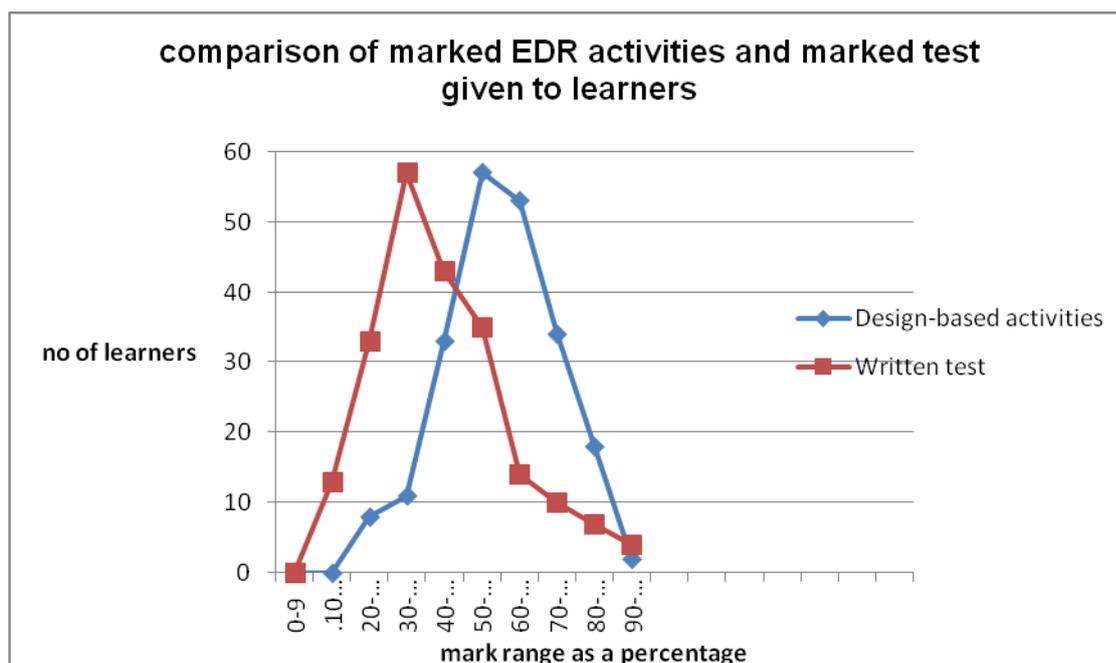
Table 2 show the results of the two marked activities for 10 schools with a total of 216 learners. The comparison was mainly on the learners` performance in the set activities and written test and not on individual schools. The purpose of the comparison was to establish a correlation between these two activities and to determine in which of the two activities learners performed better. This further provided data on whether learners perform better on practical questions or on theoretical questions.

**Table 2: Graphical comparison on the performance of learners on EDR activities and problem solving in 10 schools (N=216).**

Mark range	EDR activities		Problem solving	
	Total learners	%	Total learners	%
90-100	2	0.9	4	1.9
80-89	18	8.3	7	3.2
70-79	34	15.7	10	4.6
60-69	53	24.5	14	6.4
50-59	57	26.4	35	16.1
40-49	33	15.3	43	19.9
30-39	11	5.2	57	26.5
20-29	8	3.7	33	15.3
10-19	0	0	13	6.0
0-9	0	0	0	0
	<b>216</b>	<b>100</b>	<b>216</b>	<b>100</b>
% No of learners with marks 40% and above	<b>91.2%</b>		<b>47.7%</b>	

Results on table 2 show that learners performed well in the EDR activities with 91.2% of the learners scoring marks above 40% and in written tests only 47.7% of the learners scored above 40% mark. This might indicate (among other possible factors) that learners understand more what they do (practically) than the solving of theoretical problems.

**Figure 2: Comparison of EDR activities sheets and test given to learners (N=216).**



Pearson's product moment correlation  $r = 0.65$  indicates a high correlation (Mulder, 1993) between student EDR activities and the written tests. The learners performed poorly in their tests compared to the activities and this might be due to the poor understanding of the formula and concepts as well as the fact that learners might understand more when they do hands-on experiments whilst making their own observations than in tests where they are required to do problem solving and interpret the phenomenon. Furthermore, during lesson activities learners could share ideas whereas during tests they are expected to work on their own.

### **Implications**

#### 1. Recommendations for practice: Implications for teaching and learning.

Professional development programmes should enhance teachers' content knowledge. Science is dynamic and therefore teachers use new effective teaching approaches. According to this study the professional development with regards to workshops was not effective in the Vhembe district. Professional development programmes should include teaching activities in their lessons for better understanding of the science concepts by the learners and engage learners' hands on and minds on during the lessons. In addition, teachers need to teach for understanding and opportunities should be offered for lifelong learning experiences.

#### 2. Recommendations for the design of learner activities

To facilitate conceptual understanding the activities should be designed making use of materials which are readily available within learners' environment. The physical phenomenon being studied should be linked to the learners' everyday experiences and examples to be drawn from what they observe in the area in which they live.

#### 3. Recommendations for further research

This study recommends that future researchers should use a bigger sample of teachers and learners. During the development of the design-based activities, teachers should be involved so as to instil a sense of ownership in them. The activities are not to be imposed on them but produced by the teachers themselves.

### **Conclusions**

Activities and written tests:

The performance of learners in the given developed activities was good. The learners were actively participating in the learning process as seen by the fact that they all participated in the activities and completed the activity sheets. The learners were empowered with the learning outcomes in physical science. There is a high correlation ( $r = 0.65$ ) between activities and the written tests. Some learners who did well in activity questions also performed well in solving of problems on the Doppler Effect.

The reason why they performed badly in tests might be that learners have some difficulties with understanding the concepts (Thornton & Sokoloff, 1998). To facilitate conceptual understanding of the Doppler Effect, activities should be designed making use of materials

which are readily available within learners' environment the science equipment available in targeted schools. The physical phenomenon being studied should be linked to the learners' everyday experiences and examples to be drawn from what they observe in the area in which they live.

## References

- Arion, D., Crosby, K., & Murphy, E. (2000). Case study experiments in the introductory Physics curriculum. *The Physics teacher*, 38(6), 373-376.
- Cobb, P., Confrey, J., diSessa, A., Lehrer, R., & Schauble, L. (2003). Design Experiments in Educational Research. *Educational Researcher*, 32(1), 9-13. Retrieved November 18, 2010 from <http://er.aera.net>
- Creswell, J. W. (2005). Educational research; Planning, conducting and evaluating quantitative and qualitative research. New Jersey: Pearson Prentice Hall.
- Department of Education, (2003). National curriculum Statement Grades 10-12 (General). Physical Sciences. Government printer Pretoria.
- Erikson, G. (2001). Research programs and the students' science learning literature. Improving science education. In R. Millor, J. Lemch, & J. Osborn (Eds.), *The Contribution of Research*. Pp271-292. Buckingham: Open University Press.
- Ganaras, K., Dumon, A., & Larcher, C. (2008). Conceptual integration of chemical equilibrium by prospective physical science teachers. *The Royal Society of Chemistry* 2008, 9, 240-249.
- Hein, G. E. (1996). Constructivist learning theory. *The Museum and the needs of the people CECA (International Committee of Museum Educators) Conference*. Jerusalem, Israel, 15-22 October, 1991. Exploratorium, 3601 Lyon St., San Francisco. Retrieved September 12, 2011 from <http://www.exploratorium.edu/ifi/resources/constructivistlearning.html>
- Hendricks, A., Sadeck, M., & Spies, A. (2007). Focus on Physical Sciences Grade 12. Maskew Miller Longman, Cape Town, p54.
- Johnson, B., & Christensen, L (2000). Educational Research: Quantitative and Qualitative approaches. Allyn & Bacon, Boston.
- Kibler, R. J., Cegala, D. J., Watson K.W., Barkel, L.L., & David, T. M. (1981). Objectives for instruction and evaluation. Allyn and Bacon Inc. Toronto, USA.
- Killoran, I. (2003). Why is your homework not done? How theories of development affect your approach in the classroom. *Journal of Instructional Psychology*, 30(4), 309-315
- Luke, L. (2010). Self-monitoring to minimize student resistance to inquiry. Retrieved January 18, 2011, from <http://www.phy.ilstu.edu.jp/teo/>
- Mulder, J. C. (1993). Statistical techniques in education. Soft cover edition. Haum Tertiary Publishers.

- Mupezeni, S. & Kriek, J. (2012). The challenges and prospects of teaching the Doppler Effect in grade 12. Unpublished master's dissertation, University of South Africa, Pretoria, South Africa.
- Nieveen, N. (2007). Formative Evaluation in Education Design Research. An Introduction to Educational Design Research. Proceedings of the seminar conducted at the East China Normal University, Shanghai (PR China), November 23-26, 2007.
- Nui, N. W., & Wahome, A. N. (2005). SMASSE Project. Strengthening of Mathematics and Sciences in Secondary education. Kenya.
- Ping, Z-L. (2002). Changing the approach. *Physics Education, News*, p 182
- Thornton, R. K., & Sokoloff, D. R. (1998). Assessing student learning of Newton's laws: The force and Motion Conceptual Evaluation and the Evaluation of Active Learning Laboratory and Lecture Curricula. *American Journal of Physics*, 66(4), 338-352. University Press.
- Van den Akker, J. (1999). Principles and methods of development research. In J. van den Akker, R. Branch, K. Gustafson, N. Nieveen, and T. Plomp (Eds.), Design approaches and tools in education and training (pp. 1–15). Dordrecht: Kluwer Academic Active Learning Laboratory and Lecture Curricula. *American Journal of Physics*, 66(4), 338-352. University Press.Publishers.
- Von Glasersfeld, E. (1989). An exposition of constructivism: why some like it radical. In R. B Davis (Ed.), *Constructivist view on teaching and learning of mathematics*: JRME.
- Wademan, M. (2005). *Utilizing development research to guide people capability maturity model adoption considerations*. Unpublished doctoral dissertation. Syracuse: Syracuse University.