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Evaluation of a Three-Step Biophysics Problem-Solving Strategy in a Biophysics and Numeracy Class of Students Recruited from Disadvantaged Communities in South Africa.

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ABSTRACT

Disadvantaged schools in South Africa are characterized by merger resources, a shortage of science equipment and inexperienced science teachers. These factors hinder effective teaching and learning, consequently students' potential remains untapped. Students from these schools lose out in science oriented careers such as medicine and engineering. In order to correct this inequality the Ministry of Higher Education and Training sponsors one year foundation programs commonly called extended degree programs. Sefako Makgatho Health Sciences University runs a foundations course in medicine to cater for the disadvantaged students. Foundation Biophysics and Numeracy is one of the foundation modules taught. This paper reports on an intervention mechanism (a three-step biophysics problem-solving strategy) used to increase throughput in foundation Biophysics and Numeracy module. This study is a retrospective analysis of the three semester tests and course mark for three cohorts 2010, 2012 and 2013 enrolled for Foundation biophysics and Numeracy module. The last two cohorts were exposed to a three-step biophysics problem solving strategy. 44.4% of the students got below the 50% pass mark pre-intervention whilst post intervention 100% passed with 8.8% of them getting above 70% pass mark in 2012. In 2013, 22% got below 50% pre-intervention. Post intervention 4% of students got 49% and 60% got over 70%. Course marks averages of 62%, 76% and 78% were recorded for the 2010; 2013 and 2013 cohorts respectively.
A three-step biophysics problem solving strategy improved the quality of pass marks. It also promoted conceptual understanding of biophysics principles.

Keywords:
Biophysics, numeracy, problem solving, three-step strategy

Introduction

Biophysics is one of the six one year foundation modules meant to enable disadvantaged students from disadvantaged schools, particularly in rural communities to access the medical degree program. It is envisaged that on successful graduating as medical doctors they are highly likely to take up appointment in their disadvantaged communities. Without this kind of program, students from disadvantaged schools would find it impossible to successfully compete for places in the medical program offered at Sefako Makgatho Health Sciences University (SMU). The same applies to other South African universities. All require excellent grade 12 passes in mathematics and physical science as prerequisites. Furthermore, limited spaces exist for the students who intend doing medicine as a career.

Disadvantaged Students in a South African Context

Van der Flier et al (2003) defined a disadvantaged student as one who had inadequate access to quality educational services. Consequently their full academic performance is hindered. Alex and Mammen

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(2016) stated that schools in disadvantaged communities fail to implement curriculum because of their low budgets. The two authors further noted a study by Mji and Makgato who pointed that schools offering mathematics and science in disadvantaged communities do not have enough facilities and equipment to promote effective learning and teaching. In addition to these retrogressive factors, (Maree, Aldous, Hatting, Swanepoel & van der Linde, 2006) established that in impoverished communities learning is also retarded by a multitude of factors among which include: the poor training acquired by the teachers and insufficient leaner support materials. Three quarters of the students enlisted for the Biophysics and Numeracy module at SMU fall in this category. They come mainly from the rural schools having received "inferior education" compared to that of their counterparts in the private, urban and peri-urban schools. Maree et al., (2006) further noted that these students lack informal mathematical knowledge. In order to accommodate students with weak mathematical skills, SMU introduced the component of basic mathematics and elementary statistics hence the module is named Foundation Biophysics and Numeracy. Furthermore, a three-step biophysics problem solving strategy was introduced in order to increase throughput and to restore confidence to the students who leave high school with limited understanding of principal concepts of physical science and mathematics which are a prerequisite of Biophysics and Numeracy module.

The three-step physics problem solving strategy. A strategic design is the most important part of problem-solving. Ability to solve biophysics problems plays a crucial role in mastering biophysics concepts. A student who develops from being a novice biophysics problem solver to a fully-fledged problem solver attains a higher degree of conceptual assimilation as well a good ability to perform visual analysis of abstract biophysics phenomena. In this section a three step biophysics problem solving strategy is presented. Prior to detailing the proposed three-step biophysics problem solving strategy, some important and helpful definitions are given below.

Definition of a problem and problem solving. Physics problems have been discussed (Chetty, 2012; Maloney, 2011; Meyer, 1992; Mundalamo; 2006). Abdullah (2009) relying on the work of Resnick defined a "problem" as a situation in which an individual encounters a task not previously encountered and needs to find a solution in the absence of a completely defined mode of solution. Such a task should be new to the individual, although processes or knowledge already available can be called upon for solution. A problem may exist whenever there is a gap between where you are now and where you want to be, and you don't know how to find a way to cross that gap (Wenning, 2002). However, Maloney (2009) pointed out that not all tasks or situations constitute a "problem". It is the skill and the knowledge that the individual brings in the interaction process that determines whether the task or situation is a problem or not. To an expert, the path or solution to the task is obvious, the expert only sees the "problem" as an exercise (Domelen, 1998; Gordon, 1992; Heller et al., 1992; Maloney, 2009; Meyer 1992). According to Maloney (2009) the "problem" in essence should be a task that is characterized by three components namely: "the initial state; the goal state and the procedures to eliminate the gap between them." In addition to the above definitions several others can be found in literature, however all share common elements. In essence all researchers agree that a problem is encountered when dealing with a task of a given grade of difficulty where an answer is not available at hand (Domelen, 1998; Maloney, 2009).

In this research paper our understanding of a "problem" concurs with some common elements already established in literature (Domelen, 1998; Gordon, 1992; Heller et al., 1992; Maloney, 2009; Meyer 1992). Accordingly, we develop our understanding of the essence of a problem from the nature of tasks/situations at hand and the knowledge and experience brought to accomplish them. Tasks/situations that make up a problem are very broad, they may generally be classified under a particular knowledge domain such as chemistry, biology, and physics (Maloney, 2009). In this research we choose to narrow the tasks/situations to encompass the biophysics domain hence we classify as a problem in biophysics a task of a certain degree of difficulty in which the answer is unknown. It can be obtained in a process that involves application of biophysics concepts. A task classified as a biophysics problem can be solved using biophysics knowledge already possessed, following a particular procedure, referred to in this study as a three-step biophysics problem solving strategy. A person who possesses the ability to successfully solve problems may be regarded as having acquired problem solving skills. However, to determine what constitutes a "problem solving skill", and whether it can actually be imparted can be a nightmare. It is beyond the scope of this paper.

Problem solving may be defined as a cognitive process directed at achieving a goal when no solution method is obvious to the problem solver (Meyer, 1992). This definition takes into account the abilities of an expert and a novice. The student is in most cases is a novice problem solver, has little knowledge domain in the field of study. On the other hand an expert may be advanced undergraduate students in their final year of specialization, graduate students and experienced university professors (Maloney, 2009). Biophysics problem solving skills involves mapping out strategies that formulate a sequence of events or steps that leads to the answer, such steps can be learnt. Biophysics problem solving can be learnt just like physics problem solving. Gordon (1992) stresses that once practiced over and over again, the physics problems internalize within the individual to a point that they become second to nature. The same can be said about Biophysics problems.

In this paper we present a three-step biophysics problem-solving strategy (method) that comprises of three main steps namely: strategy design, implementation of the strategy and evaluation of the results obtained (Chetty, 2012; Gordon, 1992; Heller et al. 1992; Styer, 2002). A student who manages to successfully implement the above biophysics-problem solving steps will find biophysics problem solving enjoyable and exciting. Once approached with a spirit of exploration, these problems certainly never disappoint. Ability to solve biophysics problems improves the student’s cognitive skills and ultimately improves conceptual assimilation.

Strategy design. Strategy design constitutes the most important part of the solution process, if unsuccessfully carried out, the whole process becomes a failure. Strategy design begins with reading and analysis of the question. Here the problem solver forms a representation of the internal model of the task/situation at hand. This process is critical, it enables the problem solver to make sense of as well as to visualize the physical system paying particular attention to its behavior. This process makes complete sense of the biophysics concepts and principles involved (Maloney, 2009). Failure to make a correct internal representation impedes progress leading to dismal failure when solving the biophysics problem. However, the situation may be remedied by re-representation, a further skill that will enable the problem solver to identify the stumbling point. In addition to internal representation is external representation. The later describes the tasks and the procedure to be followed when solving the problem. The essential aspects in the process of external representations involve:

- Developing understanding of the question through qualitative description using pictures and words (Heller et al., 1992).
- Drawing of relevant diagrams where possible and listing down the given data.
- Writing down what the question requires so as to keep the objective in sight.
- Writing down the required relevant mathematical formulas.
- Re-writing the formula, making subject the unknown variable to be calculated (this procedure applies to all problems of quantitative nature).

An average student is encouraged to read the question at least three times. A hurried approach often leads to failure to understand what the problem requires often leading to loss of marks. Furthermore a rushed approach regularly leads to poor interpretation of the relevant biophysics concepts involved hence dismal performance on the part of the student.

Implementation of the strategy. Implementation and execution of the strategy constitute the second most important stage towards achieving a solution of a biophysics problem. It requires one to work in a neatly organized manner that will enable the examiner to follow the working with ease. Most marks are allocated at this stage hence great care and neatness is called for. The execution tactics involves:

- An analysis and interpretation of the physics concept involved in order to justify the procedure to be adopted
- Substituting given data into appropriate equations.
- Simplification of the equations to obtain the final solution

During the execution process one has to make sure that data substituted into the formula has appropriate units. In the event that units given are not S.I units then they should be converted into S.I units.

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Evaluation process. Evaluation of the results obtained is the final stage. This stage is always often over looked by majority of inexperienced biophysics students yet from it can be concluded whether or not the student has understood the biophysics concepts involved. The final result gives the student a chance to check whether the answer obtained falls within the "reasonable range". The evaluation process thus involves checking:

• Dimensionally consistency
• Significance of results.

Here the student checks the answer to see whether it is numerically reasonable. The significance of its sign should also be checked. For example when calculating acceleration, a negative value will signify retardation.

• If an appropriate number of significant figures have been used in the final answer (Heller et al. 1992).

This study sought to answers the following research question:

• Can the performance of students from disadvantaged communities be improved by affording to them relevant facilities and a good support system in a foundation Biophysics and Numeracy module?

Materials and Methods

This study is a retrospective analysis of semester tests and a final examination mark for three cohorts 2010, 2012 and 2013 enrolled for Foundation Biophysics and Numeracy at SMU. This paper reports on the performance of these cohorts. Majority of these students were drawn from disadvantaged schools mainly characterized by scarcity of resources. Most of them attained adequate achievement (50 - 59%) in mathematics and physical science in their grade 12 examinations. A small fraction had substantial achievement (60 - 69%). These results were far below the grades that would guarantee them a place in the medicine program at SMU. All the students did the same grade 12 curriculum offered in public schools. Based on their averaged grade 12 results, it was assumed that students enlisted for the foundation Biophysics and Numeracy module with the same cognitive characteristics. This module is one of the six foundation modules offered at SMU in foundation medicine programme. Successful completion of the course with a pass mark of 50% and above in all foundation modules (Biochemistry, Biology, Biophysics and Numeracy, Study skills, English for Medicine and Anatomy and Physiology) guarantees the students an opportunity to enter first year medical degree program (MBChB) offered by the university.

The Biophysics and Numeracy curriculum was designed in 2010 during the inception of MBChB-ECP and later updated in 2012. The principal lecturer has always been the author. Tutors (post graduate students) change every two years. For the academic years 2010 and 2011 the same tutors were maintained. Two new tutors were employed for the academic years 2012 and 2013. The Biophysics and Numeracy module was designed to be a practical physics course that teaches students about the interaction between physics and the human body through appropriate experiments with an emphasis on problem solving. The first quarter of the semester covers basic mathematics and elementary statistics. The rest of the first semester deals with force and energy on anatomical structures and then lastly temperature, pressure, fluid motion and their effect on the body. The second semester covers characteristics of materials, electromagnetism and its application to biological systems, basics of sound and optics and their applications. Finally radioactivity and the generation of X-rays and their interaction with the body are covered. The course is structured such that there is one lecture a week lasting 40 minutes, a tutorial session a week with a duration of 140 minutes and a practical session also once a week lasting 240 minutes.

A traditional approach was used to deliver the lectures for the 2010 cohort where the lecturer did most of the talking whilst students took notes. Students had been previously issued with a study guide and a laboratory manual. During tutorials, tutors worked several problems for students on the board and later handed over a series of biophysics problems to them, to work on. At the end of each tutorial session, students wrote a tutorial test. Three semester tests and a final examination were written. These covered the same objectives and scope as the biophysics semester tests written by the 20102 and 2013 cohorts.

Upon realizing the challenges encountered by the 2010 cohort, an intervention mechanism (a three-step biophysics problem-solving strategy) was employed with the 2011, 2012, and 2013 cohorts. Further support included providing students with study notes, lecture slides and study guides with clearly outlined study objectives and expected outcomes. Feed - back was provided to the students either face to face or via the blackboard immediately after they completed assignments or tests. Learning and teaching relied on use of a combination of learner and teacher centered activities.

The performance of the students and the impact of the three step biophysics problem solving strategy and its role in facilitating conceptual understanding by students was is evaluated using a pre - intervention test, a post intervention test, biophysics tutorial and semester tests and a final examination. The pre-intervention test measured the students' biophysics problems skills and their level of assimilation of the concepts of force as applied to biological systems. The post intervention test measured the ability of students to apply the three step biophysics problem solving strategy and their level of assimilation of the concept of force. Both tests were not considered in the final course mark. Test 1 covered numeracy (basic mathematics and elementary statistics), Test 2 measured conceptual assimilation on force and energy on anatomical structures, temperature, pressure, fluid motion and their effect on the body. Test 3 covered characteristics of materials, electromagnetism and its application to biological systems. Test 4 covered basics of sound and optics and their applications; and lastly X-rays and their interaction with the body. The final examination integrated all the covered topics. The final course mark was a combined mark of the 3 hour final examination mark which contributed 40% and the four semester tests, tutorials and practical marks which contributed 60% (weighed as follows: 80% for the four semester tests and 20% for both the practical and the tutorial marks).

However, the report of this study is focused on the 2010, 2012 and 2013 cohorts. Discussions were held with the students (2012 and 2013 cohorts) at first encounter. An explanation was given about the structure of the Biophysics and Numeracy module and the expected outcomes. Students were each handed a study guide and a laboratory manual. The relevance of biophysics as well as the importance of numerical skills in their medical career was stressed. Students were given an opportunity to air their views on the past experiences in physics and mathematics which are a prerequisite for biophysics. The objective of this exercise was to build their confidence in working with the biophysics and basic mathematics (numeracy) concepts in the Biophysics and Numeracy module. During the discussion the students were briefed on the importance of team work as well as the significance of active engagement. Collective learning (Chetty, 2012) was emphasized. All the above aspects contribute towards mastering of problem solving skills and development of good work ethics. Students (2012 and 2013 cohorts) were given a pre intervention test as their first written work. It covered the concept of force and its application in biological systems. Table 1 below shows the criteria used to evaluate the pre - intervention test and post intervention test 1.

Selection of Participants

The study population comprised and 50 students registered in 2010; 45 students registered in 2012 and 50 students registered in 2013 for the foundation medicine programme (MBChB-ECP) offered at SMU. These students matriculated with limited functional understanding of some core concepts in mathematics and physical science, thus the aim of the study was to demonstrate that:

- Brain training of students is possible through imparting to them biophysics problem solving skills. The skills involve mastering of problem solving strategies as well as logical reasoning.
- Students with disadvantaged academic background once given "artificial cogitation'', the intellectual equivalent of artificial respiration (Heller et al., 1992) can produce outstanding results.
- The three-step biophysics problem strategy improves students' understanding of biophysics concepts.

Table 1 Evaluation criteria for the pre and post intervention test 1.

Expected steps and order of writing them	Mark allocation
Has the student made qualitative description of the physics phenomena using diagrams?	1
Has the student listed given data	0.5
Has the student listed the unknown or what is to be calculated or found?	0.5
Has the student provided the force diagram?	1
Have the forces been resolved correctly on both the y- axis and the x-axis?	2
Has the resultant force been correctly calculated?	2
Has the student written the appropriate mathematical formula?	1
Is the appropriate mathematical formula re-written making subject the unknown variable that is required to be calculated?	1
Has the data been correctly substituted into the formula?	2
Are the units correct in the final answer?	1
Any signs to show that the answer has been checked to see if it is numerically reasonable	1
Has dimensional consistency been evaluated?	1
Have appropriate number of significant figures been used?	1

The three-step biophysics problem solving strategy (intervention mechanism) was introduced to students during their lecture period following the pre-intervention test. The students were then given an opportunity to consolidate the learnt biophysics problem solving strategy during the tutorial session. At the end of the tutorial session, a post intervention test was administered. This was assessed based on the criteria given in table 1. However, this test was not counted in the final evaluation. It was used as a barometer to measure the impact of the nearly introduced intervention mechanisms (the three-step biophysics solving strategy).

Students worked in small groups of three or four in during tutorial sessions. These groupings were maintained throughout the year during tutorial. The smallness of the groups gave students an opportunity to effectively participate in group activities and discussions thus engaging with ideas at the same time improving their communication skills. During the tutorial sessions at least two different groups were assigned to do the same problems. Others groups did different problems but of the same level of difficulty. All groups applied the three-step biophysics problem solving strategy. Students presented their answers on the board, others reviewed the answers and compared with theirs. This presented them with an opportunity to modify and internalize the strategy. Modification of the strategy was done to suite its application to specific problems. The tutor and lecturer intervened where students encountered difficulties. At the end of each tutorial session, the students were individually assessed with a uniform biophysics problem based on the concepts covered during the tutorial and in the previous lecture. In some cases the questions linked to concepts covered in previous lectures. The task was conducted in order to determine the student's level of understanding of the biophysics concepts and principles covered during the particular tutorial session. A total of 13 tutorial tests were administered. These were assessed using tests 2, 3 and 4. Thirty percent of the content in the final three hour examination included basic aspects of numeracy and elementary statistics.

Results

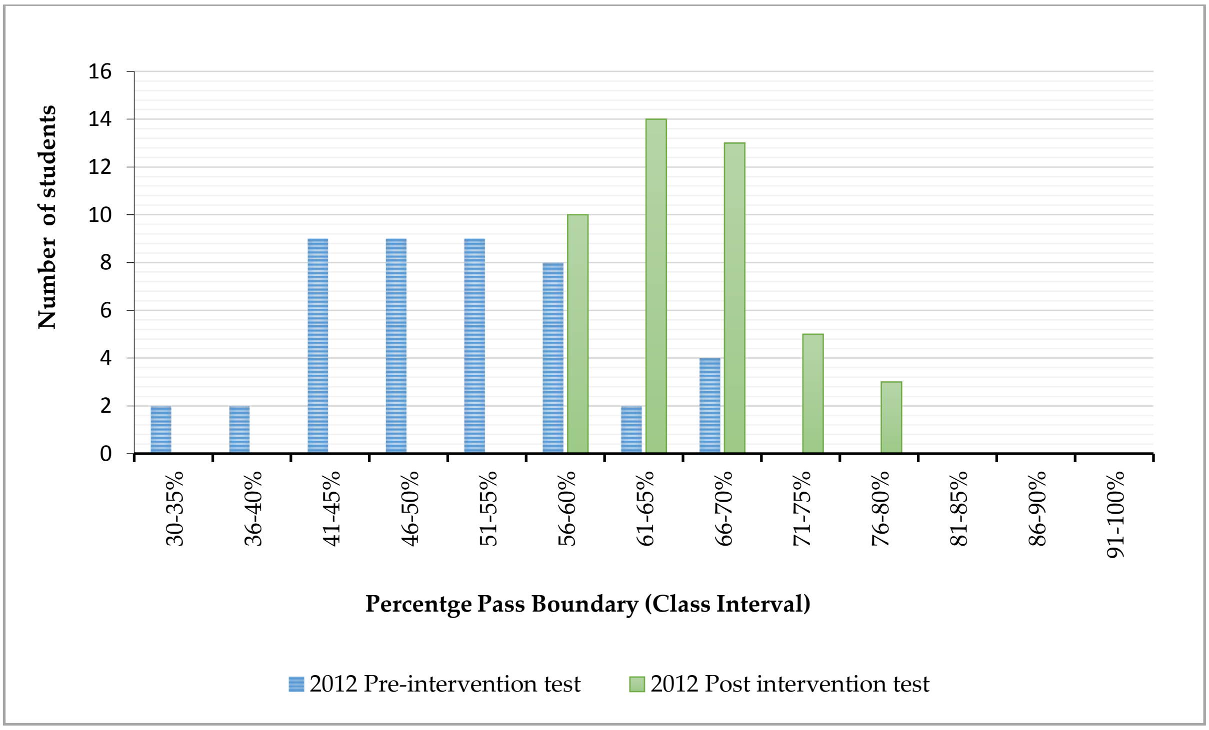

Figure 1. Distribution of pre and post intervention marks on the concept of force for the 2012 cohort.

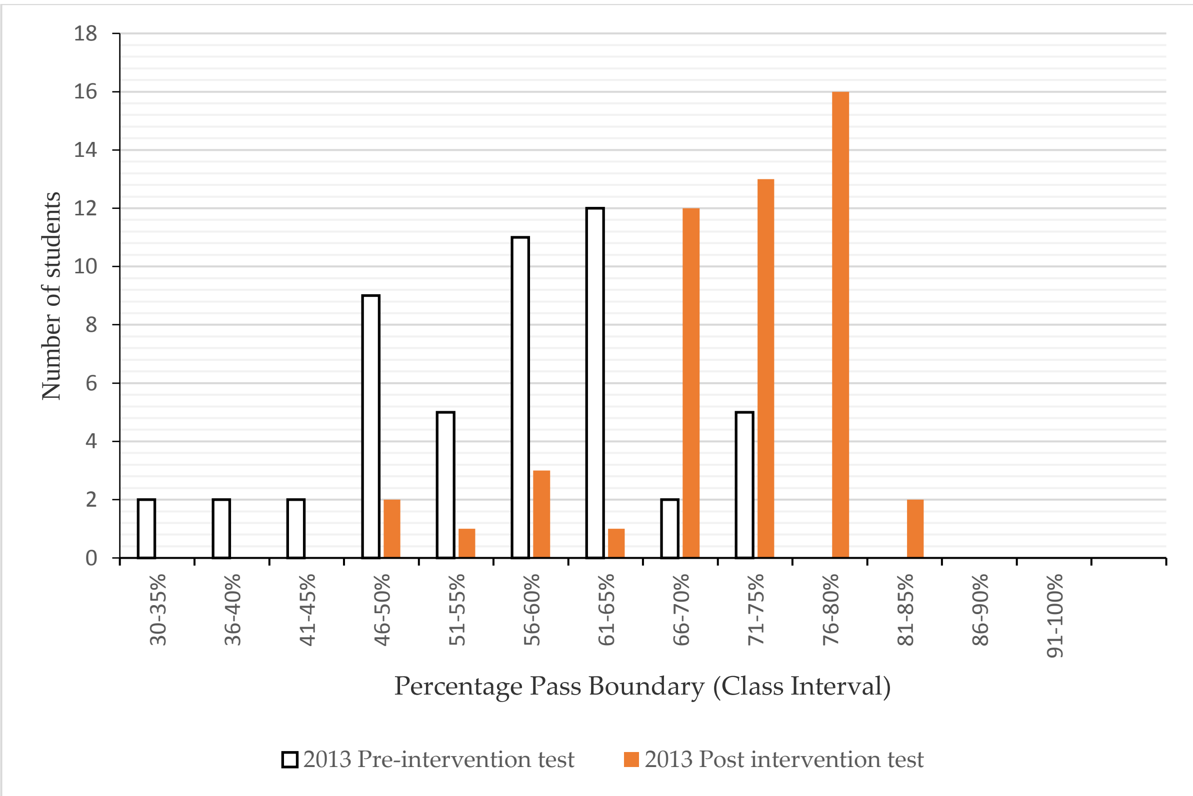

Figure 2. Distribution of pre and post intervention marks on the concept of force for the 2013 cohort.

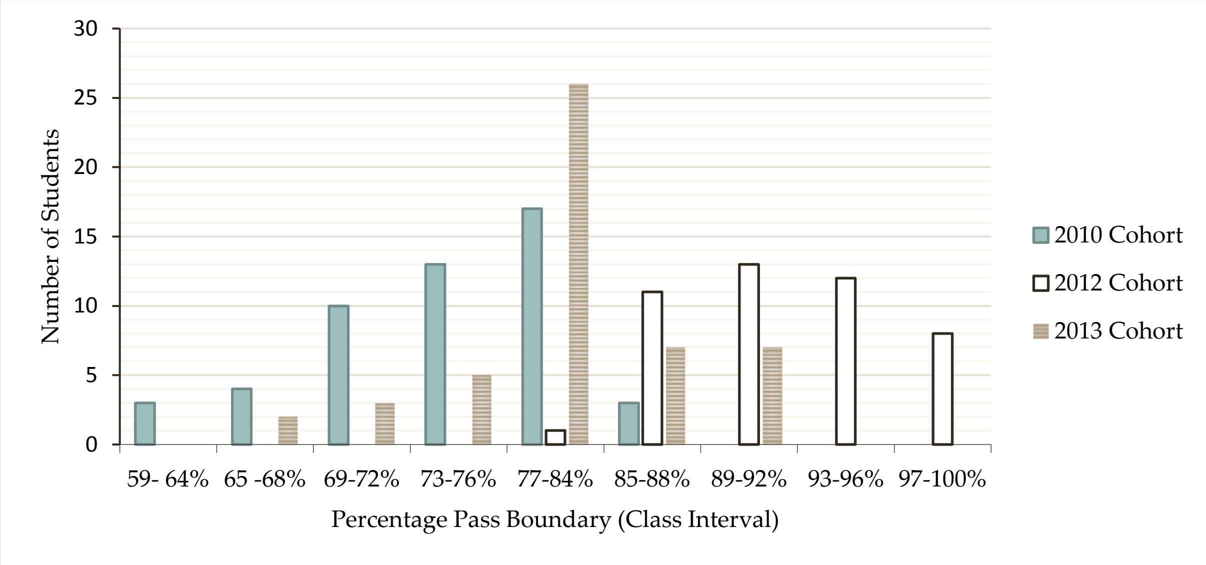

Figure 3 Distribution of biophysics tutorial test results for the three cohorts (2010, 2012 and 2013).

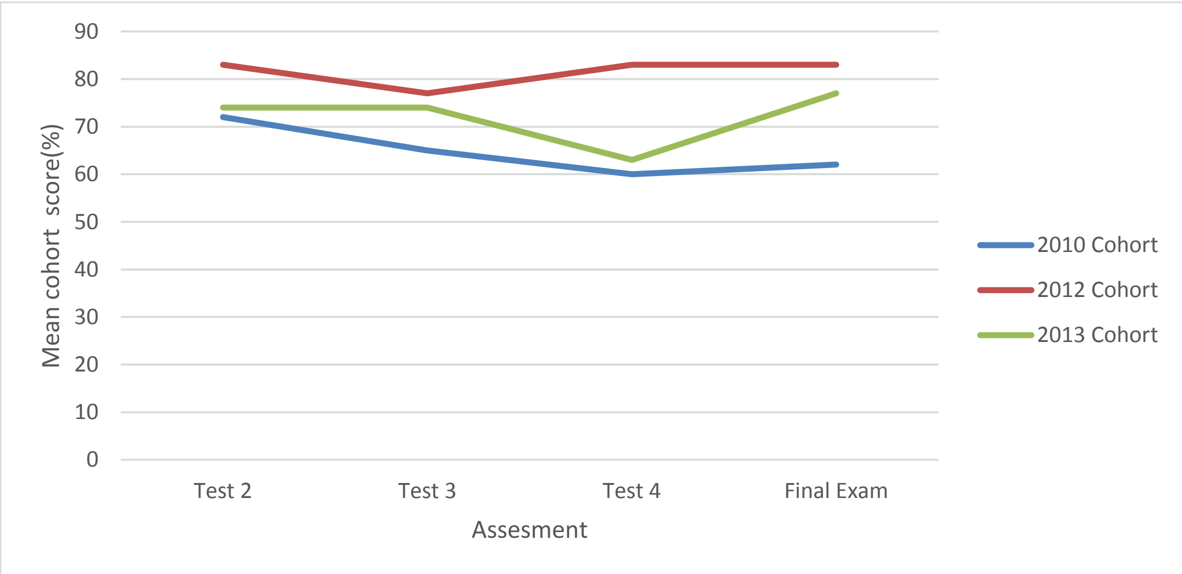

Figure 4. Comparison of marks achieved by 2010, 2012 and 2013 cohorts in Biophysics assessments

Discussion

Results and experience of working with the 2010 MBChB-ECP cohort proved that students from previously disadvantaged schools had challenges in coping up with the traditional methods of teaching biophysics and as well as acquiring biophysics problem solving skills. Marks achieved by this group (2010 cohort) in the module were mainly boarder line, however 100% throughput was achieved.

In order to facilitate the new entrants to cope with the challenging biophysics concepts, an intervention mechanism (a three-step biophysics problem solving strategy) was devised and successfully implemented in three biophysics cohorts (2012 and 2013). Majority of students 69% (31 out of 45) from the 2012 cohort failed the pre- intervention test compared to 100% who passed the post intervention test. For the 2013 group, 30% failed the pre-intervention test compared to 4% who failed post-intervention while the majority 96% (48 out of 50) passed the post –intervention test. Students' scripts for the pre- intervention tests showed that in both groups majority of students solved the biophysics problems without following the steps in table 1. Many important steps were left out. Those who managed to arrive at the correct final answer lost most of the marks because they left out the vital steps. From their answer scripts, it was also observed that they just plugged their data in the mathematical formula without putting into perspective what they were required to calculate. Few attempted to rearrange the mathematical formula to make subject the unknown quantity. Generally students failed to manipulate the units correctly. In most cases their answers had wrong units.

Results of the post-intervention tests administered on both 2012 and 2013 cohorts showed great improvement in the biophysics problem solving abilities. The same concept of force was examined as was in the pre-intervention test. Questions set were very similar despite varying degrees of difficulty. In figures 1 and 2, a contrast is made for the performance pre and post intervention for the 2012 and 2013 cohorts. From the two bar graphs it can be seen that the students' biophysics problem solving skills improved tremendously after they had been taught the three-step biophysics problem solving strategy. Students managed to clearly identify the given data, wrote done the unknown quantity, drew relevant force diagrams. Furthermore, they made proper analysis of the biophysics phenomenon and wrote down relevant mathematical formulas. The unknown quantity was also made subject of formula in almost all answer scripts. Substitution of data was properly done. However, a few steps were omitted here and there leading to loss of marks. Of concern was their disregard of the importance of units. The three-step biophysics problem solving strategy played a significant role in developing their analytical skills and ultimately improving their ability to grasp abstract biophysics. This is evidenced by the meritorious achievement in tests 2, 3 and 4 for the 2012 and 2013 cohorts.

Among these three cohorts, only the 2010 cohort (50 students) did not get exposure to the three-step physics problem solving strategy. This explains why their quality of marks is second-rate compared to the other two groups. From figure 3, it can be seen that the 2012 cohort achieved the best biophysics tutorial marks with all the students (45 out of 45) achieving marks in the range of 74 - 100%. For the 2013 cohort 30 out of 50 students had tutorial marks falling within the range of 74 - 100% whilst for the 2010 cohort only 20 out of 50 students had the marks falling within the 74 - 100% range. Differences in performance between the 2010 and the other two cohorts (2012 and 2013) are certainly attributed to the successful assimilation of the three-step biophysics solving problem strategy learned and applied by the two groups. However, the differences in performance between the 2012 and 2013 cohorts can be attributed have individual cognitive abilities since they had the same lecturer and the same tutors.

A graphical analysis of figure 4 leads to the conclusion that the three-step biophysics problem solving strategy improved the performance the 2012 and 2013 cohorts. However, despite registering pass marks in the same assessments (tests 2, 3 4 and the final examination), the quality of marks achieved by the 2010 cohort was low. The achievement by the 2012 and 2013 cohorts in the biophysics module testifies that indeed students from disadvantaged communities have great potential which remains untapped. They fail to achieve good results in high school simply because of lack of resources and inadequate preparation. The three- step physics problem solving strategy played a significant role in improving the pass rate. It enabled students to have a good understanding of the biophysics principles and concepts.

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