Interactive teaching of mechanics in a Ghanaian university context

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Interactive teaching of mechanics in a Ghanaian university context/ V. Antwi – Utrecht: Freudenthal Institute for Science and Mathematics Education, Faculty of Science, Utrecht University / FIsme Scientific Library (formerly published as CD-β Scientific Library), no. 76, 2013.

Dissertation Utrecht University. With references. Met een samenvatting in het Nederlands.

ISBN: 978-90-70786-17-5
Keywords: interactive teaching/curriculum development/design research/ university/mechanics/physics education/conceptual understanding/Ghana
Cover design: Vormgeving Faculteit Bètawetenschappen
Printed by: Drukkerij Wilco, Amersfoort

Interactive teaching of mechanics in a Ghanaian university context

Interactief onderwijs in mechanica in de context van een Ghanese universiteit

(met een samenvatting in het Nederlands)

Proefschrift

ter verkrijging van de graad van doctor aan de Universiteit Utrecht
op gezag van de rector magnificus, prof. dr. G.J. van der Zwaan,
ingevolge het besluit van het college voor promoties
in het openbaar te verdedigen
op maandag 10 juni 2013 des middags te 4.15 uur

door
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geboren op 13 januari 1966
te Kumasi, Ghana

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Chapter 1

General introduction

1.1 Introduction

In the 21st century, where survival and wealth depend on science and technology, youth's mastery of science will be more essential than ever before (Fantz, De Miranda & Siller, 2011). For Ghana to realize accelerated development in the 21st century, the country needs good quality science and technology education, with many students reaching high levels of mastery and insight. Achieving this depends largely on the effectiveness and efficiency of science teachers in the schools (Ezeliora, 2005).

The present situation in Ghana with respect to science education is rather weak. According to the international comparison studies TIMSS, Ghana's eighth graders in science (JHS 2) took the 44th position out of 45 countries that participated in the test (Martin, Mullis, Gonzalez & Chrostowski, 2004). In TIMSS 2007, they ranked last among 48 participating countries (Martin, Mullis, & Foy, 2008). In TIMSS 2007, Ghana's eighth graders had average scores of 304, 342, 276 and 294 for biology, chemistry, physics, and earth science respectively, extremely low scores, especially in physics. These findings are in sharp contrast with the expressed science interest of these students, which was rather high (Anderson, 2006; Williams, Jocelyn, Roey, Kastberg & Brenwald, 2009).

Ghana's participation in TIMSS was a means to provide information on its students' performance compared to some other countries using an international yardstick. Reports from the chief examiner of the West African Examination Council (WAEC), (2002; 2004; 2008) confirm that many students have poor knowledge of science. They avoid questions requiring deductive thinking, and are unable to go beyond stating definitions. In his recommendations, the chief examiner emphasised the fact that teachers in the sciences, especially physics, should improve their methods of teaching to make physics a more attractive and less abstract subject. He proposed that teachers should actively involve students in the teaching and learning process, and he added that rote learning should be discouraged as much as possible. Thus teachers should adopt methods that will enhance student participation and understanding during teaching and learning by relating physics examples to their environments and real life activities, and allowing students to gain practical experience such as the use of microcomputer based laboratory (MBL) tools.

1.2 Current teaching practices in Ghana

In current practice, most Ghanaian schools place heavy emphasis on the use of lecturing without active student involvement, followed by drill and practice. In Ghanaian local parlance, this mode of teaching goes by the name of the "chew and pour" method. Studies have shown that with such an approach most students depend on rote learning and rote problem solving, without having developed the conceptual problem solving skills that all scientists value (Mazur, 1997; McDermott, 1993). The lack of conceptual understanding usually goes unnoticed because students can solve many standard problems in spite of the difficulties; they are talented and have memorized rules that are often true. For example, students know that in circular motion some force will be $F = mv^2/r$, because that formula is usually highlighted in the textbook section on circular motion. They are not sure of the force's direction or cause, but can easily calculate for *v*, because the problem has specified *F*, *m*, and *r* and asked for *v*. Simple algebra yields *v*, whether or not the students understand the cause or direction of the force. So, while students will learn to do the standard problems, these approaches in science teaching do not help students to grow in their reasoning ability (Marbach-Ad, Seal, & Sokolove, 2001; Jungst, Licklider & Wiersema, 2003).

An excessive reliance on lecturing has the major weakness of allowing students to become passive recipients of information that has been simplified by the teacher (Hansen & Stephens, 2000). They are dependent on the teacher to tell them what they need to know, and as a result do not become responsible for their own learning (Machemer & Crawford, 2007). By virtue of the constant practice of being passive in class, such students have a low tolerance for challenge, and their learning will be relatively superficial and transient (Moust, Van Berkel & Schmidt, 2005). Students usually enter the classroom with the intention to gather all the necessary facts from the teacher. Oral culture from teacher to students is heavily depended on by students. Students are not so much textbook oriented. The few who are interested in using the textbook prefer reading from the summary portion of the book, with the view that most important ideas will have been summarised there.

The heavy reliance on lecturing and student preference for passive modes of teaching are not unique to Ghana. However, Ghanaian culture has some characteristics that might serve to reinforce this pattern: in Ghana, politeness and respect towards the elderly are highly esteemed cultural values. Whatever older people say is the truth and the young cannot put up any challenge whatsoever, else they will be regarded as not being respectful (Culture of Ghana, 2010). Legend has it that when a foreign chemistry instructor tried to get his students in one of our secondary schools more involved by asking so many questions, this was misconstrued by students and he was reported to the head of the school, as not knowing his "stuff". They assumed that he had to ask so many questions for his own clarification.

Finally, little attention is paid to the question why the science at hand is being taught, what real world phenomena the models can explain, which practical problems they can be used to solve and why students should care about any of them. The only motivation to learn that students get, if any at all, is the suggestion that the material will be important later in the curriculum or in their future careers. A well-established precept of education psychology is that people are most strongly motivated to learn things that they clearly perceive they need to know (Albanese & Mitchell, 1993). Simply telling students that they will need certain knowledge and skills some day is not a particularly effective motivator.

According to McDermott (1991), evidence indicates that for many students the standard introductory courses are not effective in helping to achieve the learning objectives. Ease in using technical vocabulary does not indicate conceptual understanding. The ability to follow certain prescribed procedures for solving standard problems, which most of our students have, does not indicate development in scientific reasoning skills. However, since the above is widely accepted practice in Ghana, there is little incentive for teachers to change their teaching habits, and to invest extra preparation time, only at the risk of finding out that class time will be too limited to cover the prescribed curriculum, and to be criticized for teaching in unorthodox ways (Bonwell & Eison, 1991).

1.3 What to do to improve science teaching?

Today, there is strong evidence that effective teaching involves active participation by students, through discussion, hands-on activities and problem solving (e.g. Hestenes, 1987; Deslauriers, Schelew and Wieman, 2011; Wieman, Perkins, & Adams, 2007). Deslauriers et al. (2011), found that even with limited training an inexperienced instructor using interactive teaching more than twice outperformed an experienced highly rated instructor using the traditional lecture in learning of his students. However, there is also evidence that such teaching requires a major shift in teachers' thinking and in their repertoire. Andrews, Leonard, Colgrove, and Kalinowski (2011) concluded that in the hands of regular teaching staff interactive teaching is not an effective tool, and that you need educational specialists to make it work.

Thus far, we know of no examples where such an approach has been attempted in Ghana or even in most of Africa. This is an important limitation of current knowledge, since the educational setting in Ghana is considerably different from that in more heavily researched geographical areas, such as the US, Asia, and Europe. As we have discussed above, the Ghanaian situation has its specificities in terms of educational resources, student attitudes and expectations, and cultural patterns. This might pose specific demands for physics teaching as well, and there is no guarantee that approaches that proved effective elsewhere can be adopted without modification.

Therefore, this research is meant to develop physics teaching strategies for the Ghanaian university context that will lead students to active participation in a meaningful teaching-learning process.

1.4 Zooming in on introductory mechanics at UEW

The University of Education, Winneba (UEW), being the home institution of the present researcher, educates Ghana's next generation of physics teachers, and it is likely that these new teachers will teach as they are now being taught. Instructional practices at the UEW are not significantly different from those elsewhere in Ghana: the curriculum is fixed and the teacher of a course is supposed to cover the entire syllabus within the allotted semester. Instructors commonly rely on lecturing. They start physics (mechanics) teaching by lecturing on general principles. They then use the principles to derive mathematical models, show illustrative applications of the models and give students some practice question(s) in similar derivations and finally test their ability to do the same during examination. Qualitative problems are mostly based on "define, state and list", which does not call for better understanding of concepts. Discussions, demonstrations, experiments and practical work, where students can interact among themselves and with teachers and teaching assistants, to confirm and validate principles and results presented during lectures, and solidify their understanding of fundamental physics principles are rarely done in UEW, usually caused by lack of equipment, a course work overload and limited available time. If the Ghanaian approach to physics teaching is to be changed, this is the place to start.

Within the UEW physics teacher education programme, we had to choose a particular course to focus on. Beyond the practical fact that the present researcher is a teacher of introductory mechanics, there are several reasons why the topic of mechanics is an appropriate focus for this study. These include the fact that it forms the foundation for many later topics in physics. Secondly, researchers, such as McDermott, Rosenquist, and van Zee (1987), and Knight (2004), have identified a number of alternative conceptions and other student problems in mechanics. It is therefore necessary to find out the sort of misconceptions or alternative ideas students in UEW carry to mechanics class. Thirdly, in view of the negative public perception that mechanics is tedious, mathematical, abstract and fundamentally irrelevant, the challenge in an introductory mechanics course is to convince the audience that mechanics is rewarding, fun, useful and a worthwhile endeavour (Freedman, 1996). Lastly, from the researcher's own point of view and experience, students who do not have a good grasp of concepts in introductory mechanics are likely to perform poorly in other areas of physics.

1.5 Research questions

Basing on the aforementioned considerations, the major research question for this thesis will be:

> *How may the understanding of mechanics be promoted through interactive engagement methods among undergraduate physics students in the Ghanaian educational and cultural context?*

Subsidiary research questions

- How does interactive engagement work in classroom practice?
- How do students appreciate interactive engagement teaching?
- Does the revised course lead to gains in conceptual understanding?
- What is the long term effect on students' ideas about interactive engagement teaching and learning?

1.6 Outline of the thesis

To guide the reader, we will present a brief outline of how these research questions will be addressed in this thesis

Chapter 2

In this chapter, we will present the Ghanaian educational context. We will provide the overall picture of education in Ghana as a background for interpreting this research within its context. The chapter will end by describing the challenges facing the Ghanaian educational system.

Chapter 3

In Chapter 3, we will first present an outline of the topics covered in the UEW mechanics curriculum. Secondly, we will discuss the learning difficulties as they have been described in the literature. Next, we will address affective issues of motivation and attitudes, and the more general issue of teaching and learning culture and the potentials for Ghana as derived from the literature. The chapter will be concluded with the need for improvement in the teaching and learning of UEW Introductory Mechanics.

Chapter 4

In this chapter, we will argue that the available teaching methods cannot be directly applied in the Ghanaian context, and that we need a developmental approach. We will review strong evidence that learner centred and interactive engagement methods are effective to attain deep understanding, and based on that we will present a first design for an interactive Introductory Mechanics course. We will describe the various activities, and derive expectations about the classroom process to guide the analysis of our data and observations.

Chapter 5

In chapter 5, we will evaluate our educational design based on the first classroom trial. Although we will report both on students' learning gains and on the quality of the classroom process, the focus in this first round of evaluation is on deriving implications for improving the design.

Chapter 6

In chapter 6, we will first discuss how the findings from the first field test were used to revise the design. Next we will analyse the data from the second field test, and the results will be with compared with those of the first round.

Chapter 7

In chapter 7, we will answer the research questions, and we discuss the strengths and limitations of this study. We will present recommendations for further research, recommendations for teachers who would like to set up interactive physics courses in a similar context and recommendations for teaching universities and agencies in Ghana.

Chapter 2

The Ghanaian educational context

2.1 Introduction

In this chapter, we will present the Ghanaian educational environment as a background for interpreting this research within its context. The chapter will end by describing the challenges facing the Ghanaian educational system.

2.2 Ministry of Education

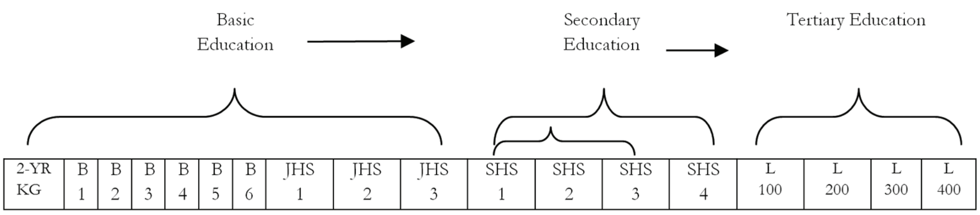
Education in Ghana is centrally administered under the purview of the Ministry of Education. The Ministry has various units responsible for education in Ghana. Ghana Education Service (GES) administers pre-university education. The West African Examinations Council (WAEC), a consortium of five Anglophone West African Countries (Ghana, Nigeria, Sierra Leone, Gambia and Liberia) is responsible for developing, administering and grading school-leaving examinations up to the secondary level (GhanaWeb, 2009). The National Council on Tertiary Education, National Accreditation Board and the National Board for Professional and Technician Examinations (NABPTEX) are responsible for tertiary education.

2.3 The Ghanaian education system

Created in accordance with a colonial model inherited from the British (Quist, 2003), the Ghanaian education system has been characterized since independence by the nationalist objective of using education to create a unified Ghanaian identity out of the country's extraordinary diversity of languages, cultures, religions and histories (Nkrumah, 1968).

For the past 25 years, the Ghanaian educational system has undergone a significant and ambitious reform process. The Education Commission Report on Basics and Secondary Education 1987/88, The Education Reform Programme 1987/88, The University Relationalization Committee Report 1988, The Free Compulsory Universal Basic Education Programme (FCUBE) 1996, The FCUBE Policy Document and Programme of Operations 1996 and The Ghana Education Trust Fund (GET Fund) 2000 are some of the initiatives from the Ghanaian government (Ghana Government Portal, 2011). Educational reform has affected all aspects of the educational system, including curricula and teachers' careers. According to Osei (2006), the Ghanaian education system has been made to adapt to modern society's needs and demands, including those of the job market. However, currently a considerable number of people are without jobs, due to collapse, redeployment or selling of most of the former state-owned institutions into the private sector, which normally needs fewer people to work with. The 1987 reform sets out to increase access to education at all levels, to improve the quality of education, diversify the curriculum by introducing vocational and technical subjects, and shorten the over-extended Ghanaian Education ladder by four years.

On average it takes at least 19 years for a child to complete his or her first university education in Ghana presently. The Ghana Education Service (GES) organizes its constituencies into a 2:6:3:4 or 2:6:3:3 format: two years in kindergarten, six years in primary school, three years in Junior High School (JHS) and four years (or three years) in senior high school (SHS). The duration of SHS has been changed from four years to three years by the new government in power since the 2009/10 academic year and students who were admitted in the year 2009 will attend SHS for three years instead. Thus, students who had admission from 2007/08 and 2008/09 will take four years to complete the SHS programme, whereas students who were admitted in 2009/10 will take three years.



KG=Kindergarten; B=Basic; JHS=Junior High School; SHS=Senior High School; L=Level

Figure 2.1: Ghana Educational System

2.3.1 Basic level of education

School enrolment at four is compulsory for all children in Ghana, for an eleven-year basic education (kindergarten, primary and JHS), though this is not realized in practice in some areas of the country. It used to be nine years of basic education, not necessarily including kindergarten, until the President's Committee on Review of Education Reforms (2002) recommended a change to eleven years. Gradually, a nursery system (known as crèche in Ghana) for temporarily taking care of children under four years old while their parents are at work, is emerging, mostly in urban areas. Most parents prefer to leave their children in this category with relatives, except in cases where the parents have no alternatives.

Basic education is free and mandatory. Abolition of school fees at basic level and provision of a capitation grant by the government of Ghana to cater for teaching materials have increased enrolment at this level. From the age of four to six, pupils are enrolled in kindergarten prior to their six-year primary education. Pupils in JHS spend three years of academic training combined with technical and vocational training, to be exposed to a range of practical activities in the technical and vocational field to familiarise them with, and stimulate their interest in technical and vocational subjects and also to give them equal opportunity to choose their future careers in either the technical, vocational or general field. Pupils from JHS wishing to continue their education into the SHS programme are required to write a West African Examination Council (WAEC) test.

Private basic schools are an integral part of the Ghanaian education system: the public basic schools are not able to accommodate the increasing population of pupils in the country. They are not free and parents or guardians have to pay for their children's or wards' educational needs and fees. Most pupils who attend private basic schools have relatively richer parents than those at the public schools, and students from these schools usually get admissions to the best senior secondary schools in the country. This is due to the fact that a notable number of these private basic schools provide infrastructure, amenities, and other logistics that promote and enhance the quality of education delivery at this level.

The language policy of education in Ghana has had a diversified history since the colonial era. Currently, it is a mixture of the use of both the local language and the English language in the lower classes of primary schools, especially in rural areas where the use of English only in classrooms would not have the expected effect on children in terms of understanding what is being taught in class (Owu-Ewie, 2006). English is strictly used in teaching from the upper primary level onwards.

2.3.2 Secondary level of education

Secondary education refers to the post-basic formal type of education. This is offered to pupils who have successfully completed basic education and have passed their WAEC tests to meet the requisite requirement. It comprises senior high, vocational and technical schools. At senior high school (SHS), students select courses leading them to programmes they may want to follow in the universities and other tertiary institutions, like the sciences (physics, chemistry, biology, core mathematics), general arts, visual arts and other courses. At the end of the SHS programme, students are again required to write an examination with the West African Examination Council (WAEC) (Quist, 2003). The vocational and technical schools provide students with the technical knowledge and vocational skills necessary for agricultural, industrial and commercial, and economic development, and to also impart the necessary knowledge and skills to be trained as artisans, craftsmen, technicians, and other middle-level technical personnel (Akyeampong, 2002). Successful completion of the secondary level of technical and vocational education leads to admission into technical and vocational colleges of education, and polytechnics.

Some secondary schools (SHS, Vocational and Technical schools) are private and they also form part of the educational system. Again, these are not free and the full cost of educational needs and fees is borne by the parents and guardians who send their children and wards to these schools. Students who attend these private schools are often those who could not gain admission into public schools or who were not given their desired course to pursue at the public schools. At the secondary level, students from public schools perform better than their counterparts in private schools, due to the good infrastructure, amenities, and other logistics that promote and enhance the quality of education delivery. Public secondary schools have better infrastructural facilities. Private secondary schools are mostly owned by individuals, and could therefore not provide all the necessary infrastructural facilities to make them compete with the public ones. Relatively more students from the public SHS gain admission to the six public universities in Ghana.

As part of the initiatives by the Ministry of Education to develop the secondary level of education in science, Findel Projects equipped about 110 Science Resource Centres (SRC) in the country from 1995 to 2000. The 110 SRCs were established mainly in unused school buildings or current science laboratories and were strategically sited to serve six secondary schools in the surrounding area. All the laboratories were supplied with a complete range of science equipment to make the teaching of science at these secondary schools more effective. Buses were provided to transport students to the centres when required (Findel Projects, 2008).

2.3.3 Higher or tertiary education

Higher education in Ghana is provided by universities, university colleges, and polytechnics. Entrance to any tertiary institution depends on the student's results in the WAEC exams. Competition is very keen due to the small number of tertiary institutions in Ghana, especially in the public institutions. Selection is based on merit. The Mature Students Entrance Examination is an alternative admission requirement, but one has to have a professional certificate, be of a certain minimum age and should have served for at least five years in a public institution or industry in Ghana.

Polytechnic education

Polytechnics offer programmes leading to the Higher National Diploma (HND) Certificates, requiring three years of study. Graduates of these programmes are qualified to work in industry and can later further their education at a university. They offer other certificate programmes which take two years to complete. Polytechnics offer additional programmes in institutional management, catering and domestic subjects leading to the Institutional Management Certificate in Institutional Housekeeping and Catering.

University education

There are several university colleges and universities in Ghana, most of them private. Public universities are operated by the government and private universities by individuals or organizations, though some may receive public subsidies in the form of public loans and grants. There are six public universities in Ghana presently. These are:

- University of Ghana (UG), Legon
- Kwame Nkrumah University of Science and Technology (KNUST), Kumasi
- University of Cape Coast (UCC), Cape Coast
- University of Education, Winneba (UEW), Winneba
- University for Development Studies (UDS), Tamale
- University of Mines and Technology (UMAT), Tarkwa

Of the listed public universities, only two are specialized in training teachers, to supply the teacher training colleges of education, secondary schools and basic schools. These are the University of Cape Coast (UCC) and the University of Education, Winneba (UEW). UEW is specialized in training only teachers, whereas in UCC, apart from the training of teachers, the institution offers other programmes as well.

University education in Ghana commonly consists of four years of majoring in a specific field of interest. The public universities offer also higher, internationally accepted degrees, which include Master of Education (M.Ed.), Master of Arts (M.A.), Master of Science (M.Sc.) and Master of Business Administration (M.BA.). They also offer other professional degrees like Master of Philosophy (M. Phil.) and Doctor of Philosophy (Ph.D.) or other doctoral degree such as Doctor of Arts, Doctor of Education, Doctor of Theology, Doctor of Medicine, Doctor of Pharmacy and Doctor of Optometry. Most of these programmes have formal apprenticeship procedures, like residency and internship, which must be completed before one is considered fully trained.

Teacher education

Teacher training is offered at the following institutions in Ghana:

(i) Colleges of education

The post-secondary teacher training colleges are now called colleges of education. Prior to 2004 the training colleges were offering a three-year post-secondary programme to train students to become teachers at the basic level. As part of a national improvement strategy to raise the entry level skills of teachers, they were upgraded in 2004 to offer diploma courses. Students spend two years on campus to learn theories of education and some other subjects, and in their third year, they are assigned to classroom mentor teachers to undertake a one-year professional placement and still continue to study through a distance mode. The courses of study here are English, mathematics, cultural studies, basic science, Ghanaian languages, educational studies, physical education and basic agricultural science. Teachers in Ghana have relatively low remuneration, and as a result students who do not qualify to enter university, and some talented but needy students who cannot afford university fees enter teacher training. As a form of motivation to get more talented students into the colleges of education, the pre-service teachers are paid monthly allowances.

Qualified teachers from the programmes are eligible to teach at the basic schools. There are 38 public and three private post-secondary teacher training colleges of education. Though some of the universities in Ghana have started training teachers to supply the basic level of education, the majority of teachers trained for the basic level of education come from the colleges of education.

(ii) Universities for training teachers

In both universities in Ghana which provide training for teachers the duration of programmes is either two or four years. Qualified teachers are awarded a Diploma or Degree respectively in their subject areas of education. They are expected to teach at the secondary level and teacher training colleges. UEW and UCC have put a programme in place to enhance the efficiency of teacher-trainees. They allow their teacher-trainees to spend the final year of their training period off-campus to undertake teaching practice in selected schools under trained mentors. This is to infuse greater professionalism into students before they graduate.

Though graduates from UG, KNUST, UDS and UMAT are not professional teachers, they sometimes end up in the teaching field to alleviate the shortage of teaching staff at the basic and secondary levels of education. To become professional teachers, they can undertake a one-year post-graduate diploma course in education at UEW or UCC.

Some students do their post-graduate courses in any of the public universities. They are trained in programmes lasting two to three years and are awarded with a master's or doctoral degree. They come out to teach at the training colleges of education (sometimes), polytechnics and at the universities.

2.4 Physics education in Ghana

Physics as a subject in Ghana starts at the level of senior high school (SHS) and the technical schools (TS). It is a compulsory subject for all science students in the SHS and students in the TS who are specializing in applied science. It is also one of the examinable subjects at the final year of the SHS and TS.

The SHS and TS syllabi are very ambitious in terms of content and practical work, due to the fact that some of the recommended textbooks which are written according to the syllabi, like GAST have almost 400 pages, 1300 entries in the index and over 200 practical and other activities (Merkus & Oduro-Afriyie, 2006). The syllabi are activity-based. The intended curriculum coverage at the SHS and TS is very broad. Students are expected to finish with the intended physics curriculum before continuing their education at the tertiary level (universities, polytechnics, training or professional colleges). In most cases, the intended curriculum is not completed at the secondary level due to the lack of or insufficient laboratory equipment, quality of teachers and inappropriate teaching methods used, large class size, and lack of facilities and resources like insufficient textbooks, lack of classrooms for teaching, apparently contributing to students' poor performance in physics and probably all the sciences at the secondary level of education (Chief examiner's report, 2008). Sometimes, those who are able to deal with the whole intended curriculum had to subject their students to numerous private extra classes in physics for a fee.

For that matter, matriculating students for physics and physics education at the universities in Ghana appear to fall within a narrower spectrum of ability. The best SHS leavers tend to filter off to overseas universities and into the more attractive fields of engineering, medicine, pharmacy and nursing, leaving those with poorer grades to pursue university physics (McClelland, 1972). Teachers are paid less compared to their counterparts with equal qualifications in different fields of occupation, but not necessarily undervalued in the community. Teaching is not seen as a financially rewarding profession by a new generation of senior high school graduates (Osei, 2006).

Some factors appear to depress university physics performance, these include a prevalent mental set to learn by rote, students' lack of interest to read textbooks, and teachers' failure to achieve students' full participation in classroom activities. Students who graduate as physicists have difficulties in getting jobs in the country, due to the limited number of industries and research centres which can absorb them. Most of them end up in classrooms to teach. Though they are not regarded as professional teachers, they are accepted due to teacher attrition with many teachers leaving the profession to undertake further study and/or alternative careers (Akyeampong, Furlong & Lewin, 2000).

2.5 Science and technology education in Ghana

Ghana and most developing countries in Africa are also using science and technology, as a matter of urgency, to achieve sustainable development. This is shown in the way the government of Ghana in the 1960s set up educational and economic policies with greater emphasis on science teaching, and put in place industries at the rural and urban areas of the country (Anamuah-Mensah, 1994). This led to the building of numerous second cycle schools and the Kwame Nkrumah University of Science and Technology (KNUST), Kumasi, and some polytechnics to train more scientists, engineers and architects to man these industries. Some incentive packages, like scholarships and allowances had to be given to science teachers and students who were ready to take up science at these institutions and other institutions like the University of Ghana (UG) and the University of Cape Coast (UCC) as it was quite difficult to get the requisite number of students to study science and technology. There was a great deal of financial assistance from foreign countries to improve science teaching and learning. Some students were offered opportunities to study abroad, especially by the industries who thought the students' areas of study had direct bearing on their type of work.

Despite many initiatives and policies from the various governments that have come to rule Ghana after independence, not all goals have been achieved in their frantic effort of developing the nation through science and technology education. Though there has been some significant improvement in terms of science and technology education status and its application, it is not to the expected level of Malaysia and some Asian countries, which had their independence almost in the same year as Ghana, 1957 and were also almost at the same level in terms of economic status. Ghana is still confronted with problems like malaria, high unemployment rates, unhygienic conditions and environmental problems. This to some extent vindicates the statement that science and technology education has not been able to expedite Ghana's development as expected, though there might be several causes for this (Anamuah-Mensah, Mereku & Ameyaw-Asabere, 2004; Fredua-Kwateng & Ahia, 2005).

According to Fredua-Kwateng and Ahia (2005), teachers at the Junior High School (JHS) level teach basic science concepts, scientific terms and facts and to a limited extent science process or inquiry skills. Teaching methodology usually consists of straight lectures or direct teaching, which requires the students to listen attentively throughout the duration of the instruction. Students are made to complete exercises that demand "return to sender" of the facts gathered from the lectures. Students are made to do hands-on activities which do not promote deep learning. They are made to follow specific instructions in completing an activity and not designing their own investigations. Usually, such activities are not on what students can observe within their environments, but usually based on references that are culturally and environmentally distant to students. Students' interest is not stimulated to enjoy science as a form of knowledge construction by themselves and the end result is that science learning is reduced to rote learning and memorization of facts, which is not productive for Ghana's development.

Science is taught as separate subjects at the secondary level of education as physics, chemistry and biology, unlike at the JHS level where it is taught as basic science. The same approach that is used by science teachers at the JHS levels is also adopted by science teachers at the senior secondary level. Students are not taught to view the various subjects as a form of knowledge concerned with understanding natural phenomena, leading to both knowledge validation and construction. Instead of encouraging and motivating students to learn through inquiry and construction of knowledge by themselves, the physics, biology or chemistry teacher is considered as the repository of knowledge who preaches for students to only listen. Teachers of these subjects often solve a few examples, mostly quantitative, for students to see, with few or no assignments or practice questions given to students. Hands-on activities are rarely done due to lack of equipment, and the few that are done with students usually follow specific instructions on how to go about the activity. The students end up not improving their cognitive domain to the level that is required of them. They stick to rote learning and memorization, and the ability to reason, adapt, apply scientific knowledge to solve problems becomes a challenge (Anamuah-Mensah & Towse, 1995).

2.6 Agencies assisting in science education in Ghana

Due to the recognition that science and technology could play a role in the socio-economic development of a nation, some agencies (both local and international) have found it necessary to assist the Ghanaian science education system to enhance student learning skills. They visualize this as providing wheels of development in the Ghanaian educational system. These agencies include the Ghana Association of Science Teachers (GAST), the Ghana Science Association (GSA), the African Forum for Children's Literacy in Science and Technology (AFCLIST) and the PRACTICAL Project sponsored by the Dutch Government.

2.6.1 GAST & GSA

GAST and GSA are two local professional science associations, doing everything possible to improve science education in Ghana. Their main purpose is to promote science literacy and raising interest in science and technology education.

The function of GAST is directed towards enhancing effective teaching at the pre-university levels of education in Ghana through the development of creative, enterprising, innovative and morally responsible science and technology teachers and laboratory technicians. They have undertaken numerous projects in assisting science teaching and learning in the country like a writing of GAST textbooks project with Unimax-Macmillan to assist the Ghanaian science teacher in using the science syllabi effectively, a project for science integration, and development of science and technology projects.

GSA is a national multidisciplinary, voluntary and non-profit group of scientists, technologists, engineers, mathematicians and others interested in promoting science, technology, engineering and mathematics (STEM). It has been providing the scientific community at universities, research institutions, industries and government with the opportunity to share scientific information among themselves and with others and to also propel their energies for the socio-economic development of Ghana. Their main vision is to have a dominant voice in science and technology advocacy by promoting and popularizing science and technology to meet national developmental needs.

2.6.2 SACOST

The Centre for School and Community Science and Technology Studies (SACOST) is a Pan-African research and material development and documentation centre which is located at the University of Education, Winneba. SACOST was established by the AFCLIST after they had decided to have a centre of excellence whose focus would be to provide ways in which school science could be linked to community knowledge of science and technology as well as to the workplace in order to promote meaningfulness through the production of curriculum materials (http://www.edu.gh/index.php/sacost-home).

SACOST's vision is to promote interdisciplinary research and developmental activities related to science and technology in indigenous, informal and formal manufacturing industries in order to improve science and technology on the African continent. They have a mission to cultivate relevant research competence, publication proficiency and quality knowledge for linking community and work place science technology with that of schools at the pre-university level. In this regard the centre is spearheading research and multimedia development activities aimed at unearthing the science and technology concepts embedded in informal and indigenous practices in Ghana and other African countries. Also the centre continuously seeks ways and means by which their findings could be embedded in the school science curriculum in an attempt to indigenise science and make it more familiar and relevant to learners.

2.6.3 PRACTICAL project

"PRACTICAL" is the acronym for Programme Reform and Alignment for increasing Competencies of Teachers and for Improving Comprehension and Application in Learning science and mathematics. The project was sponsored by the Netherlands Government Programme for the Institutional Strengthening of Postsecondary Education and Training Capacity (NPT). Both University of Cape Coast and University of Education, Winneba were involved in the project.

The overall objective of the project was to improve the quantity and quality of mathematics and science teaching staff at all levels of education, and improve the know-how and capacity in the education system for the improvement of science and mathematics education in Ghana. The long term benefit is to have a cadre of scientists and technologists to carry the country's developmental agenda forward.

The project's overall objectives were:

- Staff development to create staff capacity in the Department of Science and Mathematics Education at University of Cape Coast (UCC), Department of Mathematics and the Department of Science, both at University of Education (UEW) to enable them to train more and better qualified mathematics and science teachers for the teacher training colleges of education and senior high schools and to provide leadership training and further services for the educational system;
- Programme review to improve and align the existing curricula of sciences and mathematics education at UCC and UEW;
- Reinforcing and increasing the research capacity in UCC and UEW to support the systemic developments of science and Mathematics Education and to create postgraduate training capacity in the universities; and
- Identification and acquisition of ICT and laboratory equipment and other facilities to enable the type of training required to produce more and better-qualified mathematics and science teachers for the teacher training colleges of education and senior high schools.

It was through this capacity creation that the researcher had the privilege of doing a Ph. D. research study at Utrecht University, under NPT (NUFFIC) sponsorship. The project had a duration of four years, 2006-2009 (Merkus & Oduro-Afriyie, 2006).

2.7 Challenges facing the Ghanaian educational system

Education in Ghana is improving gradually, but with some challenges. Poor funding, inadequate staffing, lack of rooms for lessons/lectures, poor pay for teachers, lack of equipment and materials, and few possibilities for career progression are some of the challenges which make that Ghana's education seems to be lagging behind. Curriculum development at all levels requires immediate attention to make it relevant to society. For example, there is limited collaboration between tertiary education and industry, and this is hampering the development of programmes in the tertiary institutions (Nyarko, 2011).

According to Akyeampong, Furlong and Lewin (2000), though more teachers are being trained in the various teaching institutions in Ghana, the supply remains insufficient to meet demands in the various schools. Teacher attrition is a growing problem in Ghana with many teachers leaving the profession to undertake further study and/or alternative careers. Some aspects of the curriculum are too ambitious and its implementation was hastily carried out, especially in the vocationalization of the basic and secondary school curriculum (Akyeampong, 2002).

There are steps taken by the government to fix these problems, like continuous teacher development through distance education, untrained teachers training programmes, increase of female enrolment in teacher training colleges of education, and Ghana Education Trust Fund to provide supplementary funding to support the provision of education by the government throughout the country (Ghana's Development Agenda, 2006).

2.8 Conclusion

Ghana's educational system is progressing gradually despite numerous challenges. The Ministry is doing well to provide and improve infrastructural facilities at all level of education, but not well enough in promoting socio-economic growth of the country and to support a growing population. The particular goal that still needs special attention is raising the quality of teaching and learning for effective outcomes. Key themes for successful teaching and learning should be emphasized in the Ghanaian teacher training institutions for prospective teachers to understand what has to be done and to become familiar with appropriate teaching methods, as the existing pedagogical practices in Ghanaian schools are fairly inadequate. It is necessary for teachers and teacher training programmes to change course to embrace some of the new pedagogical practices that value and involve all learners (Carrington, Deppeler, & Moss, 2010).

Chapter 3

Mechanics teaching in Ghana: current practice and difficulties

3.1 Introduction

In this review chapter, we will first give a brief outline of the mechanics curriculum as it is currently practiced in UEW (Undergraduate Handbook, 2009). Next, we will discuss learning difficulties as they are known to occur with this type of courses according to the literature. First we will discuss cognitive issues, such as lack of transfer, conceptual misunderstanding of Newtonian mechanics and misunderstanding of graphs. Next, we will address affective issues of motivation and attitudes, and the more general issue of teaching and learning culture in Ghana as derived from the literature. The chapter concludes by identifying the major needs for improvement in the teaching practices of UEW Introductory Mechanics.

3.2 The introductory mechanics curriculum at UEW

At UEW, as at many other universities around the world, mechanics is one of the first topics in the curriculum. The syllabus of the introductory mechanics course is much in line with similar courses elsewhere, and with the table of contents of a typical university level text book (Table 3.1).

Table 3.2: Outline of the introductory mechanics curriculum at UEW

Lesson	Title	Topics/Concepts
1	Kinematics in one dimension	Distance, displacement, speed and velocity (instantaneous speed, average speed, constant speed, constant velocity, changing velocity) and acceleration along a straight-line path, free fall.
2	Understanding graphs	Displacement-time graph, velocity-time graphs, acceleration-time graphs and conversion of displacement(x)-velocity (v)-acceleration (a)-time (t) graphs.
3	Graphs and equations	Meaning of the shape of an x-t graph, the importance and how to determine the slope of an x-t graph, meaning of shape of a v-t graph, the importance and how to determine the slope of a v-t graph, determining the area on a v-t graph, kinematic equations and graphs.
4	Vectors and relative velocity	Vectors, scalars and mathematical concepts of vectors (the addition and subtraction of vectors graphically and vector components) and relative velocity.

Table 3.2: Outline of the introductory mechanics curriculum at UEW

Lesson	Title	Topics/Concepts
5	Projectile motion	Characteristics of a projectile trajectory, vertical and horizontal displacement in projectiles, initial velocity components, types of projectiles and projectile problems.
6a	Newton's laws of motion	Newton's first law, mass and inertia, Newton's second law of motion, Newton's third law of motion, and its demonstration.
6b	Forces	Meaning of force, contact forces, forces at a distance, mass and weight, sliding versus static friction, drawing of free body diagrams, bodies on inclined planes.
7	Momentum and impulse	Momentum, impulse-momentum change theorem, the law of conservation of momentum, elastic and inelastic momentum, momentum conservation in explosions.
8	Work, energy and power	Basic terminology and concepts of work, potential energy, kinetic energy, (total) mechanical energy, power, work-energy theorem.
9	Circular motion	Characteristics of circular motion, centripetal force, centrifugal as an imaginary force, applications of circular motion.
10	Gravitation	Kepler's laws, Newton's law of universal gravitation, satellite motion, weightlessness.
11	Rotational dynamics	Torques, centre of gravity, stability, moment of inertia, rotational kinetic energy, principle of angular momentum.
12	Revision	
13-16	Exams	

The dominant mode of teacher-student interaction instruction at UEW is the lecture. Lecturers start their physics (mechanics) teaching by lecturing on general principles. They then use the principles to derive mathematical models, show illustrative applications of the models and give students some practice question(s) in similar derivations and finally test their ability to do the same during examination. Qualitative problems are mostly based on "define, state and list", which does not call for better understanding of concepts. Discussions, demonstrations, experiments and practical work, where students can interact among themselves, teachers and teaching assistants, to confirm and validate principles and results presented during lectures, and solidify their understanding of fundamental physics principles are rarely done in UEW, usually due to a lack of equipment, an overload of course work and limited time at students' disposal.

Students in courses like this typically end up with limited conceptual understanding (Hestenes, Wells & Swackhamer, 1992), and a limited ability to transfer what they have learnt to new settings (Anyaehie, Nwobodo & Njoku, 2007).

In the next sections we will discuss the student difficulties that have been identified in the literature. The discussion will be structured according to three major areas of difficulty, namely: (i) cognitive, (ii) affective and (iii) cultural issues. Cognitive issues comprise conceptual understanding about Newtonian mechanics, lack of transfer, and misunderstanding of graphs; affective issues are students' motivation and attitudes towards physics; and the culture issue refers to the teaching and learning culture in the classroom.

3.3 Conceptual difficulties in Newtonian mechanics

In the 1990s, the insight arose that even proficient students, who successfully completed their university level physics courses, may be left with misunderstandings about the conceptual basics of mechanics (e.g. Hestenes, Wells and Swackhamer, 1992). In the years after that, a variety of conceptual issues has been described in the literature. In the following sections, we review the major conceptual difficulties that have been found with regard to: (a) conceptual understanding of Newtonian mechanics, (b) lack of transfer of conceptual knowledge to solve physics problems and (c) misunderstanding of graphs. Although research on the African continent is sparse, evidence suggests that most of these conceptual difficulties will occur across cultures (Thijs & Kuiper, 1990),

(a) Conceptual misunderstandings about Newtonian Mechanics

The persistence of conceptual misunderstandings in mechanics has been first indicated in detailed studies using interviews and observation methods. Later on, the widespread existence of such misunderstandings has been confirmed in large scale survey studies with standardized questionnaires.

For example, if students are to compare the time taken for equal sized steel and plastic balls falling from the same height under gravity and in the absence of air friction, many students will predict a shorter time for the steel ball. These students believe that heavier objects always fall faster than lighter objects under the conditions mentioned (Gunstone & White, 1981). Furthermore, some students have difficulty to distinguish between different terms used in physics. For example, Towbridge and McDermott (1980) found that students could not differentiate between distance and displacement or between speed and velocity. As a consequence, they will use the terms interchangeably. Likewise, students did not regard a change in direction (at constant speed) as a change in velocity, though they could easily identify a change in the magnitude of speed as a change in velocity. Some students misconstrue "a change in velocity" as just "velocity" and use a constant velocity value and time to calculate acceleration. Likewise, Champagne, Klopfer & Anderson (1980), report students ideas that a force will produce motion, a constant force produces constant velocity and the magnitude of the velocity is proportional to the magnitude of the force, acceleration is due to an increasing force, and in the absence of forces, objects are either at rest or slowing down. McDermott and Shaffer (1992) found that students who performed well in standard numerical problems could perform poorly on a conceptual question about the same situation.

A typical example of a large scale survey instrument is the force concept inventory (FCI), developed by Hestenes, Wells and Swackhamer (1992). The FCI is a multiple-choice "test", which consists of thirty questions with common misconceptions as distractors designed to assess students' understanding of the most basic concepts in Newtonian mechanics. Using this instrument, Hestenes et al. investigated students' understanding of the Newtonian concept of force. By comparing students' performance on conceptual questions both before and after a mechanics course, they found that many courses at the college and university levels produce only marginal gains in conceptual understanding.

Many students think that if objects with a smaller and a heavier mass collide, the force exerted by the heavier mass on the smaller one exceeds the force by the smaller one on the heavier object (Hestenes, Wells and Swackhamer, 1992). For example, when a heavier mass bus collides with a smaller mass saloon car, students think that the force of the bus on the saloon car is greater than the force of the saloon car on the bus. Perhaps the difficulty in students' conceptual understanding is due to the way they relate physics to daily life phenomena as observed and felt. In this case, they consider the badly mangled smaller saloon car, which is the outcome of the situation in most cases, to exert the smaller force.

(b) Lack of transfer of conceptual knowledge to solve physics problems

According to Freedman (1996), students can usually handle problems that are related to the worked examples in their textbooks, especially if there are special equations that they can use. However, if problems are superficially different, students will not recognise the underlying conceptual structure and the problem will be hard to solve. Strong evidence for Freedman's statement is found in the difference between students' performance in physics problems that require computation and calculation and their performance in purely conceptual, qualitative problems. For example, when students are given a question which requires more qualitative reasoning and verbal explanations, such as "a boxer wisely moves his head backward just before receiving a punch. How does this manoeuvre help reduce the force of impact?" they usually find it difficult to reason linking impulse and momentum to come out with the explanation that "as the boxer moves away from the moving fist, the time his head is in contact with the fist is increased, so his body has more time to absorb the momentum of his opponent's fist. Since the impulse of the impact is the average force multiplied by the time of the impact, the impact force decreases as the impact time increases". Whereas if this question had been put in the quantitative form, students would have easily put down the formula for impulse-momentum theorem, to work out for the variable that the question would require. The implication is that students cannot transfer conceptual understanding into solving similar but new problems.

(c) Misunderstandings of graphs

The ability to comfortably work with graphs is a basic skill of the scientist (Mokros & Tinker, 1987; Chambers, Cleveland, Kleiner & Tukey, 1983). Graphs can provide a structured overview of an entire problem situation while still allowing details to be resolved.

The first way students commonly misinterpret graphs is the graph-as-picture (GAP) interpretation, in which students will for instance interpret the shape of the graph to match the shape of the motion. In problems dealing with balls rolling in tracks or people riding bicycles over hills, students using GAP will often draw velocity-time graphs resembling the shapes of the tracks or hills, rather than showing the velocity of the ball or bicycle (Murphy, 1999).

The second common misinterpretation is slope/height confusion (SHC) in which students use the height of the graph at a point when they should use the slope of the line tangent to the graph at a point, and vice versa. McDermott, Rosenquist and Van Zee (1987) found that, even in the simple case of a straight line, the physics students confused distance represented by the height of the graph with velocity represented by the slope of the graph in a position-time graph. The situation becomes more complicated when the graphs are curved, making the confusion of slope and height more common.

The prevalence and persistence of these types of difficulties have been demonstrated by test of understanding graphs in kinematics (TUG-K), designed to assess students' conceptual understanding in graphs (Beichner, 1994). This instrument has been used to make physics teachers aware of the fact that many students have conceptual difficulties after teaching kinematics graphs. TUG-K is a multiple-choice standardized test, which consists of 21 questions with students common misconceptions as distracters. It is designed to assess students' graphing abilities and their interpretation of kinematics graphs.

According to Beichner (1994), other common difficulties students have when working with graphs, apart from those mentioned earlier, are:

- Variable confusion: students do not distinguish between distance, velocity, and acceleration. They often believe that graphs of these variables should be identical and appear to readily switch axis labels from one variable to another without recognizing that the graphed line should also change.
- Area ignorance: students do not recognize the meaning of areas under kinematics graphs.
- Some students do not know the meaning of the phrase "Graph of v-versus-t". They interchange positions by graphing the first quantity on the horizontal axis, and the second on the vertical, and still work for the slope as velocity/time.
- Students do not recognize that the concept of slope has units and have difficulty in how to determine these.
- Most students find it difficult to derive some kinematics equations from graphs.
- Students find it difficult to convert graphs. For example, most students find it extremely difficult to transform a position-time graph into velocity-time and acceleration-time graphs.

3.4 Affective issues: Students' motivation and attitudes

As a teacher in physics, one cannot avoid confronting the problem of students' waning interest in the subject (physics). This is mostly shown in the number of students who apply to study physics in relation to other science subjects like chemistry and biology, especially at the university level. Students usually regard physics as difficult to learn, abstract and dominated by males (Freedman, 1996). As a result many students drop physics as soon as they can. Although these problems are familiar to Ghanaian physics teachers, the situation is not directly comparable to that in many western countries, as the relevance of science is perceived much more positively in Ghana than in many western countries (Sjøberg & Schreiner, 2010).

According to Fischer and Horstendahl (1997), the quality of motivation was not regarded as relevant in early research on learning processes. Motivation was seen mostly as an initiator of the learning process but its influence on the quality of the process itself was not being recognised. Consequently, motivation and attitude of students were not taken into account in physics education research. However, in the mid-eighties psychological research rediscovered motivation, interest and attitude as important to learning processes, and many investigations have been made to reveal their role in the learning process (Fischer & Horstendahl, 1997; Ivowi, 2001). For instance, international meta-analyses of motivation and learning, motivational and emotional elements can be used to predict students' behaviour related to learning.

Studies by Vansteenkiste, Zhou, Lens and Soenens (2005) and Vansteenkiste, Sierens, Soenens, Luyckx and Lens (2009) show that autonomous and volitional study motivation is universally important and is associated with better learning and a higher well-being for all types of students. This is in line with the self-determination theory (SDT) by Ryan and Deci (2000). According to SDT, autonomous actions are those that are regulated and endorsed by the self and are therefore accompanied by a sense of psychological freedom and volition. Ryan and Deci indicate that autonomous study motivation positively predicts good adaptive learning attitudes, academic success, and personal well-being, whereas controlled motivation was associated with higher drop-out rates, maladaptive learning behaviours, such as procrastination.

3.5 Teaching and learning culture

Deep learning of physics will require that students talk about and revise and elaborate their ideas formed during the teaching process. By contrast, the dominant mode of teaching as used in Ghana can be grouped into three categories: (i) passive-student lectures,(ii) recipe labs, where the experimental processes are presented by the instructor for the students to follow, and (iii) algorithmic problem assignments and examinations (Osei, 2006). While similar findings have been reported from many countries, the causes of the problem, and its solutions, may vary across countries, dependent on cultural characteristics such as power distance, uncertainty avoidance, and individualism. For instance, a high power distance, and a high uncertainty avoidance would make it less likely that an open classroom dialogue would evolve (Hofstede, 1997). Ghana scores quite high on power distance in comparison to the U.S.A. or the Netherlands; while scores for uncertainty avoidance are rather similar; and scores on individualism are much lower in Ghana (see interactive maps on: http://www.kwintessential.co.uk/intercultural/dimensions.html).

Another part of the explanation for unproductive learning habits would be inappropriate beliefs about the nature of physics knowledge and learning (Schommer, 1990; Eylon & Reif, 1984). For instance, as Hammer (1994) discusses, some epistemologically naive students think that physics knowledge consists of weakly connected pieces of information. These students may believe that knowing facts, formulas, and algorithms constitute a full understanding of the material. They have the impression that:

- Practicing quantitative problems helps them to learn how to apply the formulas and concepts that will appear on the test which will affect their grade;
- Concepts are the least difficult to understand;
- The more you are able to solve difficult quantitative problems the more you understand physics.

According to Jegede (1994) some African students think that the study of science is a weird, special activity requiring some magical and superhuman explanations. As in their perspective physics or science in general has little or no relation with their own real world, but belongs to a different world which only the instructor can explain or talk about; hence no one dares to interrupt by making a contribution or asking a question (Hutchison, 2009).

3.6 Conclusions: Need for improvement

The gap between the course goals and students' achievement reflects a corresponding gap between the instructor and the students (McDermott, 2001). This calls for the need to improve students' learning of mechanics because:

- Ease in solving standard quantitative problems is not an adequate criterion for functional understanding. Questions that require qualitative reasoning and verbal explanation are essential for assessing student learning and are effective strategy for helping students to learn;
- The ability to connect concepts, formal representations, and the real world is often lacking in students after traditional instruction. Students need repeated practice in interpreting and relating concepts and formal representations (such as graphs) to the real world or physical phenomena;
- Some conceptual difficulties are not surmounted by the traditional method of instruction. Research has proved that certain conceptual difficulties continue to exist in spite of instruction. Persistent conceptual difficulties must be explicitly addressed in multiple contexts;
- A coherent conceptual framework is not typically an outcome of traditional instruction. Thus many students come out from introductory physics without having developed a coherent conceptual framework for important basic topics. Students

need to participate in the process of constructing qualitative models and applying these models to predict and explain real world phenomena;

- Growth in reasoning ability often does not result from traditional instruction. Scientific reasoning skills must be expressly cultivated within a more open class culture;
- Teaching by telling is an ineffective mode of instruction for most students. Students must be motivated to be intellectually active in order to develop a functional understanding;
- Testing/examination should change from more quantitative-centred problems to more conceptually-centred questions. These will reveal how well students have understood concepts.

In the next chapter, we will dwell on the need for developmental research, and use the major issues that confront our students and inhibit learning to develop possible solutions to these problems and describe how activities will be used during teaching along with some expectations from the use of these activities.

Chapter 4

Design research approach, possible solutions and testing of the design

4.1 Introduction

In the previous chapter we argued that university-level mechanics teaching tends to leave many of the students' misconceptions untouched, and that, although some theoretical insights are available, there is no straightforward solution to remedy this in Ghanaian teaching practice. We will now argue that this situation calls for a "design research" approach, where theoretical insights and practical experience are used to develop a teaching design that can be tried in practice in order to evaluate the underlying ideas and generate new ideas.

In the second part of the chapter, we will discuss possible solutions to promote conceptual understanding and deep learning. We will review strong evidence that learner centred and interactive engagement methods are most effective to attain deep understanding. Specifically, we will discuss the use of activities from interactive engagement methods, which allow students to interact with their peers, teacher or computer.

Based on this review, we will set up an outline for our course design, and we will describe the types of activities and assessments we will use, and the expected outcomes. These expectations will guide our analysis of the field test results in the next chapter.

4.2 The need for a developmental research approach

Although the difficulties of mechanics learning may seem quite universal across the world, the solutions that are applicable to the western world may not produce similar results when applied directly in Ghana, due to cultural and contextual differences. That is to say that, although helpful learning theories and partial solutions are available, there are no ready-made solutions based on theoretical ideas that adapt to local setting, prior knowledge, curriculum and culture. Therefore, there is a need to adapt these ideas into concrete teaching approaches that will fit with the local circumstances.

However, the study is not only aimed at developing a course that will work, but also at gaining understanding of how this is to be achieved. This type of research questions bears a relationship to the general objectives of design research, which is aimed at developing theories, instructional materials and an empirically grounded understanding of how learning works (Research Advisory Committee, 1996). This makes it necessary to evaluate not only the outcome but also the processes involved. Thus we need to understand the "mechanics" of the design.

Usually, on the first attempt, the implementation will be imperfect and the approach will have to be revised. This revision will also lead to further refinement of theoretical ideas.

Therefore to achieve a pragmatic solution to the problem, an iterative or formative research approach will be used where theories and interventions tend to be continuously developed and refined, from analysis to design to evaluation and redesign (Bannan-Ritland, 2003). Such a flexible design process not only yields greater opportunities for coping effectively with contextual and cultural factors, but also increases the practical relevance of the solution to the local setting.

4.2.1 How to ensure quality and progress: A systematic approach to iterative design

In order to guarantee not only a practical product but also a scientific knowledge gain, the iterative design process needs to be conducted and documented in a systematic fashion. The researcher has to analyse a meaningful practical problem, and then try to develop possible solutions based on theories. Because theories may vary due to the nature of the problem, differences in culture and context, iterative testing and refinement cycles of solutions should be conducted to construct powerfully built solutions to generate well-supported theories about learning and instruction, which will result in deeper understanding of complex learning environments.

Reflection on multiple sources of data, like observation and interviews, could be used to improve theories of learning and instruction and enhance implementation.

4.2.2 Design cycle

The design research cycle refers to situations where theories and interventions tend to be continuously developed and refined through an iterative design process from analysis to design to evaluation and redesign (Design-Based Collective, 2003). This on-going recursive nature of the design process is termed as the design cycle.

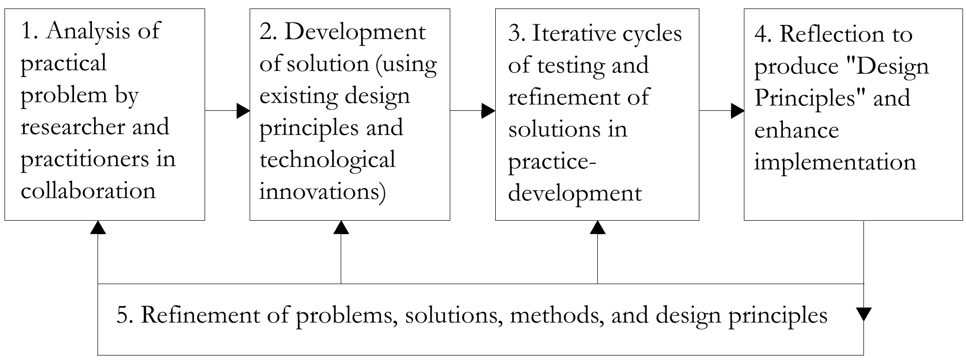


Figure 4.1: Process of design-based research (Reeves, 2006)

Van den Akker, Bannan, Kelly, Nieveen and Plomp (2007) put it that the research process in design research encompasses educational design processes. It is – like all systematic educational and instructional design processes – therefore cyclical in character: analysis, design, evaluation and revision activities are iterated until a satisfactory balance between ideals (the intended) and realization has been achieved.

Although there are many design diagrams of the process of design research, one example produced by Reeves (2006) is presented in Figure 4.1, due to its clarity and simplicity.

4.2.3 Expectation guided analysis

In a typical classroom situation, many things will be going on at any given moment, and it is highly probable that the researcher will spot interesting or surprising patterns in the data. It might be quite seductive to over-interpret these patterns, and to attribute them to features of the design. This is a major threat to the validity of the data analysis in design based research. The first thing to consider will be that some aspects of the lessons are more strongly inspired by theoretical ideas, and will be more informative after analysis than others. A further, more specific way of providing guidance will be to formulate specific expectations on how learners will respond to the learning situation.

Table 4.1: Example of the way expectations were formulated in this research in Newton's third law of motion

Activities	Goals	Task/question	Expectation
Conceptual reasoning question	(i) bring out students ideas/views on how they understand Newton's third law (ii) raise questions about the actual meaning of Newton's third law of motion. (iii) participate in the lesson (student-student and teacher-student interactions).	(i) While driving down the road, a fly strikes the windscreen of a bus and makes a quite obvious mess in front of the driver's face. (i) This is a clear case of Newton's ………… law of motion. (ii) The fly hits the bus and the bus hits the fly. Which of the two forces is greater: the force on the fly or the force on the bus? (iii) Identify the action and the reaction.	(i) Some students may think that things having greater mass (larger size) will produce the greater force. (ii) Some students will identify objects (bus and fly) to represent action-reaction force pairs.

The most elaborate way of formulating guiding expectations for the analysis, and to ensure that the outcomes of the analysis will be theoretically relevant, might be to describe a Hypothetical Learning Trajectory (HLT) beforehand (Simon, 1995; cf., Klaassen, 1995). But looking at this study, which involves the iterative use of activities designed with several topics of a complete mechanics course, a fully specified HLT will be out of reach. What is more appropriate is the guide of prediction of how the students' thinking and understanding will evolve in the context of the learning activities with each new topic or groups of topics, and that is basically what the study focuses on. An example of such an expectation guide is presented in Table 4.1.

4.3 Identifying directions for change

4.3.1 The desired kinds of learning

First of all, it is important to define the desired kind of learning aim. It will be helpful to frame the aims in terms of Bloom's revised taxonomy, which is presented in Figure 4.2 (Anderson & Krathwohl, 2001; c.f., Bloom, Engelhart, Furst, Hill & Krathwohl, 1956). It this taxonomy, the following levels of learning aims are being distinguished:

- *Remembering*: Can the students remember/memorize and recall facts or information by defining, duplicating, listing, memorizing, recalling, repeating, reproducing or stating?
- *Understanding*: Can the students understand and explain ideas or concepts by classifying, describing, discussing, explaining, identifying, locating, recognizing, reporting, selecting, translating or paraphrasing?
- *Applying*: Can the students use the information in a new way by choosing, demonstrating, dramatizing, employing, illustrating, interpreting, operating, scheduling, sketching, solving, using or writing?
- *Analyzing*: Can the students distinguish between the different parts by appraising, comparing, contrasting, criticizing, differentiating, discriminating, distinguishing, examining, experimenting, questioning or testing?
- *Evaluating*: Can the students justify a stand or decision by appraising, arguing, defending, judging, selecting, supporting, valuing or evaluating?
- *Creating*: Can the students create a new product or point of view by assembling, constructing, creating, designing, developing, formulating or writing?

Students in most cases could easily memorize facts and rote skills. However, the aim of mechanics teaching is that students will also be able to apply the information in a new way, break material into its constituent parts and determine how the parts relate to one another, make judgements based on criteria and standards and put elements together to form a coherent or functional whole. If a student is able to perform these processes, that will be regarded as evidence of deep conceptual understanding.

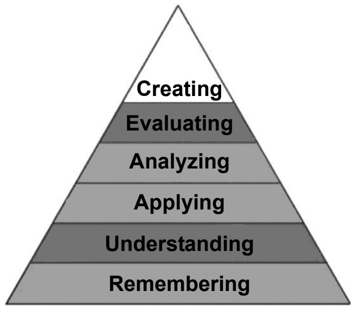


Figure 4.2: Levels of intellectual behaviour for engagement, meaning making and deep learning in students (Bloom's taxonomy revised, Anderson & Krathwohl, 2001).

4.3.2 Possible solutions in different ways of teaching

In search of teaching approaches that would yield a better conceptual understanding, Hake (1998) made a survey of 62 introductory physics courses with about 6500 students, where pre- and post-tests results were available for the conceptual reasoning tests of Halloun & Hestenes (FCI, MD and/or MBT). In order to compare across courses with students of different levels, he developed a normalized gain score, $\langle g \rangle$, to express the effectiveness of a course to promote conceptual understanding. Using this gain score, he classified courses in one of three groups:

1. "High-g" courses, with $(\langle g \rangle) \geq 0.7$;
2. "Medium-g", with $0.7 > (\langle g \rangle) \geq 0.3$;
3. "Low-g" courses, with $(\langle g \rangle) \geq 0.3$.

Looking into the instructional formats of these courses, Hake distinguished between two types of teaching; (i) Interactive Engagement methods and (ii) Traditional methods. He classified interactive engagement methods as those designed at least in part to promote conceptual understanding through interactive engagement of students in heads-on (always) and hands-on (usually) activities which yield immediate feedback through discussion with peers and /or instructors. Those reported by instructors to make little use of interactive engagement methods, relying primarily on passive-student lectures, recipe labs, and algorithmic-problem exams, were classified by him as traditional methods. Hake found that the students of teachers who made considerable use of interactive engagement methods in their teaching, achieve a gain of 0.48, about twice as students who were taught with the traditional method, 0.23.

The most frequently used "interactive approaches" were:

- Collaborative peer instruction (Heller, Keith & Anderson, 1992);
- Microcomputer based laboratories (Redish, Saul & Steinberg, 1997);

- Concept tests (Mazur, 1997);
- Socratic dialogue inducing labs (Hake, 1987; Tobias & Hake, 1988);
- Active learning problem sets (Heuvelen, 1991);
- Modelling (Hestenes, 1987).

The above mentioned approaches have pedagogical features of encouraging students to assume responsibility for their own learning, to create a community of learners, and an open exchange of ideas. Again, this confirms that students learn best when they can develop and effectively use a variety of thinking and reasoning strategies, develop self-regulatory skills, adapt relevant strategies to the learning context, and be motivated to learn rather than feeling that they are being made to learn (Prince, 2004). Thus, for a teacher it is not enough to be passionate about the subject he teaches; to plan relevant and interesting activities; and to deliver fascinating information - but rather he should also create an opportunity for students to speak up in class, to feel that they can contribute, and to give the support and encouragement they need to learn.

We will now review approaches that have been found effective to promote interactions in classroom and to enhance learning, in order to identify further features of an effective physics classroom.

Teaching necessitates the students to come prepared

In many introductory science courses, students tend to start studying the textbook only after the lecture. To achieve productive student involvement, it is essential that students come prepared. Their ideas and contributions play a vital role in the teaching process. For instance, if the students are well-prepared, their responses to conceptual reasoning questions will give the instructor insight into what students find difficult, complementing the instructor's ideas on what materials need most emphasis (Crouch & Mazur, 2001).

This is unlike the traditional lecture approach where most students can come to class unprepared because their ideas will not be needed. According to cognitive scientists, educational researchers and contemporary psychologists, a brief preview of text in books will improve students' ability to follow the class, for they have seen the new terminology and will recognize signposts that will help integrate the classes into an overall picture (Hubin & Ridell, 1977). In a study by Cummings, Laws, Redish and Cooney (2004), a physics major student remarked that after struggling through the first half of his junior level mechanics course, he felt that the course was now going much better. What had changed? Did he have a better background in the material they were covering now? "No", he responded, "I started reading the book before every class. That helps me a lot. I wish I had done it in Physics One and Two". As the authors conclude, this student had learned something very important.

Open, high quality dialogue/discourse with peers and with teacher

Peer instruction engages students during class through activities that require each student to apply the core concepts being presented, and then to explain those concepts to their fellow students. Unlike the common practice of asking informal questions during a lecture, which typically engages only a few highly motivated students, the more structured questioning of peer instruction involves every student in the class. Students are given a few minutes to formulate individual answers. They then discuss their answers with others around them trying to convince each other of the correctness of their answers and finally report their answers, which may have changed based on the discussion, to the instructor (Mazur, 1997; Crouch & Mazur, 2001; Heller, Keith & Anderson, 1992).

Mercer (1996) found evidence that learning can be made more effective by improving the quality of the discourse. An experimental teaching programme was designed to enable children in British primary schools to talk and reason together and to apply these skills in their study of science. The results indicated that children could talk more effectively and talk-based activities could have a useful function in scaffolding the development of reasoning and scientific understanding. Mercer's view on science education is that science is a discursive process, where students are inducted into a way of representing and understanding phenomena. Most students in our schools have been trained to become skilful in passive listening, so there is a need to find and add quality discourse or talk-based activities to encourage and motivate students into active engagement in practical inquiry and social interaction as a means to support the developments in understanding of concepts (Tobias & Hake, 1988). Questions and activities should be put in such a way so as to engage students into interacting with partners while they still carry out their investigations.

Schmitt and Lattery (2004) supported the promotion of student discourse to bring effective learning. They proposed two modelling programmes: Socratic modelling and modelling discourse, which can facilitate classroom teaching and learning. With Socratic Modelling, words like "what, why, when, and how" are used by the teacher in asking questions so that students come up with better explanations by themselves. In some cases the approach will be used to get divergent views from students.

With the modelling discourse method, students work in small groups to explore and uncover physical relationships on their own, with some guidance from the teacher. Modelling discourse is applied by providing conceptual reasoning questions, which will engage students in thinking in groups. A plenary session follows for students to voice the outcome of what they have discussed.

In all these approaches the instructor takes the role of facilitator rather than transmitter of knowledge. By asking questions, the instructor first assesses students' conceptions, and then helps them see the discrepancies between their preconceptions and scientific concepts. Learning process takes place when students can resolve those discrepancies and assimilate the new knowledge to their intellectual resources. Discourse in teaching and learning serves as a tool to recognize how well students have learnt and are able to relate different topics to each other.

Relate and practice physics concepts to multiple real-world contexts

Making physics relevant in students' learning is an important aspect of physics education. This involves the ability to draw in examples from daily contexts to begin learning or to apply concepts that have been learnt to familiar everyday phenomena that students observe and experience around them. Making explicit connections between course materials and everyday physics to increase students' belief in the relevance of physics to the real world and develop their problem-solving skills to apply their physics knowledge outside the classroom is very useful (Martinuk, Moll & Kotlicki, 2010).

As students learn, they are not expected to learn only the principles, laws and definitions, which is termed as the canonical knowledge, but also how the knowledge is developed and could be applied to real-life situations (Goldberg, Otero & Robinson, 2010). This will make learning more meaningful. Students need access to a resource of real-world phenomena, if a meaningful classroom discussion is to take place. This resource can be developed and made common to all members of a class through the supply and use of contexts by both the teacher and students. This may increase students' confidence to apply knowledge in a wider range of tasks (Whitelegg & Parry, 1999).

Relating physics concepts to real-world contexts reveals the shortcomings of students' current conceptual frameworks and can help to wean students from erroneous beliefs on how reality operates. Thus instruction based on real life contexts can help students' existing mental models to evolve into more accurate conceptions of reality (Feurzeig & Roberts, 1999). This might be also amusing and relevant to students' daily life.

One of the important goals of a teacher is to help students to practice with concepts across multiple contexts so that they can apply the new knowledge to different situations. This is also known in educational cycles as transfer of learning, which deals with transferring and translating one's knowledge and skills from one problem solving-situation to another. This is a seldom-specified but most important goal in education (Perkins & Salomon, 1992): to gain knowledge and skills that can be used both in school and outside the school, immediately and in the future.

According to Perkins (1993) understanding a topic of study is a matter of being able to perform in a variety of thought-demanding ways with the topic. For instance, to explain, muster evidence, find examples, generalize, apply concepts, analogize, represent in a new way, and so on. This goes beyond just knowing, for instance when students have to find new examples of Newton's theory at work in everyday experience and make other extrapolations.

Hands- on experience with real objects and/or computer tools

Redish, Saul and Steinberg (1997) replaced traditional problem-solving recitations in introductory calculus-based mechanics classes for engineering students with active-engagement tutorials using microcomputer based laboratory equipment (hands-on). A comparison of the results of lecture classes taught by six different teachers shows that the MBL tutorials resulted in a significant improvement compared to traditional recitations. Computer based tools have been developed to overcome a number of technical obstacles often facing students in the traditional physics class or laboratory. First, the tools can relieve students of the time-consuming and distracting traditional process of data collection. Second, data is presented graphically in real time, allowing students to quickly view the data in understandable form and evaluate it. Third, the speed with which data is collected and displayed allows students to examine a larger number of physical phenomena. Rather than spending the period collecting and plotting data, students can instead dedicate their time to analysing and discussing the collected data. Finally, another consequence of the tools' general nature is that they can be used in physics classrooms of all levels; from elementary school to the university (Thornton & Sokoloff, 1990).

Hands-on experience with computer tools has become possible and fruitful in our senior high schools and universities. For example, students often have conceptual difficulties in interpreting graphs. Thornton and Sokoloff (1990) suggested a possible means of remedying students' problem of interpreting distance-time, velocity-time and acceleration-time graphs, through the use of microcomputer-based laboratory tools. Students use this tool to collect physical data that are graphed in real time and that can be manipulated and analysed. This encourages students to take an active role in their learning and to construct physical knowledge from observation of the physical world. Many instructors have found that lectures become more useful when students become active participants in the lecture (Heuvelen, 1991). The tools provide convenient and effective means for collecting and displaying physical data in a form that students can remember, manipulate and think about.

Using computer simulation becomes a powerful activity for engaging students in doing and thinking about science, particularly physics. By setting up a simulation in which students can vary parameters and see the effect of these variations, their view of an equation is powerfully enriched (Christian & Belloni, 2001). Simulations can also act as effective means of stimulating curiosity in students. They help students to understand their environment. Computer simulations can be valuable tools when it comes to bridging the gap between teaching and students' conceptual understanding of physical concepts (Tarekegn, 2009; Gokhale, 1996). Educational research has demonstrated repeatedly that students learn much more effectively when they themselves are in control of such tools to find knowledge (McKagan, Handley, Perkins & Wieman, 2009; Wieman, Perkins & Adams, 2007).

Students are encouraged to reflect on their initial ideas and responses

According to Mason (2009), reflection is essential to learn from problem solving. He investigated how students naturally reflect in their physics courses about problem solving and evaluated strategies that may teach them reflection as an integral component of problem solving. He concludes that students who reflect with peers have a larger gain in their final examination.

Halloun and Hestenes (1987) made an attempt to improve physics teaching by applying the model theory of instruction. Modelling theory was used in the design of a method to teach problem solving in introductory mechanics. According to Hestenes' instructional theory, they needed an instructional method which promotes a model-centred approach to problem solving, and the method should have a dialectical and reflective components to promote the substitution of "Newtonian knowledge" for defective "common sense" knowledge (Hestenes, 1987).

Students' encouragement or motivation to reflect on their initial ideas and responses could have a relation to Hestenes' work on modelling instruction in mechanics. After the students have made an attempt to bring out their initial ideas on the conceptual reasoning questions, the most interesting part is to look at the answers provided and the procedure they followed to see whether they can add anything new or can improve on their initial answer, especially with some of the new knowledge they may acquire during the interactive teaching and from their peers.

Constructive learning processes are being scaffolded

Constructivist conceptions of learning assume that knowledge is individually constructed and socially constructed by learners based on their interpretations of experiences in the world. Since knowledge cannot just be transmitted, instruction should consist of experiences that facilitate knowledge construction (Duffy & Jonassen, 1992). Knowledge construction where scaffolding is not provided could be disadvantageous to students by taking too much time, which is the situation in most cases, but going in the wrong direction is also a possible consequence. For example, if you just put students in the world to discover Newton's laws, it will take them many days, months or years to discover them or they may not even come to that realization, hence we need to guide the process (Kirschner, Sweller & Clark, 2006). Thus, for constructive learning processes, students need to be scaffolded by the teacher. It could be in the form of providing hints or asking leading questions for the learner to see his or her way through. Guidance can be provided to students in class discussions, problem solving and the use of microcomputer based laboratory tools.

In a traditional lecture approach, the way the teacher thinks about how the topic will be easily handled or understood by the students, is mere assumption. The teacher who has no interactions with the students, cannot check whether handling or understanding really takes place on the spot, because he or she is talking alone and does not interact to realize whether he or she is successful or not. Traditional teachers, who are fond of teaching this way, often think that the students are learning a lot (Mazur, 1997). After using standardized tests, they realized afterwards that the students were not learning as expected. In situations where students are taught by this approach, just a few benefit.

Besides the six conditions mentioned above, to be successful with interactive teaching in Ghanaian classrooms, there is the need of a particular classroom atmosphere, which is quite different from the usual atmosphere as observed in current practice. So the seventh condition is creating a safe, inviting and ambitious classroom culture.

Creating a safe, inviting and ambitious classroom culture

Creating a safe, inviting and ambitious classroom culture is necessary for all interactive approaches: collaborative peer instruction, concept tests, Socratic dialogue inducing labs, active learning problem sets, modelling and microcomputer based laboratory. Students' full participation is needed under these circumstances, and it is up to the teacher to create the necessary atmosphere in the classroom that would invite students to participate, make them eager to answer questions, motivate them to read and solve problems on their own and let them feel safe, without being threatened, in contributing their share during the teaching process (Stewart, 2003). This requires creating an atmosphere that values individual contributions and addresses the learning needs of each of the students (Cross, 1992).

These techniques mentioned have several merits. First, the students have something constructive to do during the lecture; it is a remedy for the dormant or inactive state that often grips students in a conventional lecture. Second, students are forced to discuss physics with their peers and to defend their ideas. Third, students get immediate feedback as to whether or not they understand a concept that has been presented in class, and any points of confusion can be corrected at an early stage in the students' apprehension of the concept. Last, the instructor can learn a great deal about his students' understanding of the material to set tutorials or problem solving questions that are within their capabilities.

4.3.3 Design guidelines for Interactive Engagement (IE)

Possible solutions to learning problems lie in the way we teach. The predominant use of the traditional lecture method, where instructors give a lengthy lecture, which is then followed by short questions or sometimes none at all, should be replaced by approaches where students are actively involved in the teaching and learning processes in the classroom. Many authors have proposed a variety of teaching methods to overcome problems like those mentioned earlier on. These methods generally induce a situation in which knowledge has to be constructed by the students themselves, and is not being spoon-fed to them by the instructors.

It should be considered that all students are not created equal; classes are invariably made up of individuals who have different backgrounds, experiences, and natural aptitudes. The use of interactive engagement approaches caters for these individual differences and helps all individuals to develop better understanding of concepts.

After studying the literature, a number of conditions of teaching process, which might be ways to improve students' learning and increase interactions in the classroom, are found as:

- Teaching necessitates the students to come prepared.
- Open, high quality dialogue/discourse with peers and with the teacher.
- Relate physics concepts to multiple real-world contexts, and practice them.
- Hands-on experience with real objects and/or computer tools.
- Students are encouraged to reflect on their initial ideas and response.
- Constructive learning processes are being scaffolded.
- Creating a safe, inviting and ambitious classroom culture.

We have identified that these conditions of teaching process are worthwhile to be tried in the Ghanaian context. In the next section we will show how we used these elements in designing the course through the construction of learning activities.

4.4 From guidelines to teaching and learning activities

4.4.1 General course structure

The design of our course has been built on the seven design guidelines we derived in the previous section. For each of the design guidelines, we selected one or more learning activities that would contribute towards that end (Table 4.2). In order to create a recognizable structure for the students that would stimulate interactive engagement throughout the course, we set on a recurring cycle of activities.

Table 4.2: Design guidelines and activities

No.	Design guidelines	Activities						
		CQ	**CRQ**	**L/IT**	**R**	**AQ**	**MBL**	**T/PS**
1	Teaching necessitates the students to come prepared	√	√					√
2	Open, high quality dialogue/ discourse with peers and with teacher		√	√	√	√	√	√
3	Relate and practice physics concepts to multiple real-world contexts			√	√	√		√
4	Hands-on experience with real objects and/or computer tools						√	
5	Students are encouraged to reflect on their initial ideas and response				√	√		√
6	Constructive learning processes are being scaffolded			√	√	√	√	√
7	Creating a safe, inviting and ambitious classroom culture	√	√	√	√	√	√	√

CQ: Concept quiz, CRQ: Conceptual reasoning questions, L/IT: Lecture/interactive teaching, R: Reflection, AQ: Application questions, MBL: Microcomputer based laboratory tools, T/PS: Tutorial/ problem solving.

In order to stimulate the students to come prepared (1, the number refers to design guidelines in Table 4.2), each meeting would start with a concept quiz. A typical three-hour meeting would continue after the concept quiz with three or four cycles, each addressing a topic or group of topics. Each topic (or group of topics) cycle has been divided into activities. For each new topic it was deemed important that before receiving any new information, students would activate their prior knowledge through conceptual reasoning which is connected to real world situations (2 & 3). To get students actively engaged in constructing new knowledge, the lecturing/interactive teaching part would involve predictive and explanatory questions where students have to supply answers. Lecturing/interactive teaching will also relate to real-world activities (3). At certain times microcomputer-based laboratory (MBL) tools, simulations and animations will be used to gather physical data and to reproduce features of physics phenomena in an invented environment (4). After each topic (or group of topics) cycle treated, students would need to connect to their initial ideas by reflecting on and revising them (5). In order to get students to be fluent in the new knowledge and generalise beyond the context in which it had been offered, students need to apply the knowledge in new contexts (3). In order to engage students in further practice, with less teacher guidance, there would be a tutorial/problem solving session some days after each meeting.

Support in the form of hint or guide will be provided to students, especially during tutorial/problems solving sessions, when they encounter difficulties in learning and applying concepts (6). This support will diminish in subsequent sessions as students tend to gain control of their difficulties. Design guidelines (6-7) would engage students in a dialogue and a culture of interactive participation in the entire activities in the cycles and the tutorial sessions. Other teaching techniques that could be helpful, like think-share -present, project and presentation will be employed.

The next table summarizes how the activities will be structured into a 60-minute lesson plan (Table 4.3). Apart from lecture/interactive teaching, where more than one of the interactive engagement approaches will be used, only one of the approaches listed will be employed in a particular activity.

Table 4.3: Structuring of activities in the first cycle of a meeting

Cycle/ block	Activity	Purpose	Interactive engagement (IE) approaches used	Planned time in minutes
	Concept quiz	To encourage students to do their reading assignment before they come to a lecture.	Teacher-student discussion.	10
1	i. Conceptual reasoning question (or concept cartoon)	To evoke students' prior knowledge and create the need for further learning.	Group and plenary discussion or think-share-present.	10
	ii. Lecture/ interactive teaching	To introduce new conceptual information to students.	Predictive and explanatory questions and answers; microcomputer based Lab (MBL) tools; simulations and animations.	20 for 3 blocks; 15 for 4 blocks
	iii. Reflection	To find out how students could connect the information to their prior knowledge.	Group and plenary discussion or think-share-present.	10 for 3 blocks; 7 for 4 blocks
	iv. Tutorial / application question	To see whether students have acquired problem solving ability.	Group and plenary discussion; student-student and teacher-student interactions.	10 for 3 blocks; 8 for 4 blocks

In the next sections, detailed accounts and examples on the implementation of these activities and teaching techniques will be considered. Possible expectations of the implementation of the activities of the design on students will also be looked at.

4.4.2 Specification and expectations for recurring activity types

Concept Quiz

This technique is adopted from Mazur (1997). Students will be required to complete short quiz questions on some concepts they are to study in each lesson, and this will be done at the beginning of every class in every week. The concept quiz will test whether students have done the pre-class reading. Each question will be specifically based on a single concept, not solvable by relying on equations (in most cases), have multiple-choice answers (sometimes), unambiguously worded and neither too easy nor difficult. The concept quizzes will form part of the students' continuous assessment (20% of the final mark). This will aid students who lack the initiative to read before attending lectures to do some reading in order to actively take part in class discussion. Some of the concept quiz questions will be selected from Mazur (1997).

The concept quiz will bring out students' understanding on some concepts after doing the reading assignment, especially during discussions of the questions, upon which proper measures will be developed to address such problems during the lecture/ interactive teaching. By so doing students will learn and have better conceptual understanding of the materials they had read in advance. Below, some examples of concept quiz questions with some multiple choice answers on Newton's laws of motion (Lesson 6) are provided. This question was used during the second round of data collection:

1. Which of these laws is not one of Newton's laws? (a) Action is reaction, (b) F=ma (c) All objects fall with equal acceleration, (d) objects at rest stay at rest.
2. The law of inertia (a) is not covered in the reading assignment, (b) expresses the tendency of bodies to maintain their state of motion, (c) is Newton's third law.
3. (i) State Newton's 2^{nd} law of motion and explain. (ii) Consider the interaction between a foot, and a ball, which interact simultaneously (at the same time). Identify the pair of action-reaction forces.

Expectations

It is expected that

- Students who do their reading will be able to answer most of the questions.
- After students get used to the concept quiz being part of the meeting, students will mostly come prepared.

- Students will be more focused on the task, after coming prepared. Thus less noise and disturbance is expected at the start of concept quiz.

Conceptual Reasoning Questions (CRQ)

Conceptual reasoning questions refer to questions which do not demand a straight-forward answer by the use of laid down regulations, where students have to just follow a specific routine and come out with a definite result as the answer to a question (Kadijevich, 2002). In conceptual reasoning questions, students will be required to analyse, reason, synthesize, test and support their answers with explanation. Some of the CRQs will be taken from Hewitt's books (Hewitt, 2001; 2010) and Hewitt's Next Time Questions (Hewitt, n. d.). The reasonableness of a student's line of argument or thinking will mostly be considered.

Cartoon-style drawings with questions on specific concepts for students to put forward a range of viewpoints will sometimes be given. These are called concept cartoons, and they will be used to support conceptual reasoning questions. These are adapted from Hewitt's Next Time Questions (Hewitt, n. d.). Students are to discuss, and sometimes argue about, answers, and it is in such discussions that learning occurs. The reason for using these concept cartoons is that it will make students ideas explicit and challenging. An example of a conceptual reasoning question on the topic of instantaneous and average speed is given:

Conversation between a policeman and a driver who was charged with speeding.

Comment on the conversation between the police officer and the driver.
Note: The road is winding, it is not straight as it is shown in the picture.

Expectations-

It is expected that

- Students will come out with their prior conceptions or knowledge on the conceptual reasoning question.
- Students will give reasons to support their prior knowledge on the subject matter.

- Students will argue their case with peers and come up with physically meaningful conclusions. They will compare various reasons given by their peers to see those explanations that are authentic in scientific reasoning especially in the plenary discussions.
- Students will show dissatisfaction with their answers, to create the need for learning.

Lecture/interactive teaching

In this activity, a short lecture will be given to students with the purpose to introduce new conceptual information to them through real life examples and explanations. In order to make the teaching more interactive, it will be interspersed with predictive and explanatory questions where students have to supply the answers. In some cases microcomputer-based laboratory (MBL) tools will be used to collect physical data that are graphed in real time, to be manipulated and analysed. For example, in the teaching of graphs in kinematics and Newton's third law, students working in groups of four members will be allowed to interact with motion and force sensors interfaced with computers to describe their motions and experiment on Newton's third law respectively. In UEW the use of MBL in teaching is quite recent. The type of MBL tool used is called "Coach 6". Coach 6 is a tool which is made by the AMSTEL Institute of the University of Amsterdam for the active integration of computers in Science and Technology education, with the view that such learning tools will give the science learner power to explore, measure and learn from the physical world (Kedzierska & Dorenbos, 2007). With this method, students will be able to relate graphs to their physical movements. For example, through the use of motion sensors/detectors and coach students will be able to observe displacement-time graphs, velocity-time graphs and acceleration-time graphs of the motions listed below by their movement on the computer;

1. i. Using Coach and motion sensor, describe the displacement-time graphs of your motion (a) standing still; (b) moving at constant speed in a specific direction; (c) moving away and coming back at constant speed; (d) moving away and coming back with different speed; (e) moving away, stopping and coming back.
   ii. Transform your displacement-time graphs to velocity-time and acceleration-time graphs.
   iii. Describe and analyse these graphs by comparing the shapes.
2. "Walking the graph": students will replicate already plotted x-t and v-t graphs on the computer, by their movement/walking.

By the use of simulations, students will be made to predict and practice curved x-t graphs and their transformations to v-t and a-t graphs. For example

- Students will be made to study different dot diagrams of x-t motions with a changing velocity (curved graphs) and their transformations to v-t and a-t graphs. Thus positive and negative changing velocities (slow to fast and fast to slow) will be considered.

- They will also be made to enter different values for initial position (m), initial velocity (m/s), acceleration (m/s^2) and time (s). Students will be made to study the shape of the position time graph and transform the shapes to v-t and a-t graphs.

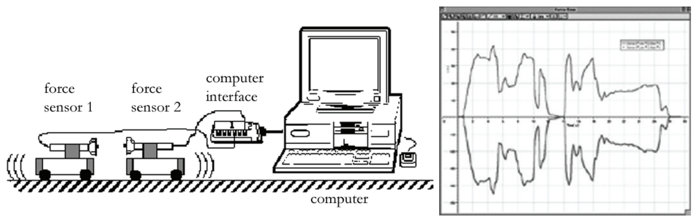
Also, students will be able to predict the relative size of forces that two identical carts exert on each other and the forces two unequal (mass) carts will exert on each other in a collision (Thornton & Sokoloff, 1990).

An example of lecture/interactive teaching and the use of MBL on Newton's third law:

Newton Third law of motion
State Newton's 3rd law and use 1 daily life example to support your answer.
Students' response: ………………………………….

Application of Newton's 3rd law of motion
Give some examples of Newton's third law in real life situations.
Students' response: ……………………………………

The use of Microcomputer Based Laboratory Tool (MBL-coach VI and force sensors) to explain Newton's 3rd law
Students are guided to connect the two force sensors to two low-friction carts (as shown below) and observe the result of their interaction on the graph on the computer by going through the following processes.



- Observe the forces that two identical carts exert on each other when one collides with the other; let students compare the two graphs formed and relate the forces being exerted ($m_1 = m_2$).
- Observe the forces two carts exert on each other when one collides with a second weighted with a metallic block; let students compare the two graphs formed and relate the forces being exerted ($m_1 \neq m_2$).

Expectations

It is expected that

- Students will participate by answering the interactive questions in the lecture teaching.
- Students gain better understanding of mechanics concepts to replace their prior conceptual knowledge as well as better understanding in kinematics graphs through the use of hands on experience with computer tools.

Reflection

During reflection, students will be given another chance to reflect on their initial ideas on CRQ and revise them if necessary after the lecture/interactive teaching. For example, the conversation between the police officer and the driver – the CRQ activity is again given to students to discuss in groups, to see whether they would be satisfied with the answers they provided initially. If not, they will have to improve or revise their answers after discussing with their group members. It will be required of students to improve their answers with new knowledge they will gain from the interactive teaching. In so doing they are expected to replace their common sense knowledge with suitable Newtonian concepts.

Expectations

It is expected that

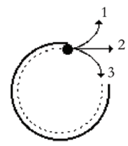
- Students will use the new information in lecture/interactive teaching to redress their initial misconceptions by forming proper concepts. Thus, students could siphon meaningful aspects of the lecture/interactive teaching and relate it to their views or answers given initially during the group and plenary discussions of the CRQ.
- Students will have an open and high quality dialogue/discourse with peers and teacher.
- Students will show signs of conviction by improving or rejecting their initial answers for a right and meaningful answer.

Application questions

These are questions related to what has been discussed in the CRQ, interactive teaching and reflection, but at higher order level, where students will have to apply or transfer the knowledge gained to solve or explain questions. The purpose of this activity is to enable the teacher to see whether students have acquired problem solving abilities. Thus the activity will allow the teacher to be sure whether students have understood what has been taught and discussed, and will be able to apply the acquired information in dealing with new but similar problems they encounter. To make it more interactive, group discussion, plenary session, think-share-present activities and presentations will be used.

Some of the application questions will be selected from Hewitt's book (Hewitt, 2001; 2010). An example of an application question on Newton's first law of motion:

> A group of physics teachers is taking some time off for golf. The golf course has a large metal rim which putters must use to guide their ball towards the hole. Mr. Boakye guides a golf ball around the metal rim. When the ball leaves the rim, which path (1, 2, or 3) will the golf ball follow?



Expectations

It is expected that

- Students will be able to apply and transfer the new knowledge gained to solve similar but new problems.
- This type of application and transfer of knowledge will be successful for a majority of students.

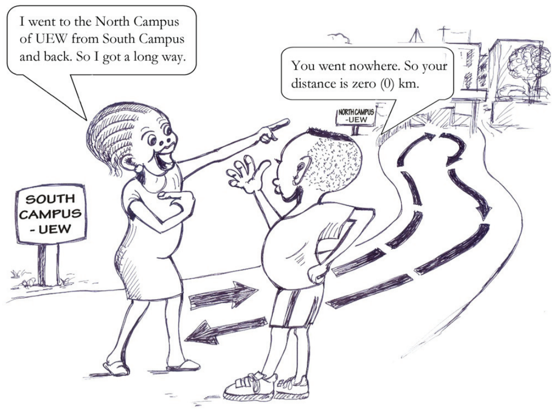
Tutorial/Problem solving session

Each lesson is followed by a tutorial/problem solving session. This is a session where students will meet to solve selected qualitative and quantitative problems. The questions will be given to students about a week before the session. It will take place some days after the completion of each meeting, so as to allow students to engage in discussing the questions among themselves and consult other books for solutions, before the session for the discussing of the problems. Students are to solve some of the questions as assignment and submit it. The assignment will constitute 10% of the final mark. It will help the teacher to know the fluency of students' problem solving ability. The use of problem solving was suggested by many physics education researchers, especially in situations where little can be changed in lecture due to constraints (McDermott, Shaffer & Somers, 1994; McDermott and Shaffer, 1992).

During the tutorial/problem solving session, all the students gather to ask for explanation and justification from their peers, who will be answering questions at a particular time. This mutual critique will help students to think about correct physics concepts and principles to be used and applied to the problems (Heller, Keith & Anderson, 1992). The teacher comes in to help or guide students, by providing hints or explanations, in questions where students find it difficult to comprehend or in areas where the approach or explanation is wrong. Some tutorial/problem solving session will be selected from Hewitt (2001; 2010) and Hewitt's Next Time Questions (n. d.).

Examples of some questions for problem solving on kinematics:

> 1. Listen to the conversation between Ama and Kofi and comment on it.
>
> *Supplementary question*: Reframe the 2nd part of Kofi's statement if he wanted to maintain 0 km.



2. Daniel moves 5 km to the east and 12 km to the north, all by bike. What is Daniel's (a) distance? (b) displacement?

3. An automobile starts from rest and accelerates to a final velocity in two stages along a straight road. Each stage occupies the same amount of time. In stage 1, the magnitude of the car's acceleration is 3.0 m/s2. The magnitude of the car's velocity at the end of stage 2 is 2.5 times greater than it is at the end of stage 1. Find the magnitude of the acceleration in stage 2.

4. A motorist wishes to travel 40 kilometers at an average speed of 40 km/hr. During the first 20 kilometers, an average speed of 60 km/hr is maintained. During the next 10 kilometers, however, the motorist goofs off and averages only 20 km/hr. What should be the speed of the motorist to drive the last 10 kilometers?

Expectations

It is expected that

- Students will discuss the questions among themselves or read from textbooks to gain a clearer understanding before coming to the tutorial/problem solving session. Thus students will come prepared and feel responsible for their own learning.
- Students who discuss the questions or read textbooks for more information will be able to answer most of the questions.
- Sometimes the teacher has to scaffold students' learning process.

4.4.3 Other helpful teaching techniques which were adopted

Projects and presentation

Projects are usually extensive tasks undertaken by students to apply, illustrate, or supplement the classroom lessons. Projects will be assigned to students in groups of three or four members to deliberate on and present to the class. The task will be given to students about a week before the presentation session. Some of the tasks will be selected from Hewitt's conceptual physics book (Hewitt, 2001). The groups will be expected to report their findings to the class for questions, explanations and clarifications. This will encourage students to do group work. It will also help students to learn how to find out things for themselves or how to do research into finding solutions to problems.

When students are working in groups, they interact with their peers and share ideas for better solutions to the task ahead of them. Projects have shown to be an effective technique for helping students learning a complex skill (Collins, Brown & Newman, 1989; Brown & Palincsar, 1989; Lunetta, 1990). Students share their conceptual and procedural knowledge as they discuss the task together.

Example from a project on vectors

Group (3 or 4 members) presentation on the use of "walking through the lawn" and the "Pythagorean Theorem" to check whether $A^2 + B^2 = R^2$ or $\sqrt{(A^2 + B^2)} = R$.

(a) Students search for lawns where people have walked through/across where the application of the Pythagorean Theorem is possible.
(b) Students measure the horizontal distance, A, and the vertical distance, B, (all on the ground), meeting perpendicularly, that make up the length of the path through the lawn with a metre rule or tape measure and record.
(c) Students find the sum of the square of the horizontal distance, A^2, and the square of the vertical distance, B^2. *Thus* $(A^2 + B^2)$.
(d) Students find the square of the path length through the lawn, R^2.
(e) Students find the square root of R^2 to get R.
(f) Students again measure R on the lawn with a tape measure.
(g) Students compare the two values of R (calculated and measured on the lawn) and provide with their conclusions.
(h) Students use a chalkboard protractor to measure the angle between the path length (through the lawn) and the vertical distance, α; and the angle between the path length (through the lawn) and horizontal distance, β.
(i) Students calculate these angles using the appropriate trigonometry sign;
$\sin\theta = \frac{opposite}{hypotenuse}$; $\cos\theta = \frac{adjacent}{hypotenuse}$; $\tan\theta = \frac{opposite}{adjacent}$
(j) Students compare their values from the trigonometry signs that correspond with α and β, and draw their conclusions.

Expectations

It is expected that

- Students will work collaboratively on the assigned task.
- Students will know how to relate classroom work to the physical world, and will verify the reality of some theorems used in classrooms.

- After students get used to presentations of tasks in the classroom, they will be more confident in doing presentations.
- Students will have open and high quality dialogue/discourse with peers and teacher.

Think-Share-Present

Think-Share-Present is adopted from "Think-Share-Pair" which was proposed by Lyman (1981). In think-share-present, the instructor will pose a question and gives students about three minutes to think about the question and write the answer down. This is necessary because it gives students a chance to start to formulate answers by retrieving information from long-term memory. Students then share with a neighbour sitting nearby and discuss their ideas about the question for about two minutes, before they present whatever they come out with, to the entire class, during general discussion. The think-share-present structure gives all students the opportunity to discuss their ideas. This is important because students start to construct their knowledge in these discussions and also to find out what they do and do not know.

This enables students to be involved in classroom learning. They learn how to argue their case out by convincing their peers on reasons why his or her line of thinking is the best. It makes it virtually impossible for students to avoid participating, thus making each person accountable. This technique was sometimes used in place of group discussion to get all students involved in answering the conceptual reasoning question.

For example, in finding out whether all students have a conceptual understanding of "work" as it is applied in physics, the following questions will be given to students as conceptual reasoning questions:

> Read the following statements and answer with explanations whether or not they represent examples of work.
>
> (a) A teacher applies a force to a wall and becomes exhausted.
> (b) A book falls off a table and free falls to the ground.
> (c) A waiter carries a tray full of meals above his head by one arm straight across the room at constant speed.
> (d) A rocket accelerates through space.
> (e) A man is holding a bucket full of water vertically and moving horizontally over a distance.

In order to get every student involved and to find out whether a majority of students could apply their understanding of "work" effectively, they will be made to think and answer the questions individually by writing their answers and explanations down, share their answers and ideas with the person sitting next to him or her, for them to come out with a shared compromised answer and explanation to the questions by writing their final answers down. Lastly, they will present the outcome of their results to the entire class. Hence the name think-share-present.

Expectations

It is expected that

- Students will think and apply their prior conceptual understanding to answer the questions individually.
- All students will get involved by sharing/arguing their cases out with peers sitting next to them, to come out with a compromised conclusion and explanation.

Scaffolding and creation of safe classroom culture

There are two other strategies which will be relevant to most of the activities described for better understanding of concepts and full participation of students. These are:

Constructive learning process is being scaffolded

Scaffolding will be provided in the activities where students will answer questions or solve problems, and will not get the opportunity to tackle them again. In such circumstances, where students will find it difficult to get the correct answers or understanding, the teacher will scaffold students' efforts in the form of providing hints or further explanations. Scaffolding will be mostly used with interactive teaching, reflection, application question and tutorial/problem solving sessions.

Creation of a safe, inviting and ambitious classroom culture

This will be provided in all activities. For students to contribute their share in the teaching and learning of physics there will be the need to create a congenial atmosphere in the classroom that will allow students to talk freely without any fear and to participate fully.

4.5 Assessment

Assessment is a very powerful force to guide students' learning. If the examination is not in line with the set learning aims, it is likely that the students will take the examination as the true message about what is important. Students will write an end of semester examination in the introductory mechanics course, after the end of the series of meetings to treat all topics required under the course.

Care will be taken that questions will be based on the content of the lessons. The questions will be more qualitative than quantitative; about 70% and 30% respectively. The final grade of a student in physics at the end of each semester is determined by addition of his continuous assessment (CA), which is 40% and final exam, which is 60%, to give a 100% mark. The various grades are shown in Table 4.4.

Table 4.4: Grades of final exam

Grade	Range in %
A	80-100
B^+	75-79
B	70-74
C^+	65-69
B	60-64
D^+	55-59
D	50-55
E (or fail)	0-49

End of semester examination would be split into qualitative and quantitative sections. Qualitative questions will constitute section A, whereas section B will focus on quantitative problems. Students' results for the qualitative and quantitative sections would be converted to mean proportion scores.

4.5.1 Comparing the new examination questions with the old examination questions

The examination questions are going to be compared under three characteristics: (i) types of questions which are in the old one and not in the new one, (ii) types of questions which are in the new one but not in the old one, and (iii) types of questions that are in the old one and also in the new one.

The old examination questions

The old examination questions (2006/07) are more quantitative (about 80% quantitative and 20% qualitative), and formula-based problems. Thus students who are well-versed in the use of formulas will be able to score. The few qualitative questions are not concept based and do not demand students to critically think, analyse, evaluate, apply and transfer knowledge gained. They are mostly recall questions, asking students to define, state, prove or derive. Most questions do not relate to real world problems that students are familiar with or questions that will enable students to apply their physics knowledge to understand their environment. There are no illustrative diagrams in the questions to improve students' understanding. Examples are:

(1) Define the following terms as applied to motion in a straight line:
  (i) average velocity
  (ii) instantaneous velocity
  (iii) relative velocity.

(2) An elevator descending at a constant speed of 4 m/s is uniformly brought to a stop in 1.6 s. If a man whose weight is 150 kg stands in the elevator, calculate the force exerted on him by the floor of the elevator during

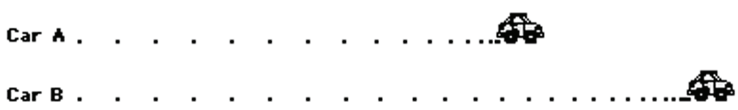
(i) the constant speed and

(ii) the uniform retardation period.

The new examination questions

The new examination questions (2010/11) are more qualitative (about 70% qualitative and 30% quantitative). Students need to understand concepts before they can apply or transfer their knowledge in solving. They need to critically understand, apply, analyse and evaluate the questions before they can provide solutions or answers. There is no recall question, like define, prove or state. Most of the qualitative questions are based on real life problems that students could identify within their environment. With the quantitative questions (2010/11), students need to have a basic understanding of concepts before they can solve them. The questions are not formula-based, which would reward students who can easily memorize formulas. There are many illustrative diagrams that are used to enhance students' understanding of the questions. Examples are:

(I) Two cars of equal mass are traveling down the UEW road with equal velocities. They both come to a stop over different lengths of time. The dot diagram for each car is given:



(i) At what approximate location on the diagram (in terms of dots) does each car begin to experience the impulse?

(ii) Which car (A or B) experiences the greatest acceleration? Explain.

(iii)Which car (A or B) experiences the greatest change in momentum? Explain.

(iv)Which car (A or B) experiences the greatest impulse? Explain.

Old and new examination questions

Apart from the fact that the two examinations consist of section A and B, and also have quantitative problems (2006/07 - 80% quantitative and 2010/11 - 30% quantitative), there were no other similarities as regards the type of questions used.

Comparing the old (2006/07) and new (2010/11) end of semester examination questions, we have realized that the new end of semester examination entails questions that students cannot answer straight away by memorizing facts or formulas. Instead, questions which relate to real world activities, stimulate thinking, application and transfer of knowledge are used. More illustrative, diagrammatic questions and formula-centred quantitative problems that require conceptual understanding are used in the new end of semester examination questions.

4.6 Conclusion

In this chapter we have argued why we opted for a design research approach. Based on the literature we outlined seven conditions for an effective interactive teaching approach. Next we described the type of activities of the new course and formulated expectations for each of these activities. Finally we presented the consequences for assessment of the course.

In the next chapter, we will evaluate the implementation of the first trial or round of the proposed interventions in the Ghanaian university setting, to see how the design will cope effectively with contextual and cultural factors and also how to improve the practical relevance of the solution to the local setting.

Chapter 5

First round of evaluation

5.1 Introduction

In this chapter, we will describe the first field test of our design. Since it is to be expected that a series of lessons designed from behind the desktop will contain practical shortcomings, a main focus of this first trial was to see whether the proposed activities would work out as intended, and how the activities in the lessons would need to be improved in order to achieve the intended classroom process.

We will first present the research method, including the research setting and the instruments. Second, we will present our findings with regard to learning outcomes and students' evaluations. Next, we will present our analysis of the classroom process, focusing on student-student and teacher-student interactions. In the conclusions for this chapter, we will focus on the implications for the design.

5.2 Research method

5.2.1 Participants

Participants in the study were all first year University of Education, Winneba (UEW) students who took the mechanics course in the first semester of the 2009/2010 academic year. There were seventeen students involved; fifteen males and two females. They had all taken physics in senior high school (SHS). The average age of students was 25 years (s.d.= 5.6). This average reflects the fact that few students go to university directly from senior high school. Most of them have to either do remedial classes to get a qualifying grade to go to university, or they have got a teacher's degree at a college of education (three years), and taught for a minimum of three years, in order to qualify for study leave with salary to further their university education. Participants' senior high school certificate examination grades in physics ranged between B3 (good) and C6 (credit). Most of the students had C6 with few students having B3, C4 and C5.

5.2.2 Research setting

The research was carried out in the Department of Science Education, University of Education, Winneba, (UEW). In Ghana, English is used as the language of instruction from the upper levels of primary education up to university level. The lecture room was equipped with computers and a white board. The room was furnished with laboratory benches and stools. The fixed nature of the benches made group discussions more difficult to arrange but students managed when there was the need to do so.

There was a camera assistant in the classroom who helped in videoing both plenary discussions and group work. Since there was a limited staff capacity in the physics education unit and the research was specifically about the researcher's own field of teaching, the researcher was the teacher of the course.

5.2.3 Instruments

Given the purpose of the study, we needed to collect data on (i) learning outcomes, (ii) students' opinions on the use of interactive engagement approach in teaching and (iii) the classroom process. Next, we will describe the instruments that were used to assess each of these aspects.

Learning outcomes

To assess gains in the conceptual understanding of mechanics, we used the force concept inventory (FCI) both as a pre-test and as a post-test. Students had 30 minutes to answer the questions in each case. It has been argued that in order to assess the quality of instruction, the difference between pre- and post-test score is not a good measure, because it will lead to a ceiling effect in initially more proficient students. In an attempt to compensate for this, Hake (1998) proposed a gain score as follows: $\langle g \rangle = (FCI_{post} - FCI_{pre})/(1 - FCI_{pre})$. This reflects the actual improvement divided by the initial room left for improvement. Of course, the downside of this metric is that for a high pre-test score (small denominator) it becomes very sensitive to small random differences, but for an assessment at the classroom level, this disadvantage was considered acceptable against the advantage that the Hake gain score allows one to compare results across classes of different ability ranges. –

Similarly, in order to assess students' understanding of graphs, we used the TUG-K (Test of Understanding Graphs in Kinematics), both as a pre- and a post-test. The pre-test was taken a day before the lesson on graphs (2^{nd} week). The post-test was taken the day after the close of the lesson on graphs (3^{rd} week). Gain scores were computed using the same type of gain scores we used with the FCI.

The mechanics baseline test (MBT) was used to assess quantitative problem solving skills. This test was taken only as a post-test because it emphasizes concepts that cannot be grasped without formal knowledge about mechanics. This test was taken the next day after completion of the mechanics course (they had a short break after answering the FCI, and then answered the MBT afterwards). Forty five minutes were given to students to complete the test, as some computations were required. Their mean proportion correct scores were analysed and compared with some results of students in the United States of America (USA).

Students' scores in end of semester examinations, concept quizzes, assignments, and projects were compiled and converted into mean proportion scores. Sample of students' work in these areas were also gathered. These were analysed to identify specific strengths and weaknesses of students.

Students' opinions

At the end of the course, students filled out questionnaires to give their opinions about the activities used in the teaching process. The questionnaire comprised two parts. The first part of the questionnaire required of students' personal information on age, sex, year of admission, senior high school (SHS) attended and their grade in physics (Appendix 2, I). Students were not to include their names and index numbers, to free their minds from fear of being victimized.

The second part sought students' opinion about the types of activities and sessions used: concept quiz, conceptual reasoning question, lecture, reflection, application question activities and tutorial sessions used in the meetings. With each activity, there were four items that students had to respond to (appendix 2, II). The first question in each activity was different and dealt with the specific benefit that students derived from that particular activity. The other three questions were the same for all activities. The questionnaire was not a standard instrument. It was specially designed for this study, but had a good reliability (α) in the Ghanaian context, shown in Table 5.6. Students were to rate the activities using a five-point Likert scale questionnaire with responses ranging from strongly disagree-SD (1), disagree-D (2), not sure-NS (3), agree-A (4), and strongly agree-SA (5).

Students answered the questionnaire on the same day after the completion of the course. All 17 students took part and spent about 15 minutes in answering the questionnaire. It took place in the same room where the teacher and students had the meetings/lessons (P2).

In addition to the questionnaires at the end of the course, interview sessions were held between selected students (groups of three or four) and the teacher (or sometimes a colleague teacher) after at least two meetings with students to inquire their opinions on the use of interactive engagement approaches in teaching, its effect on them and suggestions to improve or support their learning. Five interviews were done in all, two of them were conducted by the researcher and three by colleague teachers. The same interview schedule was followed in all (appendix 1). This was an indication for the teacher to see how students were coping with the new approach of teaching. In most cases, it took about thirty to thirty-five minutes to complete one interview schedule. It was mostly done in physics laboratory room P2.

Classroom process

All lessons and tutorial sessions were recorded on video. All group discussions were recorded using audio recording devices. These were used to observe how students were learning; how they held discussions with their colleagues, participated in class, the arguments they put forward to support their answers, the teacher-student interaction pattern, frequency of asking questions, and their reasoning to support their answers. Selected video and audio recordings were transcribed and analysed to find out about the quality of the discourse and students' understanding. The episodes selected for transcription and further analysis were chosen based on the following considerations: they had to be sessions with substantial mechanics content in an area with well-known conceptual issues, and they had to be after the first few lessons when the students still had to get used to this mode of teaching.

5.3 Learning outcomes and student perceptions

Students' results in pre and post FCI, pre and post TUG-K, MBT, concept quizzes, assignments, projects and end of semester examination will be presented. Impressions gathered from student responses to questionnaire items and interview will also be looked at.

5.3.1 Learning outcomes

Students' correct scores in pre and post FCI, pre and post TUG-K, MBT, and end of semester examination (2009/2010) were converted into mean proportions and tabulated as shown in Table 5.1.

Table 5.1: Proportion correct and gain scores on FCI, TUG-K and MBT

	2009/10			
Test	**N**	**Pre (SD)**	**Post**	**Hake gain**
FCI	17	0.17 (0.09)	0.59 (0.09)	0.51 (0.11)
TUG-K	17	0.27(0.05)	0.69(0.07)	0.58(0.09)
MBT	17	-	0.48 (0.08)	-

Students prior conceptual understanding, as indicated by their pre FCI score, was considerably lower compared to a large sample of university students in United States of America, USA (Hestenes, Wells & Swackhamer, 1992). However, the average Hake gain for this course fell within Hake's "medium-g" value, $0.3 < g < 0.7$; which is a typical range for average effectiveness of courses in promoting conceptual understanding (Hake, 1998). In fact it was much higher than the gain for the average traditional course in the Hake sample and very close to the average gain score for interactive engagement courses (average gain for traditional courses .23 ± 0.04sd; for IE-courses: 0.48 ± 0.14sd).

Students' mean proportion scores in *pre* TUG-K indicated that they did not have enough conceptual understanding of kinematics graphs (description and transformation of graphs, calculating and getting the meaning of slope and area under graphs) before the beginning of the lesson. However, their mean TUG-K score after the course was about 0.30 above what Beichner found with students after their instruction in kinematics (Beichner, 1994).

In comparison to the same sample of university students in the USA (Hestenes, Wells & Swackhamer, 1992), the mean proportion correct score of MBT for the 2009/2010 academic year group was about 0.20 less, which is in line with the results found on the FCI post-test.

Table 5.2: Mean proportion correct on concept quiz

Year gp.	No	Q1 (SD)	Q2 (SD)	Q3 (SD)	Q4 (SD)	Q5 (SD)	Q6 (SD)	Q7 (SD)	Q8 (SD)	Q9 (SD)	Q10 (SD)
2009/10	17	0.64 (0.14)	0.49 (0.15)	0.63 (0.17)	0.61 (0.12)	0.76 (0.36)	0.48 (0.12)	0.66 (0.26)	0.42 (0.28)	0.83 (0.16)	0.25 (0.15)

Each weekly lecture started with a concept quiz written by students. Table 5.2 presents the mean scores per week. Students mean scores were not encouraging in weeks two, six, eight and ten. On closer inspection it turned out that the questions in these sets did not match the reading assignment sufficiently well. Questions here will be revised to be within students' capabilities in the next round of implementation. Ten out of the eleven-week lessons prepared were taught. Impromptu and frequent power outages caused a delay in the teaching and some contents were sacrificed in week 11 at the end.

Table 5.3: Mean proportion correct scores on homework assignment

Year gp.	No	A1 (SD)	A2 (SD)	A3 (SD)	A4 (SD)	A5 (SD)	A6 (SD)	A7 (SD)	A8 (SD)	A9 (SD)	A10 (SD)
2009/10	17	0.68 (0.10)	0.61 (0.11)	0.73 (0.09)	0.69 (0.09)	0.77 (0.08)	0.77 (0.08)	0.76 (0.09)	0.78 (0.07)	0.82 (0.04)	0.84 (0.04)

Ten homework assignments were submitted by students. Their weekly mean proportion correct scores showed some consistency with increasing scores. Assignment questions will be repeated in the next round.

Table 5.4: Mean proportion of project scores

Year gp.	No	P1 (SD)	P2 (SD)	P3 (SD)
2009/10	17	0.73(0.06)	0.78(0.03)	0.75(0.04)

Students presented three projects. Their performance in all the three projects was similar. Though students complained that the project was time consuming, they asserted the projects made them responsible for their own learning and as such they learnt a lot from them. Projects will be repeated in the next round due to their work benefit to students.

Table 5.5: Mean proportion correct scores of end of semester examination grouped into qualitative and quantitative sections

Academic group	Year	N	End of sem. exam. 0.60 (SD)	Qualitative mean 0.42 (SD)	Quantitative mean 0.18 (SD)
2009/10		17	0.35 (0.07)	0.25 (0.05)	0.10 (0.03)

The course was concluded by an end of semester examination. Students' end of semester examination results were fairly high. The end of semester examination questions contained more qualitative and real world questions than in past years. All results will be compared with the results of the next round of data collection.

5.3.2 Student perceptions

Student perceptions on the use of activities of the interactive engagement (IE) approaches were sought through an exit questionnaire and small group interviews. The subsequent sections describe the scales and statistical description of the questionnaire, a brief description of the interview schedule, and conclude with student perceptions on the use of IE approaches in teaching.

Student responses on the survey are presented in Table 5.6. Students perceived that the activities helped them to participate actively in class and to understand concepts of mechanics. From student responses, they did like all the activities used in the meetings, found them useful and showed a positive attitude about them. This positive response might be due to the following: (i) politeness of the Ghanaian culture that makes students "positive buyers" (they thought that being negative is a sign of disrespectfulness, even if the situation demands that), (ii) students trying to please the teacher (fear of being victimized by the teacher, when they answer the items negatively), (iii) and/or the fact that students did like it.

Table 5.6: Student responses on activities/sessions of the lessons

Activity	N	Mean	Std. dev.	Std. error mean	Alpha reliability (α)
1. Concept quiz	17	4.25	0.68	0.17	0.73
2. CRQ	17	4.59	0.60	0.15	0.89
3. Lecture	17	4.18	0.69	0.17	0.89
4. Reflection	17	4.43	0.67	0.16	0.84
5. Application question	17	4.46	0.60	0.15	0.94
6. Tutorials	17	4.66	0.48	0.12	0.92

The interviews were used to collect feedback on students' opinions throughout the course and to add some depth to the findings from the survey. Some selected interview guidelines and their corresponding responses from some of the students on Newton's laws of motion are shown in the subsequent fragments. To conceal the identities of students, the names used in the protocols are false.

Q. How did you participate in the interactive activities?

1. **Paul**: … In my group, I was made the leader, so I organized my people, … Most of the time too when we are doing other project work, we all contributed, we brought our ideas together. Sometimes in a group we have different ideas, but at the end of it, after a long debate we all come to a conclusion and then we take the same thing.
2. **Tony**: The reasoning questions that we discuss among ourselves, before we start the discussion, we allow everybody to think about the question to bring out his own view. So I try to bring out what I know and then discuss with my friends, not that you just say something and we accept it. We debate on it and we come to a conclusion, before we present our answer.
3. **Grace**: When we come to group discussions, when a work is given to us to discuss, through the discussion, everybody has to participate or everybody has to involve himself or herself. In other words, everybody works his or hers and after that we compare. In the comparison, we argue about everyone's answer. At the end we come into conclusion of the overall best of the answer.

Students interacted with their peers, through sharing of ideas, arguing and discussing to come to conclusions. The design of the activities yielded what was expected; to get students to interact in the teaching and learning process.

Q. What is your opinion about the activities in the lessons? Difficult or not?

4. **Paul**: To me I think it is standard, based on the way we are doing it. Certain things when you see them generally, you think they are difficult. Sometimes, you see a question, you think about it and you don't know what to do. But like I said the way we are doing it, you give us the chance to discuss, compare your answer to your friend, the person will bring his or her ideas and then you compare. So it is making everything, I will not say too easy, but standard. That is my view.
5. **Charles**: Not all of them are above my standard. Some of the activities, the approaches we use to solve it make it easy for me. The approaches towards that particular question make me understand everything. So I will say everything that we do here is standard; not too difficult and not too easy.

Students agreed that the activities were moderate; neither too difficult nor too easy. They further explained that the way we went about things, by allowing them to discuss and compare their answers with their peers before they come to conclusions did make the course easy. Thus the interactive nature of the course made learning quite easy.

Q. How could your learning be supported?

6. **Victor**: I think what we are doing, I will suggest that we continue with it and that will help us. And the suggestion, I will give here is sometimes in the class we will learn and understand and some of the questions that we do, even though we understand them very well, we are doing a lot of courses and sometimes when you want to solve a question, you forget some of the things that we have learnt. So my suggestion is that, maybe once a while or with the topics that are a bit difficult, you can give us a hand out or something like that so that we can be revising them. Especially when it is getting to examination we can read through before we write the exam.
7. **Ernest**: I think, I also have the same suggestion, maybe, after the lesson, if we can get some reference materials to read on, I think it will help us.
8. **Teacher**: What about the references in the course manual and the textbooks in the library?
9. **Ernest**: Some of the information there and the things that we acquire here they are different. And also the information that you give us, also make us understand the thing more. So with those materials it will help us more than the textbooks.
10. **Victor**: Because sometimes, the way you work things is more, what do I say, is clearer than the way it is made in the book. …. So we want to have what you have…
11. **Patrick**: If you take some of the books, for yours, you have made a summarized thing, so that whatever we do in the classroom we will understand. Whatever we learn here, when you go to the library and make comparisons, you see that things are so different. You read and you wouldn't get any understanding. So maybe, I will also suggest if after any topic you can give us your summary notes as references.

With the support of students' learning, they suggested that copies of the teacher's power point presentations should be given to them for reference, as they found it difficult to get what they learn in class from books at the library.

Q. Given the list of interactive engagement approaches/activities, (i) which one do you like best and why? (ii) Which one do you like the least and why?

12. **Victor**: … So I don't know which one to take as the best. Like this … reasoning questions, it makes us to talk. And then based on that thing, before you come too you will learn, because when a question is given, you will not like to be dormant in the group. You too you want to at least show that you have also learnt something small.
13. **Grace**: I also like the tutorials very well. Sometimes if I get a certain question, the way I think the solution should be, when I come to tutorials and we discuss and we share ideas, I get to know the right method of solving questions. And the one that I like least is the project work… (We all laugh).
14. **Teacher**: Why?
15. **Grace**: The reason is that, the project work, you know we have a whole lot of courses and subjects that we are doing, and my group members if we say we are meeting at this time, you will be going there and somebody will say this guy has travelled, this one has

gone this way… and you wouldn't know what to do. Sometimes you become frustrated. So that is my problem.

16. **Stephen**: For me I will choose the MBL, tutorials as well as simulations. But the least one is the group discussions. For the tutorials each and everyone is given a chance to go to the board and then show his ability of solving a particular question. That does not mean that when you get it wrong you will be penalized. Everybody will try his best on how the question is solved. So at the end of the day, I gained much from that. And the MBL too, every student is given the chance to interact with those tools, so that when you go out you can practice with the students that you are going to teach. The least one, with the group discussion, at times, students will be sharing his idea and another will be opposing it. It sometimes takes a longer time before everybody agrees to each other.

Students liked the use of MBL and tutorials. With the tutorials they liked the fact that they were not penalized in any way when they got a wrong answer. Some mentioned projects and discussions as those they liked the least, because some members of the group were not punctual, and also due to the prolonged arguments that they sometimes caused. However, the prolonged arguments could be a contributing factor in enhancing their learning.

Conclusions

Overall, the learning outcomes of the course, as judged by the FCI-gain scores, are well above the effects that could be expected for a traditional lecture class, and well in line with the average for interactive engagement classes. Moreover, the course was valued positively by the students. However, there were some critical issues that students mentioned which need serious attention. These include the following:

- Students thought that though some of the activities (materials or questions) were moderate, there were others which were beyond their level. This was realized in their difficulties in solving some of the questions in CRQ, application questions and tutorials. These materials need to be revised or changed to be within students' capability in the next round.
- Some students did not like project work. They thought that some members of the group were not punctual. Measures have to be put in place for students to report their colleagues who would arrive late and not participate fully in the group's work for the teacher to deal with.
- As regards arguing in discussions, that was what the materials/activities were intended to bring. However, when arguments become prolonged too often, it tends to lose its value or importance. Most students could easily become disinterested in the discussion. Measures have to be put in place where students have to write down all their ideas/arguments to be discussed with the teacher, especially when they realize such occurrence. Again, questions that could lead to prolonged arguments should be reviewed to avoid such occurrences.

Though favourable impressions were gathered from students' learning outcomes and perceptions in general, selected episodes of classroom proceedings will be examined more closely and deeply for quality learning process in the next stage.

5.4 In-depth analysis of selected episodes

In order to get directions on how to improve, we had to analyse the classroom process in detail. Because not all episodes are equally informative, and because a detailed analysis is time-consuming, we selected the most informative episodes. As an initial orientation the researcher watched and listened to all materials to reflect on the ten meetings and identify obvious successes, difficulties, and points for improvement. Based on that first viewing, it was decided that the most relevant parts for further analysis were those where:

- The students already had some experience with interactive teaching, so that starting problem had been overcome.
- Students had relatively many conceptual difficulties based on the literature.

Based upon those criteria, the sixth meeting was selected for an in depth analysis of the classroom process. In this meeting the following topics were covered:

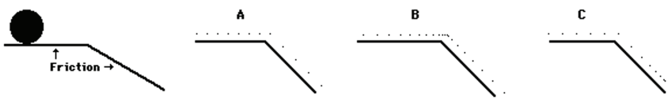
- Newton's first law of motion.
- Newton's second law of motion.
- Newton's third law of motion.

Corresponding portions of the video and audio recordings were transcribed and some parts of students' verbal explanations on concepts and questions in mechanics were analysed. Names used in the protocols are all false. This is to conceal the real identities of students involved.

The meeting started at 7:30 am, with concept quiz questions on Newton's laws of motion, which were used to test students' understanding on their preparatory reading of the laws. The people present were 17 students, the camera assistant and the teacher.

5.4.1 Concept quiz

Each new topic was introduced by giving a concept quiz to assess the knowledge gained from the reading assignment, so as to motivate students to come prepared. The aim of the design for these questions was that a well prepared student could perform well. Some of the questions were selected from Mazur (1997). Below are the questions involved:

Question	**Proportion correct sc.**
(1) Which of these laws is not one of Newton's laws? (a) Action is reaction, (b) F=ma, (c) All objects fall with equal acceleration, (d) object at rest stays at rest.	0.75
(2) The law of inertia (a) is not covered in the reading assignment. (b) expresses the tendency of bodies to maintain their state of motion. (c) is Newton's third law.	0.77
(3) Impulse is (a) not covered in the reading assignment (b) another name for force (c) another name for acceleration.	0.35
(4a) Two boys are playing ice hockey on a television. A stray puck travels across the friction-free ice and then up the friction-free incline of a driveway. Which one of the following ticker tapes (A, B, or C) accurately portrays the motion of the puck as it travels across the level street and then up the driveway? 	0.10
(4b) A ball is rolling across a horizontal land. It then encounters a steep downward incline (see diagram). Friction is involved. Which of the following ticker tape patterns (A, B, or C) might be an appropriate representation of the ball's motion? 	0.40

Students' mean proportion correct score on the quiz was about 0.48. In comparison with most of the other concept quizzes, this was a low score. Looking at the questions more precisely, it turned out that questions one and two were a good match with the reading assignment. Scores on questions 3, 4a and 4b were less than 0.5. Question three turned out to be ambiguous and confusing to students, and moreover was not part of their reading assignment. Question four (a) evoked some discussions as shown in the fragment below:

17. **Students**: (Some responded) C, (others) A, B and so on
18. **Teacher**: Those saying A, what are your reasons?
19. **Regina**: Sir, me A, because they say, friction-free ice, so that, that there will be no opposition in the movement of the hockey puck. So if it is moving with something like this force then it continues, then we want to look at the race eh,…
20. **Teacher**: What about those who chose B?
21. **Patrick**: Sir, you realize that it will go with the constant speed, and then it continues with it for some time before as it is climbing up then it starts reducing its speed.
22. **Teacher**: Do you agree with what he is saying?
23. **Tony**: Sir, it is C.

Many students would stick to incorrect answer options even after the explanation. As it turned out in question 4a, the friction-free made the question ambiguous, so that multiple answers could be defended.

It turned out that some of the quiz questions were meant more for conceptual reasoning questions and outside the reading assignment. Questions should be looked at again to be either rephrased or changed so that students who come in prepared can benefit. The time allotted for this activity was exceeded by ten minutes due to the ambiguity of some of the questions which caused some confusion and students found it difficult to accept the correct answers.

5.4.2 Newton's first law of motion

Newton's first law of motion was the first topic in the sixth lesson after the discussion of the concept quiz questions with students. In this section we will provide a chronological account of the classroom processes.

Conceptual reasoning questions (CRQ)

The aims of the conceptual reasoning questions were that:

- Students would voice their prior knowledge on Newton's first law of motion, which would enable the teacher to help them with the proper concepts of Newton's first law of motion during the lecture.
- Students would argue their case out with colleagues and come up with physically meaningful conclusions.
- Students would show dissatisfaction with their answers, to create the need for learning.

Students were made to form groups of at least four members each. The members of each group were to discuss the conceptual reasoning questions and try to come out with a jointly agreed-on answer. Later, students were to come out with their views on the answers to the class. The following questions were projected on a screen for the various groups to discuss:

(1a) A coin was put on a card and placed on a glass. Why will the coin drop into the glass when a force accelerates the card?

(b) To dislodge ketchup from the bottom of a ketchup bottle, it is often turned upside down and thrust downwards at high speeds and then abruptly halted. Which of Newton's laws of motion explains this phenomenon. Explain.

For the first problem, about the coin, some groups had difficulty in interpreting the situation at hand, due to lack of visualization:

24. **Tony**: … So when a force accelerates the card it will cause the coin to fall, because now the coin and the card will be at rest, but looking, comparing the card and the coin, the coin is heavier than the card. Have you seen? So the one with the heavier mass will fall or drop into the glass. Because you see when you compare the card, the force, when any force acts on it, it can't drop.
25. **Charles**: Because it is not heavier.
26. **Tony**: …, it is not heavier comparing the masses. So the coin will drop instead of the card, due to difference in masses. So the difference in masses will determine the acceleration. So if the mass is low, then it means that the force, you see force itself, force causes acceleration, so force is depending on the mass. So force it only cause a body to accelerate…

From the group of Tony, Charles, Mike and Ernest.

More generally, students tended to focus on other aspects of the motion than the instructor had intended:

27. **Patrick**: … So I am saying that it is because of gravitational force, because the force will act on the coin into the glass.

From the group of Stephen, Patrick, Richmond and Seth.

Next, students tried to involve their prior physics knowledge, but it did not seem to connect:

28. **Stephen**: It is obeying the law of inertia, but then if this one should move, the law of inertia is disobeyed.
29. […]
30. **Patrick**: I think that is the idea, the inertial reference frame…
31. […]
32. **Stephen**: Newton's 3rd law, action and reaction.
33. **Other members**: Opposite reaction, 3rd law. Action and reaction, it is going up and down.
34. **Stephen**: Action and reaction are opposite and equal.

From the group of Stephen, Patrick, Richmond and Seth.

In his first contribution, Stephen appropriately invokes the concept of inertia (Newton's first law), but later on, the discussion diverges towards Newton's third law. Part of the difficulty might be that it is not really clear to students what needs to be explained. It might help to present the problem as a comparison between two cases: one where the card is being pulled slowly, and the coin moves along, and one where the card pulled quickly, and the coin stays in place.

In the case of the ketchup bottle, the question turned out to be clear to students, and at least one group made a connection with Newton's first law, but could not give a better explanation to the effect of the continuous movement of the ketchup when the bottle was halted. They focused their attention on the start of motion of ketchup, but not about the continuous movement of the ketchup, leading to a wrong explanation.

35. **Tony**: (*Tony reads the question again*). It is the first law, because while the thing is at rest, you apply a force to cause the thing to come down. So it is the Newton's 1st law of motion that cause the, this thing to come. So gravitational force acts on it downward, because when you apply you see that gravitational force…

In the plenary discussion, the situation of the first question, involving the card and the coin, had become clear, but when it came to explaining what happened, many students still could not focus or relate their explanations of why the coin failed to move with the card to inertia, they concentrated only on the falling coin:

36. **Teacher**: … Why will the coin drop into the glass when a force accelerates the card?
37. **Stephen**: Sir, although when the coin is lying on the card, acceleration is acting, but it's acting downwards. Immediately the card is removed, the card is moving horizontally and acceleration is acting downwards so it will force the coin to move downwards.

Though the teacher tried to bring into the attention of the students that in some circumstances the coin could move along with the card, they did not see anything wrong with their answers that it was due to the force of gravity that the coin moved into the glass, as the force that was applied accelerated only the card:

38. **Victor**: Some of us are saying that, is like the card is on the glass and then the force was applied to the card to accelerate the card. The force was not applied to the coin. So since the force was applied to the card, the force was able to accelerate the card and come out under the coin. And then the coin…
39. **Teacher**: But they were in contact…
40. **Victor**: Yes, so when the card came out, then the force of gravity now acted on the coin to get inside the glass.
41. […]
42. **Charles**: Sir, we said the force was applied only to the card and does not have effect on the coin. So because it wasn't applied to the coin, the coin will fall while the card will accelerate.
43. […]
44. **George**: … The force we are talking about is the external force that will disturb the coin. No force had been acted on the coin to disturb it. No external force has been acted, except the force that was on it already. You see, so when the force is applied, it is being

applied only to the card and the coin will try to be in its same state of rest. You see, because you have not disturbed it, it will fall in the glass.

One of the students tries a demonstration, and it turns out that the coin does move along, but this is still insufficient to focus on explaining what happens in the horizontal direction:

45. **Kingston and his group**: (Kingston came to the front of the class to make some demonstration about the question)… When a force is applied (*he hit the book serving as a card, but the coin failed to drop down*).
46. […]
47. **Kingston**: Although the coin moved a little with the card, but because g is acting vertically, not horizontally, so it acts on the coin, to retard the coin not to move faster with the card. So it falls into the glass. That is gravitational force is acting on the coin.

The students did not see any problems with their explanation for the effect of the coin falling into the glass. As can be seen from lines 38, 40-44 and 47, they did not show any dissatisfaction with their answers, which would have created the need for learning.

Next, the discussion shifts towards the ketchup question. As already turned out in the group work, in this case the phenomenon was clear. Students invoked different laws to explain the phenomenon, but applied them incorrectly:

48. **Philip**: Sir, there will be a force. Newton's 3^{rd} law will be applied to this.
49. **Teacher**: Why, Newton's third law?
50. **Philip**: Sir, there will be opposite action and reaction, …
51. […]
52. **Kingston**: Newton's third law of motion which states action and reaction are equal but opposite in direction. So this one when you do it like this, (*Kingston demonstrating with his hand by moving it up and down*), g acts on it, and there is a viscous force, viscosity (*students burst into laughter*).
53. **Paul**: Sir, we related our answer to the first law.
54. […]
55. **Ernest**: Sir, we also said that, it's first law, because the thing will continue to be in its state, unless external force is applied. So gravitational force is the external force which was applied to the object.
56. […]
57. **Seth**: The same thing, we use the third law.
58. **Teacher**: Explain, why the 3rd law?
59. **Seth**: We did not talk about the viscosity (students laughed), because when it was pushed you realized that the force moving from the other end and the force that is here, (*using the hand to demonstrate*), will be the same…

Students did voice their ideas and conceptions, and they gave explanations, but most students did not support their ideas by relating them to Newton's first law of motion (inertia). Some students were able to link the first and second questions with Newton's first law of motion, but failed to give appropriate explanations for why the coin failed to accelerate with the card and dropped into the glass. This goes to support one of the aims of the activity; to let the instructor know the prior conceptions of students. Students seemed satisfied with their explanations (lines 38, 40-44 and 47). This could not support the aim that students should be dissatisfied with their results to create the awareness of the need to learn. The assignment needs to be modified to have students focused on the specific issue that needs to be explained in terms of Newton's first law (inertia). The time allotted for this activity was also exceeded by five minutes due to some prolonged arguments by students during group interactions.

The second question involving "the movement of the ketchup bottle" seemed to be more meaningful to students and also triggered more of a need for further learning than the first question (lines 55-59). Hence only the second question will be used in the next round of data collection, with more clarification of the target, as to which of the Newton's laws of motion will explain the continuous motion of the ketchup when the bottle was abruptly halted.

Lecture

The lecture session was a part of the design where the teacher's goal is to make distinct concepts clear by giving examples of daily life activities which can be explained by the use of Newton's first law.

The teaching was mainly a traditional lecture with occasional questions which demanded chorus response from students. For example,

60. **Teacher**: … The definition has two parts. The first one is talking about objects at rest. That means when you have an object at rest, it continues to be at rest. That means when the velocity is zero, it continues to be at rest. An object at rest, it doesn't mean there are no forces acting on it. Do you understand?
61. **Students**: Yes sir.

Students were not given the opportunity to express their views on what the teacher wanted to relay to them. Not many real life and meaningful examples were included in the lecture, for example, the teacher did not give any specific example in line 60 to support the fact that when an object is at rest, it does not really mean there are not forces acting on it. Also, the extra time used during the concept quiz and conceptual reasoning questions made that the teacher rushed through the lecture.

Review of material before the second round is necessary. The lecture should have more teacher-student interactions, to give students an opportunity to express their level of understanding. More real life examples should be included to guide students to relate Newton's first law in some activities they experience within their environments, such as what happens to passengers when a vehicle stops, moves or negotiates a sharp curve suddenly. This will help students to understand and relate the law to real life situations.

Reflection

Students are given another chance to reflect on their answers to the conceptual reasoning questions. The aim of reflection is to find the effect of lecturing on students' answers and to also give students the opportunity to revise their initial answers.

The discussion in this activity ran along much the same line as the original discussion in CRQ:

62. **Victor**: …, Newton's 1st law. That a body continues to be at rest when it is at rest and also… So in this case the two bodies are at rest, and now the force is applied to only the card but not to the coin. So it will cause the card to accelerate and then since the force is not applied to the coin, the coin will continue to be at rest.
63. **Teacher**: Why? Why does it want to be at rest?
64. **Victor**: Because the force was not applied to it, it was at rest already.

The teacher is pressing for further explanation, but it might be unclear what exactly deserves further explanation.

The same applies for the shaking of the ketchup bottle; the students recognize that the ketchup will continue its movement when the bottle halts, but do not come up with any specific explanation in terms of inertia:

65. **Victor**: I think, when you shake it, that is move it downwards it is forced to move with the velocity of the bottle. And then as you stop, it's like, the bottle is moving and the ketchup will be forced to move forward with the what, with the bottle, so it will be forced to come out.
66. **Teacher**: No, what about when it stopped, what happens. Yes Bruce.
67. **Bruce**: It's like when it is in motion with the bottle, as you stop the bottle it continues to move, so it tries to come out.

Though the students were able to state that the two questions could be explained by Newton's first law of motion, some stuck to their original explanations. Students could not draw on any meaningful aspects of the lecture to relate to their answers. They were not able to revise their initial answers.

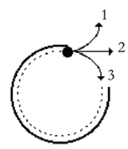
The reflection activity is more important and would still be included in the next round of data collection. CRQ needs to be improved in terms of its demand and more realistic examples should be included in the lecture for students to utilize the opportunity to revise their initial ideas with proper concepts in the reflection.

Application questions

To be sure whether students have understood what has been taught and discussed, they were given similar but new question(s) where they had to transfer the knowledge gained to solve or explain. These questions were called application questions. It was expected that students would be able to apply the acquired information in dealing with new problems they encounter.

The application question in this case was similar to a question in the force concept inventory (FCI). This question was used because of the well-known mistake students make in answering it:

> A group of physics teachers is taking some time off for golf. The golf course has a large metal rim which putters must use to guide their ball towards the hole. Mr. Boakye guides a golf ball around the metal rim. When the ball leaves the rim, which path (1, 2, or 3) will the golf ball follow?



While most students were unable to apply Newton's first law to arrive at the correct answer, others were able to do so.

68. **Stephen**: Sir, I think it is 3 because it is still in motion, so it will try to follow that circular path.
69. […]
70. **Mike**: Sir, I will say 2 simply because at that particular point there wouldn't be any guide for it, so it will continue in that straight path.
71. **Teacher**: Why that straight path? Yes, George.
72. **George**: Sir, em, since there is nothing to disturb this thing. When it was moving in the circular path, there was something that was keeping it in that state of motion. So when it gets to the other side which has nothing to act upon, it tries to move upon the straight path.
73. […]
74. **Victor**: Sir, it is 3. It's like the body is accelerated by the force that is one particular force giving it a specific direction. … And now there is no force acting on it to change its direction. If it had been set to circular direction it will continue to follow that direction, unless another external force will act on it.
75. […]
76. **Regina**: Sir, I said 3.

The teacher comes in to give an explanation:

77. **Teacher**: You see, I wanted you to relate it to first law of Newton. What did he tell us? An object when it is moving, it prefers to always move with the same speed in a...
78. **Teacher and students**: In a straight line.
79. **Teacher**: You see it prefers to move in a straight line, unless an unbalanced force acts on it. So whenever you accelerate any object, it starts moving in a straight line. So you see that this one, it was supposed to, it started from here, it was supposed to move in a straight line but because of the curvature or the circular nature of the object, it is forcing the ball to move in a circular manner… So it comes out here and there is nothing to force it to move in a circular manner, so what happens, it just moves in its straight line again.

The question was appropriate for some students to apply the knowledge gained. Only a few of them applied insights from the lecture to answer the question, a majority failed to recognize that all objects continue to move in a straight line, unless an external force acts on it to move otherwise. When the teacher called their attention to Newton's first law, all the students were able to achieve a clear conclusion about the ball's direction of motion.

The question did fit within students' capabilities and also revealed their misconception of Newton's first law in circular motion, though a majority of the students could not arrive at the right path that should be taken by the golf ball. It gave an opportunity to explain Newton's first law in circular motions. The question would be repeated in the second round of data collection.

Conclusions

It was realized that

- Although the first CRQ resulted in student-student interactions and made students voice their preconceptions, they were satisfied with their incorrect explanations and the need to learn was not created. The second question was more promising, although its wording caused some confusion, which took too much time. We expect that one good CRQ will be sufficient, therefore the second question's target will be clearly spelt out and used during the second round of data collection because it triggered a need for further learning.
- A main part of the teaching consisted of lecturing without much student involvement. There should be more real life examples and questions to improve teacher-student interactions and help students to relate Newton's first law to real life activities.
- Students could not see the need to revise their initial answers during reflection. They stuck to their original ideas, as they were satisfied with them.

- Though some students were able to apply the knowledge gained during the lecture to support their answers, most students' lack of understanding and ability to apply Newton's first law to circular motion was revealed. The question would be repeated in the next round, to improve students' conceptual difficulties in Newton's first law of motion in relation to circular motion.

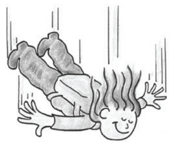
5.4.3 Newton's second law of motion

Newton's second law of motion was the next topic to be dealt with. The aims of the various activities for Newton's second law of motion were the same as those presented in the lecture about Newton's first law of motion.

Conceptual reasoning questions

In this activity students were to use five minutes to discuss the question in groups and another five minutes for plenary discussion. The question was picked from Paul Hewitt's Next Time Questions (n. d.).

> As she falls faster and faster through the air, her acceleration (i) increases, (ii) decreases (iii) remains the same (iv) becomes zero.



Students did not answer the question well, as they failed to give good reasons to support their choice of answers. This is shown in the following fragment:

80. **Students**: Some said, it will increase, others said it will remain the same.
81. **Teacher**? Why.
82. **Stephen**: Because it is only acceleration due to gravity which is acting.
83. **Teacher**: No, there is wind. Just look at the diagram, there is wind.
84. **Some students**: It will increase. It will increase.
85. […]
86. **Tony**: I think that air resistance is not neglected.
87. **Teacher**: Yes, it's not neglected…
88. **Student**: (Students remain silent).

Though the question about the falling parachutist was a good example to explain Newton's second law of motion and triggered the need for further learning (line 81), it needs to be extended to give the students opportunity to express what will happen to the falling parachutist's velocity, her acceleration and the force on her, when she falls in the absence of air, and when she falls faster and faster through air. Students would have better understanding when these two situations are presented.

Lecture

Twenty minutes were set aside for this activity. The teaching concentrated mostly on the use of the equation for Newton's second law of motion, $a = \frac{F_{net}}{m}$, to solve quantitative problems.

89. **Teacher**: … It means we are talking about Newton's 2nd law. Let's look at something. You see, when forces are unbalanced there is an acceleration. The acceleration depends upon the net force. (Teacher goes to the board to explain). When we talk of unbalanced force, then it means the object is accelerating. Do you understand?
90. **Students**: Yes sir.
91. **Teacher**: So when an object is accelerating, then there is a formula that guides it and that formula is $a = F_{net}/m$. That is the net force over the mass. When you have an equation like this, … with the mass to be constant, then it means that … when the force is bigger, the acceleration will be bigger. When the force is smaller acceleration will be smaller. Also when the force applied is constant, then it means that when the mass is bigger, will the object accelerate faster?
92. **Students**: No sir.
93. **Teacher**: It can't accelerate faster, but when the mass is lighter, what happens to the acceleration? It can easily move very, very fast. So when the force is constant, then mass is inversely proportional to acceleration. But when the mass is constant, acceleration is directly proportional to…
94. **Seth**: Force.
95. **Teacher**: Force. So when the force is doubled, acceleration is doubled. When the force is tripled acceleration is tripled. Do you get it?
96. **Students**: Yes sir.
97. **Teacher**: This is inversely proportional, when the mass is doubled, acceleration is …
98. **Teacher and some students**: Is halved.
99. **Teacher**: Whatever it is it becomes an inverse of. When the mass is tripled, the acceleration becomes...
100. **Teacher & students**: one-third.

The method of teaching was a mixture of interactivity and a traditional lecture. The lecture did not contain real life phenomena which could be related to the CRQ, for students to reason to improve their initial answers to the CRQ during the reflection stage. The lecture could be improved by using real life examples relating to the CRQ.

Reflection

Ten minutes were used for this activity. Students in various groups were to use five minutes to revise their initial answers, if they wanted to do so and use another five minutes for plenary discussion.

In the plenary session the students still stuck to their original ideas.

101. **Teacher**: As she falls faster and faster through the air, her acceleration (i) increases, (ii) decreases (iii) remains the same (iv) becomes zero.
102. **Some students**: (i) increases.

Students could not deduce any meaningful experience from the lecture to improve their initial answers, because the lecture did not include examples that could relate to the CRQ.

For the activity of reflection to be utilized more by students, lecture and conceptual reasoning questions should be related, so that lecture content addresses the CRQ situation. Though students could not benefit from the lecture to improve their initial answers, the activity is useful and would be included in the next round data gathering.

Application question

Again ten minutes were used for this activity. Students were to use three minutes to solve the problem individually, another three minutes to compare their results with the person sitting next to him or her and the final four minutes to solve the problem on the board while the teacher moves round to look at students' solutions.

> Suppose that a sled is accelerating at a rate of 2 m/s^2. If the net force is tripled and the mass is halved, then what is the new acceleration of the sled?

One student could partially apply the equation of Newton's second law of motion to solve the question, but could not get to the final answer. He was guided by the teacher to get to the final answer.

103. **Teacher**: … Yes Bruce, Bruce, come and try.
104. **Bruce**: (He went and put his solution on the board). (The teacher came in to guide him to get to the final answer).

$$a_1 = \frac{F}{m} \ldots\ldots\ldots (1)$$

$$F = ma, \; 3F = \frac{1}{2}ma, \qquad a_2 = \frac{3F}{\frac{1}{2}m} = 6\frac{F}{m} \ldots\ldots\ldots (2)$$

$$6Fa = ma$$

$$a = \frac{6F}{m} \qquad \textit{comparing equations (1) and (2)}$$

$$a_2 = 6a, \; \textit{but } a_1 = 2(m/s^2)$$

$$a_2 = 6 \times 2 = 12(m/s^s)$$

The application question was related to the lecture content. Most of the students could not transfer their understanding of the equation to solve the problem as expected. However, one student could partially apply the knowledge gained to solve the question.

Though most students could not solve the application question, such questions need to be introduced to guide students to understand the relationships that exist among variables in the equation of Newton's second law of motion; acceleration, mass and net force. Similar questions that will improve students' conceptual understanding of relating the variables in the equation of Newton's second law will be used to help students to apply and transfer the knowledge they will acquire. Examples of such problems should be discussed during the lecture.

Conclusions

- The CRQ did not lead students to delve deep to reveal their prior knowledge on the subject to the instructor. However, it did create an awareness of the need for further learning. With the CRQ, it might help to present the problem as a comparison of objects falling in the (i) absence of air and (ii) in the presence of air, for students to get a clearer understanding. Once improved it could be used in the second round.
- Lecture and CRQ should be related in order to address the situation in the CRQ.
- During the reflection, students still stuck to their initial answers. This is because the lecture content did not relate to the CRQ. This activity is useful and it would be repeated in the second round. When the CRQ and lecture are related, it is likely students could revise their initial answers.
- Most students could not apply their understanding of the equation of the second law to solve the application question. Such types of questions will be used in the next round of data collection to help students apply and understand the relationship of the variables with each other, when one variable remains constant. Such examples should be included and discussed in the lecture, so that students could apply them in solving similar but new problems.

5.4.4 Newton's third law of motion

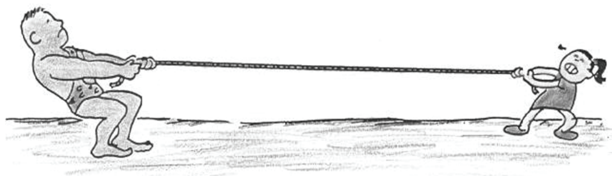
We started with Newton's third law of motion after students had a break of about 20 minutes. The aims of the various activities in the lesson about Newton's third law of motion were the same as those presented in that about Newton's first law of motion.

Conceptual Reasoning Question

Two questions were given to students to discuss in groups. The second question was selected from Hewitt's Next Time Questions (n. d.). Ten minutes was allotted for this activity: five minutes of group discussion and five minutes of plenary discussion. The questions were:

(1) While driving down the road, a fly strikes the windscreen of a bus and makes a quite obvious mess in front of the face of the driver. (i) This is a clear case of Newton's ………… law of motion. (ii) The fly hits the bus and the bus hits the fly. Which of the two forces is greater: the force on the fly or the force on the bus?

(2) Paul and Josephine pull on opposite ends of a rope in a tug of war. The greater force exerted on the rope is by (i) Paul (ii) Josephine (c) Both the same.



In discussing the first question, it was realized that some students have difficulty in identifying and understanding Newton's third law of motion from real life situation. There was disagreement as to which of the laws could be used to explain the motion (line 106), which could create the need for learning.

105. **Teacher**: … While driving down the road, a fly strikes the windshield of a bus and makes a quite obvious mess in front of the face of the driver. This is a clear case of Newton's.... law of motion?
106. **Students**: 3rd law, 2nd law.

After further explanation of the question, students were clear that it was the third law. However, they were not able to identify the action and the reaction (lines 112-117).

107. **Teacher**: … Is it 1st, 2nd or 3rd
108. **Students**: 3rd.
109. **Teacher**: Why 3rd?
110. **Students**: Action and reaction.
111. **Teacher**: So which is the action and which is the reaction.
112. **Regina**: The action is the hitting of the fly and the reaction is the mess that resulted from the reaction.
113. **Teacher**: … So which is the action and which is the reaction?
114. **Regina**: The hitting of the fly.
115. **Teacher**: …, and the reaction is...
116. **Regina**: The mess that resulted.
117. **Seth**: I think the reaction is the movement of the fly.

Though a majority of the students could depict that the forces involved in this situation were equal, some students had difficulty to conclude that the forces were equal in both cases. The need for further learning was created (lines 119-128). They thought that the body with the greater mass should exert the greater force. The need for further learning was not created in students. The fragment below illustrates this:

118. **Teacher**: … The fly hit the bus and the bus hit the fly. Which of the two forces is greater?
119. **Students**: The bus, sir they are equal, no they are not equal.
120. **Teacher**: Which of the two forces is greater? And he is asking the force on the fly or the force on the bus?
121. **Students**: The force by the bus. (Some also said) both forces are the same.
122. **Regina**: They are equal just that they have different directions.
123. **Teacher**: So which is which?
124. **Some** students: They are equal.
125. **Teacher**: Why are they equal?
126. **Some** students: They are not equal.
127. **Teacher**: Why are they not equal?
128. **Stephen**: If they are equal, then the bus will stop.

The teacher brought in question 2 for students to come out with their ideas. Again, some students thought that Paul, who has the larger mass, would exert the greater force on the rope (lines 132-135). This is shown in the fragment that follows:

129. **Students**: (Some said) the bigger, (others said) Paul and (others still said) both the same.
130. **Tony**: Paul.
131. **Teacher**: Why?
132. **Tony**: Because of his mass he can pull … Josephine.
133. […]
134. **Richmond**: Because of his mass he can pull.
135. **William**: Sir, I think it's the bigger one, because force is directly proportional to mass, so when the mass is larger the force will be greater.

Some students seemed to apply Newton's third law that action and reaction are opposite and equal. They considering the forces to be the same.

136. **Stephen**: Sir, I think, it will be the same, since Paul is pulling, is the same, the action he is taking to pull eh, Josephine will be the same...

Even though some students considered the forces between Paul and Josephine on the rope to be the same, their thought changed when Josephine was moved closer to Paul. Thus, if their forces are the same, why should there be a winner then:

137. **Regina**: I think it will be the same, the reason why, if the lady had been drawn by the man to his side, that is when I will say that the man...
138. **Tony**: The woman is about to fall.
139. **Regina**: Then the man's force on the rope is more than the woman.

The questions did evoke students' prior conceptions on Newton's third law as expected. Students did voice their ideas and conceptions about the first and second questions. Most students were dissatisfied with the answers given by their colleagues, as they tried to challenge their line of argument with regard to the first question (lines 106, 119-128). This would create the need for learning in students. With the second question, students were satisfied with the answer that if Josephine, who is smaller, is being pulled by Paul (the bigger), then Paul should exert more force on the rope than Josephine should exert (lines 132-135, 139).

Students were confused with the fact that the effects of hitting (the bus and the fly) and pulling (Paul and Josephine) were different as both relate to mass. This is a general conceptual difficulty, which is illustrated by the way students were discussing those situations. They got confused by the size difference, because they knew the effects would be different.

The first question did fit the students well, more than the second question, as it created the need for learning. Students had a clearer understanding of the situation in the first question. Only the first question will be used in the next round of data collection, due to its clarity and its creation for the need of students to learn.

Lecture and Reflection

About twenty minutes were used for the lecture and the reflection. The lecture was basically on Newton's third law. Conceptual reasoning questions were used as examples to discuss during the lecture. The fragments of the teaching are shown below.

The teacher used the conceptual reasoning questions as examples to explain Newton's third law of motion to students:

140. **Teacher**: … If you look at the first question, what we did, the fly and the bus, they all exert the same…
141. **Teacher and students**: Force.
142. **Teacher**: Because of action and reaction.
143. […]
144. **Teacher**: Action is a force. Reaction is also a force… Remember force is mass times acceleration. So maybe, the mass of this is bigger, … as the fly hits the car, the car will by all means go back. There is a push, but only that sometimes it is so small that you cannot see it. So because the car has a higher mass, its acceleration backwards will be very, very small. Sometimes you cannot even see it. No by all means, there is a push alright. But sometimes the mass is so big to such an extent that it's very difficult to see it moving backwards. As for a smaller mass, you can easily see, that was why, the

acceleration was so big for the fly in that direction. The reason that led to its splashing on the windshield. Do you understand what I am saying?

145. **Students**: Yes sir.

A student still has difficulty in comprehending the situation between Paul and Josephine. He seemed to think that it should be Newton's second law of motion. Probably they thought that with equal forces there should not be any movement. Once there was movement, then force would be directly proportional to acceleration, so Newton second law applies:

146. **William**: In fact, this Newton's 3rd law, I am somehow confused about the two, the big man and the small woman..
147. […]
148. **William**: Because acceleration is directly proportional to force.

From the teaching and reflection, most of the students agreed that the forces that they exerted on each would be the same in both cases, perhaps just to accept what the teacher said. But William was holding on to wrong epistemological commitments and reasoning, as he does not seem to be aware of the fact that the laws of physics are supposed to be generally valid. He might not have paid close attention to the teacher's explanation, or perhaps, was not convinced by the teacher's explanations. He did not utilize the opportunity to revise his initial idea.

The teacher should include more examples and questions on the application of real life situations for Newton's third law of motion in this activity for the next round. For example, the act of swimming, walking, paddling a canoe, and hammering a nail on the wall. This will help improve teacher-student interactions and help students to understand and revise their initial ideas at the reflection session during the second round of data collection.

Application Question

Students used less than ten minutes for this activity. They first discussed the questions in groups before the entire class discussion.

Identify Action and Reaction Force Pairs in the following

1. Baseball pushes glove backwards.

2. The ball pushes the stick rightwards.

Some students used the object to represent the action and the reaction. This is illustrated by the fragment below:

149. **Kingston**: Baseball is the action and the glove is the reaction.
150. **Teacher**: Which is the action?
151. **George**: The action is coming from the gloves and baseball will also give an equal and opposite reaction.
152. **Teacher**: The action is the force of the baseball on the glove backwards; the baseball will hit the glove and the glove will also react, push it forward. Okay what about this?

Some students had difficulty in identifying the action and the reaction in the 2nd question:

153. **Teacher**: … So which is the action and which is the reaction?
154. **Victor**: The one who throws is the action, and you hit it is the reaction.
155. **Some students**: The one throwing is the action, and you hitting is the reaction.
156. **Teacher**: No, the force of the ball hitting the stick rightwards is the action and the force of the stick on the ball leftwards is the reaction.

Most students could not properly identify the action-reaction force pairs in the application questions. They assumed the action and reaction to be the materials involved or the activities produced by these materials or the people involved, and these called for the teacher to guide them with the correct way of identifying the action-reaction force pairs.

Though the questions in this activity were good, students failed to identify the action-reaction force pairs. This is due to the fact that there were no such examples during the lecture. Such examples on action-reaction force pairs should be included in the lecture to help students' identification of such problems in the application questions, for the next round of data collection.

Conclusions

- The CRQ did reveal students' prior knowledge on how they look at the forces that are exerted on each other when the two bodies collide and in a tug-of-war to the instructor. Though students were satisfied with their answer in the tug-of-war question between Paul and Josephine, they were dissatisfied with their answers on the one who exerted the bigger force in the collision between the bus and the firefly, and this created the awareness of the need to learn. Only the first question will be used again, because it was clear, less ambiguous and created room for learning.
- Lecturing was mainly traditional, except in a few cases where students came in. More examples and questions on the application of Newton's third law of motion and

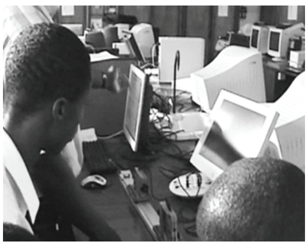
identification of action-reaction force pairs should be included to improve the lecture in the next round of data collection.

- During reflection, most students revised their initial ideas, though there was one student who still stuck to his preconceived idea. This activity will be repeated for students to revise their initial ideas.
- Most students could not properly identify action-reaction force pairs. They were using wrong expressions to describe them. When more daily life examples on action-reaction force pairs were discussed in the lecture, students could correctly identify the force pairs in the application questions. The same questions will be repeated with some additional ones for the next round of data collection.

From students' incorrect answers, especially those relating to the collision between the bus (bigger object) and the fly (smaller object), it was realized that a demonstration to verify Newton's third law of motion using force sensors and the Coach 6 tool would be relevant to improve students' understanding of the law.

Demonstration of Newton's third law of motion using MBL

The teacher demonstrated the verification of Newton's third law to students using force sensors and the Coach tool (the use of microcomputer based laboratory, MBL, tools). Force-time graphs of the collision between two force sensors put on two carts and connected to the computer through the Coach tool were plotted on the computer screen. Some pictures and fragments of the demonstration are shown below:




Students telling their views with respect to the shape of the force-time graphs plotted on the computer. Students were able to identify that the same shapes of graphs signify equal forces.

157. **Teacher**: …I have the same masses …, you see how the shape of the graph is. So what can you say about the shape of the graph? What does it tell you?
158. […]
159. **Students**: The same, the same force.
160. **Teacher**: The same shapes. So having the same shapes, which also mean the same force, what can you relate it to? Which of the Newton's laws are we talking about?

161. **Students**: Newton's 3rd law.
162. **Teacher**: What can you say in in terms of forces; are they exerting the same or not?
163. **Victor**: Since the shapes are the same, it means they are exerting the same force.
164. […]
165. **Regina**: Yes, the same force.
166. **Students**: Yes sir.

Students wanted to find out whether the same graphs would be plotted if the collision between carts involved two different masses. The fragment below illustrates that:

167. **Bruce**: Irrespective of their masses will the graph look alike?
168. **Teacher**: We are now coming to see, so the first one that we did, you saw that they were of the same mass. Let's try to increase the mass of this by adding something to it. (*The teacher added another object to one of the force sensors to make it heavier and collided it with the lighter cart*). Now we have seen that the two are not of the same mass…. So what do you see from the graphs.
169. **Some students**: The same force.
170. **Teacher**: Is it the same?
171. **Students**: Yes.
172. **Students**: (*They tried to practice on their own*).

Students were able to read from the graph that forces on both objects were the same, irrespective of the masses involved. Students were able to compare the force-time graphs on the computer to deduce that each object exerted equal force on the other. At the end of the demonstration clear conclusions were deduced that, irrespective of their masses, when two objects collide, they exert equal forces on each other. However, the effect of forces on the objects (bus and fly), which earlier triggered ideas about unequal forces after their collision was not addressed.

The demonstration will be repeated in the next round of data collection, due to its positive effect on students' understanding of Newton's third law that unequal and equal masses exert the same force on each other when they collide.

Conclusions

All students could recognize that when one object exerts a force on another, the second object exerts the same force on the first; a force equal in magnitude but in the opposite direction, especially when different masses are involved. The demonstration will be repeated for students to appreciate and understand the real meaning of the third law of Newton. The effect of the forces on objects would also be discussed further with students so that their initial ideas about unequal forces would be addressed.

5.4.5 Some tutorial questions

There were tutorial sessions every week, three days after the completion of each lesson. These sessions usually lasted for two hours. Students were given about twenty questions (mostly qualitative and related to real life situations) on the topics treated during each meeting, a week before the tutorial session, to discuss with their friends or in groups, and share ideas. Beside working on about ten selected questions to present as an assignment which was part of their continuous assessment, the teacher and students were meeting during the tutorial session to discuss all the questions. Most tutorial questions from Hewitt (2001) and The Physics Classroom (n. d.) were used due to their interactivity evoking nature. Students usually came in prepared.

As students were supposed to have discussed and solved all the problems before attending the session, the teacher was successively calling on students to provide solutions to questions, either verbally or by presenting their solutions on the board. Students were required to give explanations when asked. The teacher could provide hints or help, when students found things to be difficult.

Though a lot of questions were dealt with, only six have been used in the analysis. These were selected based on the way the students reasoned, how the interactive aspect went and what should be learnt from it, and to also identify students' learning difficulties.

Fragments of teacher-student interactions during the tutorial phase for the selected questions are shown as follows:

The aim of Q1 was to lead students to know that inertia depends on mass alone, not on speed.

Q1. Victor and Theresa are arguing in the cafeteria. Victor says that if he flings a dish with a greater speed it will have a greater inertia. Theresa argues that inertia does not depend upon speed, but rather upon mass. Who do you agree with? Explain why.

A student was able to say that inertia basically depends on mass, and bringing in speed would shift from inertia to momentum (line 180):

173. **Teacher**: Explain. I mean why do you disagree with Victor?
174. [...]
175. **Grace**: Sir, because inertia doesn't depend on the speed.
176. **Teacher**: It depends on what?
177. **Grace**: It depends on the mass of the body.
178. **Teacher**: And what was Victor talking about?
179. **Grace**: Victor was talking about momentum.

180. **Tony**: Victor was talking about distance/time, thus the speed. And inertia depends on mass. So you can't just use speed to relate inertia. So in that sense we support Theresa, because she was rather trying to point to Victor that if you want to have something in relation to inertia, then you have to use the mass but not speed.

Students were able to point out that inertia depends on mass, but not speed (lines 175-177 and 180).

In question 2, we wanted to find from students whether they could apply Newton's first law in space, to find out whether students see Newton's first law applying everywhere:

Q2. Supposing you were in space in a **weightless environment**, would it require a force to set a stationary object in motion?

The student who agreed that it would require a force to set an object in motion could also not relate the answer to mass and inertia quite as well as expected:

181. **Philip**: Here they are talking of weightlessness. When we talk of weightlessness it means there is no net force on the object apart from the object's weight. And now they are saying the object is in weightless environment, so it means it is already in motion, and it needs no force to set it into motion again.
182. […]
183. **Tony**: For a stationary object to be in motion it requires a force. So I think that irrespective of the environment it will require a force to be in motion… Sir for an object to be in motion, it requires a force to accelerate the object.

Philip was not applying Newton's first law to a weightless environment. He seemed to have a different interpretation of a weightless environment (line 181). Tony, on the other hand, seemed to apply Newton's first law to space, but did not link his explanation to inertia and mass of the object (line183), that once the object has mass it would have inertia (ability to resist motion), hence it will require a force to set a stationary object in motion.

The aim of question 3 was to give students the opportunity to relate mass to inertia:

Q3. Fred spends most Sunday afternoons at rest on the sofa, watching football matches and consuming large quantities of food. What effect (if any) does this practice have upon his inertia? Explain.

Students did well in relating the explanation of this practical situation to inertia:

184. **Patrick**: The inertia will increase. Because of the increase in mass. The inertia depends on the mass, if the mass is increased then inertia will also increase.

185. **Teacher**: What is mass?
186. **Patrick**: The quantity of matter contained in a body.
187. **Teacher**: So as he eats, he continues …
188. **Students**: To add more matter to his body.
189. **Teacher**: So what will happen to him? Yes Tony.
190. **Tony**: He will feel more reluctant to move.
191. […]
192. **Kingston**: The tendency for him to still lie in the chair is greater.

Patrick could relate mass to inertia (line 184) as expected, and could predict the effect of consuming large quantities of food while resting on the sofa (lines 190 and 192).

The aim of question 4 was to make students predict that when the forces acting on an object are balanced, the object will not move or it will move with a constant velocity. Usually, students think that in such a situation, the object could only remain stationary.

Q4. If the forces acting upon an object are balanced, then the object could: (a) not be moving. (b) be moving with a constant velocity. (c) not be accelerating. (d) none of these. (*Choose those that could be possible*).

Students could predict what would happen to an object when forces acting on an object are balanced:

193. **Regina**: Sir, a and b.
194. **Other students**: a, b, c.
195. **All students**: Yes it is a, b, c.

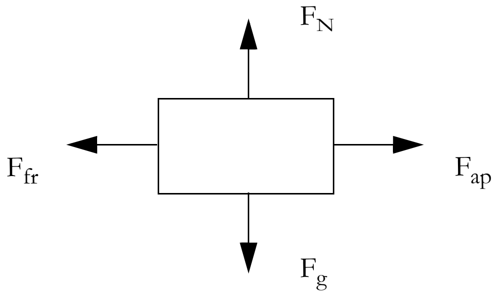
Students could predict correctly that the object would not be moving, be moving with a constant velocity and not be accelerating (193-195). The teacher could have asked further questions by allowing the students to give examples for their choice of answer to make sure they fully understood what they had chosen.

The aim of question 5 was to find how far students could use their understanding of Newton's second law of motion to solve quantitative problem. It is expected that once students understood the law conceptually, they could use the knowledge to solve quantitative problem.

Q5. Anthony applies a 4.25-N rightward force to a 0.765-kg book to accelerate it across a table top. The coefficient of friction between the book and the tabletop is 0.410. Determine the acceleration of the book. (Take g=10 m/s^2).
(*Tony went to solve question correctly after two students have failed to solved the questions correctly*)

The question was a bit difficult for most students. Most students were using direct application of values into the equation, $a=F_{net}/m$. However, one student was able to solve the question correctly:

196. **Tony**: (He drew the diagram correctly before he solved the question)



$\mu = 0.410,\quad F_{applied} = 4.250\text{ N},\quad m=0,765\text{ kg}$

$$F_{friction} = \mu \times F_{norm} = \mu \times m \times g$$

$$F_{friction} = 0.410 \times 0.765 \times 10 = 3.1365\text{ N}$$

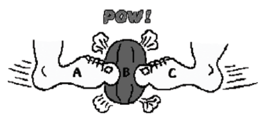
$$\text{But,}\ F_{net} = F_{applied} - F_{friction} = ma$$

$$a = \frac{F_{applied} - F_{friction}}{m} = \frac{4.25\text{ N} - 3.1365.\text{N}}{0.765\text{ kg}} = 1.456\text{ m/s}^2$$

Most students could not solve the quantitative problem as expected. However, Tony could use the correct approach to arrive at the correct answer (line 196). To improve students' understanding on how to solve such quantitative problems, it would be more appropriate to include such problems in the lecture to discuss with students.

The aim of question 6 was to find how students could identify action-reaction force pairs in an interaction.

Q6. Consider the interaction depicted below between foot A, ball B, and foot C. The three objects interact simultaneously (at the same time). Identify the two pairs of action-reaction forces. Use the notation "foot A", "foot C", and "ball B" in your statements.



Students were able to identify the action-reaction force pairs:

197. **Regina**: AB and BC
198. **Teacher**: Look at it and explain it well.
199. **Kingston**: The force exerted by foot A on ball B to the right is the action and the force exerted by ball B on foot A leftwards is the reaction. The second pair is, the force exerted by foot C on ball B leftwards is the action and the force exerted by ball B on foot C rightwards is the reaction.
200. **Teacher**: Do you agree?
201. **Students**: Yes sir.
202. **Philip**: It can also be the other way round....

Students seemed to have better understanding in identifying the action-reaction force pairs than when they were made to identify similar questions in the application question of Newton's third law of motion (197, 199 & 202).

Conclusions

From students' responses to tutorial questions, it could be realized that they came prepared. Thus, students might have had group discussions and shared ideas with their friends before coming to the session. However, there were some few questions that students could not answer. Perhaps these were too difficult or not understandable to them. Such questions will be revised to suit students' ability and used again. A few other relevant questions will also be added.

5.5 Overall conclusion

Basing on the FCI-gain scores (which have become more or less a standard criterion for good mechanics teaching), it turned out that the learning gains for our course were typical of an average interactive engagement course, and well above the gains for a typical traditional lecture class. Moreover, students' opinions about the course were quite favourable. However, many shortcomings were identified in the in-depth analysis of the classroom process. These findings suggest that there is room to improve the course, and to transform it into a high gain course. Here, we present conclusions and implications for the various activities used in the design.

- Though the design of the concept quiz was successful in making students read before they came to the lesson, students found it difficult and confusing to answer questions which did not fit well with the reading assignment. In order to achieve their full potential, the concept quiz questions should be revised so that they can be answered correctly by all students who did their reading assignment.
- The design of the conceptual reasoning question (CRQ) was successful in bringing out students' prior knowledge on concepts. Also, the intention of the design to

engage students in sharing their views through discussion, arguments, and reasoning were achieved. However, some CRQs did not trigger a need for further learning, because the students agreed about their (incorrect) answers. Also, some of the questions were worded too unclearly, leading to a loss of time and unproductive confusion about the question's intent. The implication is that the conceptual reasoning questions will be revised to trigger different viewpoints, so that the need for further learning will become evident.

- The main body of teaching consisted of a traditional lecture. As it turned out in the reflection activity after the lecture, this approach was not effective to make the students revise their initial ideas. The implication for the design is that there should be coherence among lecture, CRQ and reflection. This can improve students' understanding of concepts which could make them change their initial wrong conceptions. There should be interactive teaching rather than a lecture to signal to the teacher how students are understanding concepts.
- A demonstration using MBL tools let students see Newton's third law in a real situation and convinced them, though no reflection on the reasons for their initial answers was made. The implication is that though students are convinced when they see real situations happening, especially with the use of MBL tools or practice through multiple contexts, the reasoning behind students' initial answers should be addressed to improve their understanding.

In the next chapter, we will describe how these implications were used to develop a revised design, and we will investigate its effectiveness.

Chapter 6

Second round of evaluation

6.1 Introduction

In this chapter, we will evaluate the results of the second field test. In this test we have included a number of improvements, based on the results of the analysis of the first round data. We will group this chapter into four main parts: research method, overall learning results, in-depth analysis of Newton's laws of motion and conclusions of the second round of teaching.

We will start with the research setting, and the modifications that have been made in the second design. Next, overall learning results will be analysed and compared with the learning results of the first round. Feedback during the lecture series from the critical friend and the perceptions of the students through the use of interviews will be used to identify strengths and weaknesses of the teaching process. After these global analyses, we will examine selected episodes of classroom proceedings to see how the outcome corresponds with the expectations we have about the teaching and learning process.

6.2 Research method

6.2.1 Participants

The participants in the study were all first year University of Education, Winneba (UEW) students who took the mechanics course in the first semester of the 2010/2011 academic year. Twenty students were involved, all males. They had all read physics in senior high school (SHS). The average age of the students was 24 years (std. dev.= 5.7, variance= 32.1). The average age is fairly high, due to the fact that few students go to university directly from senior high school, while the majority either has to do remedial classes to get a qualifying grade for university or go to a college of education for three years to become professional teachers, teach for a minimum of three years before qualifying for study leave with salary to further their education at university. Students' senior high school certificate examination (SSCE's) grades in physics were between B2 (very good) and C6 (credit). Students' grades were similar to those of their counterparts in the previous year. Seven of the students had grades from B2 to B3 and thirteen from C4 to C6.

6.2.2 Instruments

Learning results were determined by test (FCI, TUG-K, MBT, end of semester examination), quiz, assignment and project. Students' perceptions were revealed by the use of questionnaire and interview, and classroom processes were gathered by audio and video recordings. All the instruments were used in the same way as in the first round, with the exception of the questionnaire and interview. The new elements in the questionnaire and the style of conducting the interview in the second round were intended to get more insight into improvements in students' attitudes towards physics teaching, their learning environment and the lecture series.

Questionnaire: Apart from questionnaire items on concept quizzes, conceptual reasoning questions, interactive teaching, application questions and problem-solving, which were used in the first round of teaching, new items on the attitude of the students towards physics teaching (interesting physics classes and interested in physics), students' cohesiveness (working well with other students, helping other students, and friendly to other students), instructor's support (having personal interest in students, considering students' feelings and problems) and students' cooperation (sharing of books and resources with other students, team work during group activities, assignment and discussion) were added. These were added with the expectation that the new design of the activities could improve students' attitudes to physics teaching and learning environments. Questionnaire items are shown in appendix 2.

Interview: Students were interviewed by a different person six months after the end of the introductory mechanics course, in the absence of the teacher/researcher. This was to allow the students to express their views on the interactive engagement approach used, and also to find out whether students could remember the effect of the interactive engagement approach. The interview guideline is shown in appendix 3.

6.2.3 Modifications in the second design

Based on the first round, recommendations were implemented in the second design:

- The choice of the concept quiz questions was based on the concepts/topics to be treated on a particular day, spread over the concepts/topics in the various blocks. Usually, three or four questions were given to students depending on the number of blocks in the lesson. Care was taken that all the questions would fall within the students' reading assignment. Since the concept quizzes were just intended to check the students' homework, extensive discussions about the answers were now to be avoided.
- One question which could reveal students' prior conceptions was used during each conceptual reasoning question (CRQ) activity (sometimes with sub-questions where necessary). Time was taken to let the students voice their opinions, but the discussion could be terminated before consensus on the proper answer was reached. (Because that would be the focus of the interactive teaching and the reflection after that.)
- Interactive teaching was used to replace the frontal lecture during the teaching session. The teaching was interspersed with planned short, predictive, classificatory and open-domain questions for students to answer. Though students were encouraged to ask questions, the teacher usually made the judgement which

questions would be answered either immediately or later. This was used as a precautionary measure to work within the available time.

- Some questions were discussed straight away instead of in the group discussion during some reflection activities.
- One similar but new question was used as application question (sometimes with sub-questions where necessary).
- The name "Problem-solving session" was used instead of "Tutorial" due to what actually went on during the session. Basically, problems were solved by students during the session, hence the new name.

6.2.4 Research setting

The research was carried out in the Department of Science Education, University of Education, Winneba (UEW). English was the medium of instruction. The lecture room was equipped with computers and a whiteboard. The room was furnished with laboratory benches and stools. The fixed nature of the benches made group discussions more difficult to arrange, but students managed when there was the need to do so.

There was a camera assistant in the classroom who helped in videoing classroom proceedings. Since there was limited staff capacity in the physics unit of the department and the research was specifically about the researcher's own field of teaching, and for fair comparison between the first and second round evaluations, the researcher was again the teacher of the course. Copies of PowerPoint presentation were given to the students after each lesson.

Questionnaire and set-up

The first part of the questionnaire (I), appendix 2, concerned students' personal information on age and birthdate, the last four digits of their mobile phone number, sex, SHS attended and their grade in physics. These were used to trace the pre- and post-questionnaire response sheets of students. So that students could be sure of not being victimized for their answers, they did not have to include their names and index numbers on the sheets. This section was answered by students in both the 2009/2010 and 2010/2011 academic year groups.

The second part (II) sought students' opinions about the types of activities, concept quiz, conceptual reasoning question, interactive teaching, reflection, application question and problem solving used in the lessons. Thus, for each activity, there were four items that students had to answer. The first question was different for each activity and dealt with the specific benefit that students derived from that particular activity. The other three questions were the same for all activities. Students in the 2009/2010 and 2010/2011 academic year responded to this part of the questionnaire, and comparisons of average values on the activities were made for the two year groups. This questionnaire was not a standard instrument but designed for this study. The reliability of the instrument in the Ghanaian context is reported in Table 6.8.

The third part of the questionnaire (III) contained items on students' attitudes towards physics and the learning environment. This part was only answered by students in the 2010/2011 academic year group. It sought to find out students' attitudes towards physics teaching, their cohesiveness, the instructor's support, and how students cooperated with one another. In each scale, there were eight items to which students had to respond. For this assessment, the relevant items were taken from Martin-Dunlop and Fraser's questionnaire items on science learning environment and attitude (Martin-Dunlop & Fraser, 2007). The Cronbach alpha reliability for the original learning environment and attitude questionnaires ranged from 0.67 to 0.98. In determining the reliability of the instrument for this study in the Ghanaian context, it turned out that the Cronbach alpha reliability was in the range between 0.71 and 0.91. The items are shown under "Items in Attitude & Learning Environment (Pre and Post), part (III)" of appendix 2. Table 6.9 reports on the Cronbach's alpha reliability for the instrument.

Students in the 2010/2011 year group answered the questionnaire items in part (III) as *pre*, before the beginning of the lessons. They were to reflect and consider situations when they were students at the senior high school. A notice was placed on the students' board, inviting all students who had registered for Phy 111, Introductory Mechanics, to meet the teacher concerned in P2, at 8:30 am. This happened a week before the beginning of lessons. Sixteen of the students attended, and answered the questionnaire on attitudes towards physics teaching and learning environment, after an explanation of the questionnaire. They spent twenty minutes on answering the questionnaire. Four students who could not take part did theirs at a later date before the course started. They were all supervised by the teacher/researcher.

Again, students were made to answer part (I), (II) and (III) of the questionnaire after the last meeting with the teacher. Students now had to answer the items on what occurred at the university in the introductory mechanics class. Students had been informed about this exercise in the previous week before the completion of the lessons. All twenty students took part. It took place at the same room where the teacher and students had the meeting (P2), and was supervised by the teacher. They used 35 minutes to complete the questionnaire.

Interview set-up

Students of the 2010/2011 group were interviewed after the end of all the lessons by a different lecturer. It was done about six months after the end of the lessons in the absence of the researcher. This long period was chosen to see whether students could still remember the interactive engagement (IE) approaches and its effect on them. The interviewer put up a notice inviting all students who took part in the introductory mechanics course in the first semester. The interviewer grouped all students involved together and asked questions for them to answer. According to the interviewer, it was a face-to-face discussion between herself and the twenty students and happened in a relaxed and friendly manner where students could express whatever they felt. The interviewer explored students' views as regards two major issues: (1) the strengths of the interactive engagement approaches used and (2) the barriers to applying interactive engagement approaches in teaching and learning of mechanics (physics). The interview guideline is shown in appendix 3. In certain areas where students found it difficult to understand the questions, the interviewer had the opportunity to explain further. Also, when students' responses were not clear to her, she questioned further to know why they held such opinions. An audio device was used to record the interview session. The session lasted about 75 minutes.

6.2.5 Critical friend

A colleague teacher attended all lessons and problem solving sessions to play a role of a "critical friend". A critical friend is defined in this study as a trusted colleague lecturer, who sits in all the lessons and asks provocative questions, provides data to be examined, and offers critiques of a person's teaching as a friend after each lesson through a format that has been given to her (appendix 4). She takes the time to fully understand the context of the work presented and the outcomes that person is working toward. The friend counterbalances the situation that the researcher acts as a teacher and contributes during the course to the success of the work by the teacher/researcher.

The critical friend in this situation is a lecturer in the Department of Chemistry Education, University of Education, Winneba. She has taught Chemistry for almost twenty years, at both secondary and university level. Currently, she is working on a science education project and is writing a PhD thesis herself. She has studied the science education literature, for instance during her visits to Utrecht University and Free University of Amsterdam.

6.3 Overall learning results, input from the critical friend and students' perceptions

In this section, we will look at students' overall learning results in pre- and post-FCI and TUG-K, MBT, concept quizzes, assignments, projects and end of semester examination scores. These learning results will be compared with the results of the 2009/2010 academic year group. Thematic clustering of FCI, MBT and end of semester examination to identify students' strong and weak areas will be formed into themes, input from the critical friend and students' perceptions from questionnaire and interview will also be clustered into themes. Conclusions will be given on the input from the critical friend and on students' perceptions on the use of the interactive engagement approach in teaching.

6.3.1 Overall learning results in pre- and post-FCI and TUG-K, Hake gain and MBT

Table 6.1: Mean proportion correct scores of pre- and post-FCI and TUG-K, Hake gains and MBT

	2009/2010				2010/2011			
Test	**N**	**Pre (SD)**	**Post (SD)**	**Hake gain (SD)**	**N**	**Pre (SD)**	**Post (SD)**	**Hake gain (SD)**
FCI	17	0.17(0.09)	0.59(0.00)	0.51(0.11)	20	0.31 (0.10)	0.66(0.08)	0.51(0.15)
TUG-K	17	0.27(0.05)	0.69(0.07)	0.58(0.09)	20	0.27(0.06)	0.71(0.07)	0.60(0.10)
MBT	17	-	0.48 (0.08)	-	20	-	0.52(0.11)	-

Students' scores in pre- and post-FCI and TUG-K, Hake gain and MBT (2009/2010 & 2010/2011), were converted into mean proportion correct scores and are presented in Table 6.1. Comparisons of results from 2009/2010 and 2010/2011 were made.

The final FCI score was higher in the 2010/2011 experiment, but the gain scores were similar. This could be attributed to the higher pre-scores. The gain scores were still similar to the scores of some university students in United States of America (Hestenes, Wells & Swackhamer, 1992).

Similarly, the TUG-K gain scores for both year groups were almost the same. Their initial and final scores were also similar. The mean proportion scores of post-TUG-K in both year groups were about 0.30 higher when compared with the mean proportion score of students that Beichner used with his TUG-K instrument after instruction in kinematics (Beichner, 1994).

Hake developed his score for FCI but not for TUG-K; and we extended his way of calculation to TUG-K gain scores along the same line. The average normalized gain used by Hake is, . The gains for TUG-K and FCI fell within Hake's "medium-g" value, ( ); which is a typical range for average effectiveness of courses in promoting conceptual understanding (Hake, 1998).

In comparison to the data set on the same university students in USA, the mean proportion correct score of MBT of the 2010/2011 academic year group was about 0.10 less (Hestenes, Wells & Swackhamer, 1992).

6.3.2 Concept quizzes

Different concept quiz questions were set for the 2009/2010 and 2010/2011 academic years. The difference in questions came as a result of setting the questions of the 2010/2011 year group to cover all the blocks within a particular lesson and also within students' reading assignment. This was not done in 2009/2010. Also, ambiguous questions were replaced with unequivocal questions, which were based on the reading assignments.

Table 6.2: Mean proportion correct scores of concept quiz

Year gp.	No	Q1 (SD)	Q2 (SD)	Q3 (SD)	Q4 (SD)	Q5 (SD)	Q6 (SD)	Q7 (SD)	Q8 (SD)	Q9 (SD)	Q10 (SD)
2009/10	17	0.64 (0.14)	0.49 (0.15)	0.63 (0.17)	0.61 (0.12)	0.76 (0.36)	0.48 (0.12)	0.66 (0.26)	0.42 (0.28)	0.83 (0.16)	0.25 (0.15)
2010/11	20	0.67 (0.27)	0.69 (0.16)	0.74 (0.15)	0.72 (0.18)	0.73 (0.18)	0.72 (0.15)	0.77 (0.13)	0.78 (0.12)	0.77 (0.11)	-

2009/2010 students had low outcomes in concept quizzes in weeks 2, 6, 8 and 10 and these have been improved in the second round (2010/2011), as there were no such dramatic drops. There was no meeting in week 10. There was a delay in the teaching due to strike action by the teaching staff, and some content was sacrificed in week 10 at the end.

6.3.3 Assignments

Table 6.3: Mean proportion of correct assignment scores (2009/2010 & 2010/2011)

Year Gp	No	A1 (SD)	A2 (SD)	A3 (SD)	A4 (SD)	A5 (SD)	A6 (SD)	A7 (SD)	A8 (SD)	A9 (SD)	A10 (SD)
2009/10	17	0.68 (0.10)	0.61 (0.11)	0.73 (0.09)	0.69 (0.09)	0.77 (0.08)	0.77 (0.08)	0.76 (0.09)	0.78 (0.07)	0.82 (0.04)	0.84 (0.04)
2010/11	20	0.65 (0.11)	0.66 (0.10)	0.66 (0.10)	0.73 (0.09)	0.75 (0.09)	0.76 (0.10)	0.85 (0.04)	0.84 (0.05)	0.86 (0.04)	-

With the mean proportion correct assignment scores, both year groups showed some consistency in their results. Their mean proportion scores increased as the weeks progressed.

6.3.4 Projects

Table 6.4: Mean proportion of project scores (2009/2010 & 2010/2011)

Year Group	No	P1(SD)	P2(SD)	P3(SD)
2009/10	17	0.73(0.06)	0.78(0.03)	0.75(0.04)
2010/11	20	0.74(0.02)	0.77(0.06)	-

The 2009/2010 year group did three projects, while the 2010/2011 year group had two due to the reason mentioned earlier (the strike action). The two projects they did were similar to those of 2009/2010. There was no significant difference between their scores.

6.3.5 Comparing examination results

Table 6.5: Mean proportion scores of examination results (end of semester & continuous assessment

Year gp.	Concept quiz 0.20	Assign. 0.10	Project 0.10	CA 0.40	End of sem. exam 0.60	Qualitative section of end of sem. exam 0.42	Quantitative section of end of sem. exam 0.18	Exam results (CA + end of sem.) 1.00
2002/03 to 2008/09	-	-	-	0.22	0.33	-	-	0.55
2009/10	0.12	0.08	0.08	0.28	0.35	0.25	0.10	0.63
2010/11	0.15	0.09	0.08	0.32	0.37	0.26	0.11	0.69

Mean proportion scores of examination results (end of semester and continuous assessment) from 2002 to 2009 were calculated and compared with the mean proportion scores for 2009/2010 and 2010/2011. The scores are presented in Table 6.5. The method of teaching from 2002 to 2009 was traditional lectures, whereas the interactive engagement approach was used in 2009/2010 and 2010/2011.

From the table, there was no significant difference in the mean proportion scores of end of semester examinations. However, the statistical difference shown in the examination results for 2002/2003 to 2008/2009 and that of the 2009/2010 and 2010/2011 was due to students' performance in continuous assessment (concept quiz, assignment & project). Thus students' continuous assessment results in the 2009/2010 and 2010/2011 year groups were relatively higher than the average continuous assessment score of their counterparts from 2002/2003 to 2008/2009.

The results shown in the table could indicate that the interactive engagement approach and the type of questions used in the continuous assessment and end of semester examinations in 2009/2010 and 2010/2011 were not detrimental to the students, though it is difficult to determine whether they had really learned more than their predecessors as the end of semester examination questions were different. To compare between the 2009/2010 and 2010/2011 year groups questions were grouped into qualitative and quantitative sections (70% qualitative and 30% quantitative). The mean proportion scores for qualitative and quantitative sections for both year groups as presented in the table show no meaningful differences.

6.3.6 Strong and weak areas by topic (thematic clustering)

In order to identify strong and weak areas by topic, we grouped the average results on identical or similar questions in FCI, MBT and end of semester exams under topics such as kinematics, Newton's first, second and third laws of motion, impulse and momentum, work-energy relationship, superposition principle and kinds of force (Hestenes & Wells, 1992; Hestenes, Wells & Swackhamer, 1992).

Table 6.6: Thematic clustering of FCI, MBT and end of semester examination (exam) for 2010/2011

Themes	Pre FCI	Post FCI	MBT	Exam
A. Kinematics	0.13	0.53	0.71	0.79
B. Newton's First Law	0.33	0.71	1.00	0.63
C. Newton's Second Law	0.17	0.36	0.56	0.32
D. Newton's Third Law	0.44	1.00	0.67	0.59
E. Superposition principle	0.13	0.60	0.69	-
F. Kinds of force	0.29	0.63	0.75	-
G. Curvilinear motion	-	-	0.51	-
H. Work-energy	-	-	0.67	0.73
I. Impulse-momentum	-	-	0.62	0.43
J. Vectors and relative velocity	-	-	-	0.77
K. Projectile motion	-	-	-	0.70
I. Circular motion	-	-	-	0.98

From Table 6.6 it may be concluded that students did well on Newton's first and third laws of motion in post FCI, MBT and exam. However, a weak score was recorded in Newton's second law of motion.

We will focus on students' strongest and weakest areas as identified in our qualitative in-depth analysis: Newton's first and third laws of motion, and Newton's second law of motion respectively. These areas were also selected for qualitative in-depth analysis in the first round.

6.3.7 Clustering of comments from the critical friend

The critical friend and researcher/teacher sat down and discussed comments that have been jotted down by the critical friend after every lesson. These comments have been clustered into themes and are presented in Table 6.7.

Table 6.7: Clustering of critical friend's comments into themes

Themes	Comments from the critical friend
Interactive teaching	Students' participation was encouraged in both small groups and whole class discussions.
	Students were engaged in group discussions. Individuals from various groups did a lot of exercises on the board.
	Students were aware that any of them could be called to answer and explain any of the assigned questions. Thus, they prepared adequately. The teacher stuck to this laid down principle. It made the class highly interactive and students exhibited a gain in conceptual knowledge through the answers they provided.
Students expressing their own ideas	Students felt highly motivated through their own correct responses and the teacher's acknowledgement of them.
	Students felt highly motivated by their own correct solutions and so were all eager to demonstrate their understanding on the board.
	The majority of the students participated throughout the lesson.
	Students were able to identify weaknesses and strengths in presentations.
Pedagogical skills	The teacher employed the use of animations, analogies, everyday life experiences and examples.
	The teacher used Coach and applets in his lessons to explain graph transformations.
	The teacher's friendly character.
	The teacher tutored students on presentation skills; (1) writing boldly (2) speaking to the class and not to the poster only.
	Bloom's order of questioning was put into practice in each block; lower order questions were asked followed by higher order ones in each block.
Classroom management	Good class management. The teacher managed classroom routines effectively.
	The teacher knew each student by name. Positive teacher-student relationship maintained.
	The teacher continuously encouraged students to adopt a more positive attitude towards their studies.
	The teacher visited various groups and helped them out with their individual problems.
	Highly intellectual students were appreciated but were not allowed to monopolize the whole class discussions. Individual differences among students were appreciated by the teacher.

Table 6.7: Clustering of critical friend's comments into themes

Evaluation	Immediate and constructive feedback.
	Most aims assigned to the activities were achieved.
	Students with misconceptions were identified by the teacher and given extra attention. They were often called upon to answer conceptual reasoning questions.
Unfavourable practices	Working beyond the stipulated time on some activities.
	Don't reprimand students too sternly if they fail to do assignments. Find ways of encouraging them to do assigned exercises.
	Prompts should not have been given to students during the quiz. They should be allowed to bring out their prior conceptions, so that you will know how best to help them out with their deficiencies.
	Students were reprimanded over a period of time but that was not necessary. Try to be diplomatic in such instances.
	The group that had the wrong outcome should have been asked to explain their line of reasoning first. Listening to the other correct outcomes explained after theirs would have helped with the restructuring of their wrong conceptions.
	Students should discontinue ridiculing each other sometimes.

Most comments were indicative of successful outcomes, for example, students were made to interact with their peers and the teacher, and did not function only as receivers but also contributed to the lessons by strongly expressing what was on their mind. There were other areas where the researcher had to improve, for instance, working within the time allotted for each activity and answering all students' questions.

Influence of the critical friend's comments on teaching

The written down comments by the critical friend did influence the teacher in several ways:

- He was motivated to continue with the use of the activities in the lessons and was encouraged to involve the students in discussions (both small groups and whole class) on problem solving; he continuously kept on asking questions relevant to the topic being treated. For students not to be seen as only the central repository of what the teacher says, as is normally observed in the traditional lecture method, the teacher was calling any student within a group to summarize their group's findings during the whole class discussion and continued to ask follow up questions to check students' understanding of what they had discussed. This also encouraged the students to participate.
- The teacher did create a more free atmosphere in the classroom where students could express their own ideas, realizing that it was something appreciated by the

critical friend. Allowing students to express their own ideas, whether right or wrong, did motivate them to participate throughout the lessons, while the teacher made it a point not to chastise students for giving wrong or ludicrous answers, but to respect diversity among students. During presentations, students were given the opportunity to critique their colleagues' work and were admonished not to mock wrong answers from the other students. Comments by the critical friend kept on reminding the teacher that students had to be guided to understand some concepts in mechanics. An important way to achieve that was through the use of real life situations or everyday activities to bring students closer to understanding of concepts in their own surroundings. Also employing animations, analogies, examples and microcomputer based laboratory tools (like Coach 6, motion and force sensors) within the students' environment were helpful in making students achieve a conceptual understanding of mechanics, and the teacher tried to employ the use of these where necessary.

- Feedback from the critical friend on the position of weak students inspired the teacher to always monitor especially the weak students' understanding, through the use of some application questions. Immediate feedback from the teacher was given to solutions that were wrong, especially during interactive teaching and application questions. He made sure that the aims of the activities were achieved to the benefit of the students. Also, the students with the most conceptual difficulties were helped during break periods or after the lessons.
- The comments about unfavourable practices were quite helpful to the teacher and had a positive influence on his teaching. Students were not given any prompts or hints in the course of writing quizzes after that comment from the critical friend. It was realized that it was better for students to come out with their own answers on how they understood the questions than to guide them quickly to the right answer. When students were allowed to give their wrong answers, the teacher would be in a position to know the types of problems confronting the students so he could apply the appropriate antidote. Also, reprimanding students who failed to do assignments ceased. More diplomatic talk was used to convince students of the need to do the assignments before coming to the problem solving session. Students were made to understand that by their doing so, the teacher would get to know where the students had difficulties and how to help them. It would make them smart in responding to questions, as they would have some idea of the answer already. This would increase students' confidence in answering questions in class. Again, the group that had the wrong outcome was made to explain their line of reasoning first and had the opportunity to listen to other correct outcomes explained after theirs. This actually helped them to revise their reasoning and to realize why theirs were wrong.

6.3.8 Students' perceptions

Students' perceptions on the use of interactive engagement (IE) approaches were sought through the use of a questionnaire and an interview schedule. We will first report on the questionnaire, which can be compared to the results of the previous years, and after that we will use the interviews to provide some more background for these quantitative results.

Comparing students' perceptions on activities of the lessons

The 2009/2010 group of students' perception of activities of the lessons was compared with that of the 2010/2011 group of students. Year 1 refers to introductory mechanics course students in the 2009/2010 academic year (N=17), while Year 2 refers to students in the 2010/2011 academic year (N=20).

Table 6.8: Comparing students' responses on activities of the lessons - 2009/2010 & 2010/2011

Activities	Year	N	Mean	Std. dev.	Sig.	Std. error mean	Alpha reliability (α) for year 1 & 2
1. Concept quiz	1	17	4.25	0.68		0.17	
	2	20	4.34	0.72	0.68	0.16	0.73
2. Conceptual	1	17	4.59	0.60		0.15	
reasoning question	2	20	4.40	0.57	0.44	0.13	0.89
3. Lecture/	1	17	4.18	0.69		0.17	
interactive teaching	2	20	4.46	0.60	0.32	0.13	0.89
4. Reflection	1	17	4.43	0.67		0.16	
	2	20	4.51	0.57	0.66	0.13	0.84
5. Application	1	17	4.46	0.60		0.15	
question	2	20	4.56	0.51	0.58	0.11	0.94
6. Tutorial/problem	1	17	4.66	0.48		0.12	
solving	2	20	4.51	0.62	0.42	0.14	0.92

From Table 6.8, it was realized that there was no significant difference between the mean values (all mean values > 4) of the responses of the 2009/2010 students and 2010/2011 students. This shows that students in both year groups appreciated all activities.

Comparing students' attitude towards physics and learning environment

Students in the 2010/2011 year group answered *pre-* and *post-*questionnaire items on attitude towards physics teaching and learning environment. Their pre- and post-responses were compared to see if there was any significant differences in their mean values. *Pre* is the reflection of students' position on physics teaching and learning environment in senior high school and *post* is the reflection of students' position after the completion of the first semester introductory mechanics course at university.

Table 6.9: Comparing students' mean values of *pre-* and *post-*responses on their attitude towards physics teaching and learning environment

	Pre/Post	**N**	**Mean**	**Std. dev.**	**Sig.**	**Std. error mean**	**Alpha reliability (α) for pre and post**
1. Students' attitude	*Pre*	20	4.14	0.98		0.22	
towards physics teaching	*Post*	20	4.31	0.80	0.50	0.18	0.72
2. Students' cohesiveness	*Pre*	20	4.18	0.81		0.18	
	Post	20	4.28	0.66	0.51	0.15	0.75
3. Instructor's support	*Pre*	20	3.78	0.99		0.22	
	Post	20	3.97	0.64	0.50	0.14	0.87
4. Students' cooperation	*Pre*	20	4.27	0.62		0.14	
	Post	20	4.39	0.67	0.47	0.15	0.90

In Table 6.9, there was no significant difference between *pre-* and *post-*responses of students' mean values. Thus students' mean values of pre- and post-responses on attitude towards physics teaching, cohesiveness, instructor's support and students' cooperation were about the same. From students' responses, both methods employed in teaching at the SHS and at the university level had almost the same effect on their attitudes towards physics teaching and learning environments, only that the mean values of items at the university level were slightly higher. This was remarkable as it was expected that the students' rating after the teaching at the university would be higher than that at the SHS. The almost equal rating could be due to the fact that students were not given the opportunity to compare the teaching at SHS and university at the same time. They answered the questionnaire items in reminiscence of SHS at the beginning of teaching at the university and those concerning university teaching after the course.

6.3.9 Interview on students' perceptions

The interview with another lecturer was used to add more value to the data of the questionnaire and dealt with students' perceptions on the activities of the meetings, students' learning environment and the new teaching approach (interactive engagement approach).

Clustering of statements of students

Crucial and important statements from students relating to strength and barriers of interactive engagement teaching from the transcription of the interview were clustered into themes and are presented in Table 6.10. The themes reveal students' perceptions of the use of interactive engagement approaches to teaching and how their learning has been influenced. Under the comment section in the table, "students" actually refers to "some students".

Most of what students said in the interview supported their responses in the questionnaire. They perceived that the activities did help them to express their own ideas, gain confidence in doing their reading assignment and to search for their own information, understanding concepts better and clearer, making everybody participate in class, removing fear from students, especially those who were afraid to talk in the presence of their peers, enabling them to memorize easily and also to recall what they had memorized when they needed it without any difficulty. The activities promoted their learning engagement, such as concentration, bringing togetherness on students (cohesiveness) and working cooperatively (cooperation) to help each other. In all, most of the students were satisfied about the use of the interactive engagement method of teaching and there were few complaints.

6.4 In-depth analysis of teaching about Newton's laws of motion

In this section, we will focus on the in-depth analysis of selected episodes of Newton's first, second and third laws of motion. The outcomes will be compared with the first round analysis. The final part will reflect on the conclusions about the whole session.

Though favourable impressions were gathered from students' learning outcomes and perceptions in general, there were still learning problems, so we made some improvements after the first round. To evaluate the effect of the improvements, selected episodes of classroom proceedings will be examined.

The same topics (Newton's first, second and third laws of motion) that were analysed in the first round of data collection (chapter 7) were again analysed after the second round, to look for the effect of the new interventions on students' learning. The analysis will be presented in the following order:

i. Concept quiz on Newton's laws of motion,
ii. Newton's first law of motion,
iii. Newton's second law of motion, and
iv. Newton's third law of motion.

Table 6.10: Examples of some students' perceptions on themes

Themes	Students' perceptions	Comments
Relating physics to real world situations	• I realized that physics was not only a course fully based on calculations, but real happenings around us. • When I was taking a stroll along the beach, I was observing the way the fishermen paddle their canoes to move forward and sideways, and I could relate them to Newton's 3rd law… • When I compared the physics I learnt in the secondary school and here, there is a far difference, because at the secondary school level I can't use physics to explain real life situations, but … here, I was able to use physics to explain real life situation…	Students perceived that the interactive engagement approach made them find answers to questions on their own became good observers of their environment and explain things in their surroundings by relating them to what they learnt in class. Thus, they could transfer the conceptual knowledge gained to explain similar but new situations in their environment.
Awareness of some misconceptions	• …, thinking formerly that in the clashing of cars the bigger car to exert greater force. • …, clashing of the fly on the windscreen. The windscreen of the bus will exert greater force than the fly would exert on the bus.	Students became conscious of some misconceptions which they carried from the senior high school. For example, some thought the object with the bigger mass would always exert the greater force in a collision with an object with a smaller mass.
Retention and concentration	• … the interactive approach has helped especially in the concentration,…, without feeling that we've been here for such long hours. • ..., in terms of retention, because we interacted with some materials, recollecting those things was not difficult for us. Even up to date, some of the demonstrations, I still have them as if they were just yesterday... So the interactive was very helpful.	Students became aware of the fact that the interactive approach was a key to their retention of what had been learnt or experienced. Their notion was that, once they interacted with some of the materials, it was quite easy to recollect the mental picture that had created on their minds. According to them, the approach was a means of gaining control over boredom in class. They felt that, as they were always active, interacting with their peers and teacher, they could stay for long hours without losing concentration.

Table 6.10: Examples of some students' perceptions on themes

Cooperative and hard work among students	• … we go round and do our own research, and the assignment … was helping us to do more research. • We call one another,, and we helped one another, which made us learn better. • It made us to be more …cooperative to one another than we did in SHS. • We were able to study in groups and to learn well by solving more problems. • So he made us to work hard every time and every day.	Students perceived that interactive engagement promoted cooperation among themselves and improved their learning. They were able to study in groups to discuss assignment problems, share ideas and help each other. Contrary to their response to students' cooperation in the questionnaire (no significant difference in the pre and post). They were mostly responsible for their own learning.
Time worthy	• … so it was not a waste of time. • … We had time to argue and discuss some of the questions and misconceptions that we carry to class. • He gives us the chance to participate, so it was time worthy. …	Students realized that the three hours spent on each lesson were time-worthy.
Benefits of IE teaching methods	• …, it explains the things better and the concepts are clearer. Unlike the other one that you are forced to memorize and you just forget about it,… you keep whatever is given to you and you reproduce, without following the actual this thing. • When that method of teaching is being used it makes everybody active, so that everybody will give his or her quota to what we are doing. • Even now we use group discussions to solve problems on our own..., we are self-initiative now, because we continue to read and learn on our own before classes. • …, interactive approach is good because it also removes fear from the students.	Students perceived the IE teaching to bring a lot of benefits: It explained concepts better and clearer, everybody in the class was actively involved in what was going on, it helps in committing things to memory than the traditional lecturing and also removed fear from students, especially those who were afraid to talk initially in the presence of their colleagues were able to do so later. It has also made them to read or learn without being told to do so.

Table 6.10: Examples of some students' perceptions on themes

Teacher's evaluation	• He was understanding us. Through the use of animations and some explanations, I was able to understand the concepts well. • … was really imparting a whole lot of knowledge,… because I realized that he did a whole lot of diagrams, animations and that animations really helped us. He sometimes used pictures to explain situations, … • ...the way he leaves interactive questions for us to discuss. That makes us come out with the various suggestions, agree and disagree with each other to come out with the facts.	Students saw the interactive engagement approach used by the teacher to be good, and were quite positive that it had an impact on their learning. They saw the teacher to be more approachable and understandable, and the use of animations, diagrams, and pictures help them to conceptualize numerous concepts.
Making students learn	• …, some of us are the types who are able to learn under pressure. And he provided this pressure on us. • And you will see that the quiz will force you to learn.	Students perceived that the quizzes, assignments and other activities did provide the necessary pressure on them to work harder. They conceived that because some of them were the types who learn under pressure, the interventions put in place contributed to their hardworking style on daily basis and effective learning habits.
Students' recognition	• Actually, the way he took keen interest in all of us. Sometimes he knew all of us by our surnames and our Christian names. He knows every student by his name, unlike other lecturers, who were just the type that come to class, got to the class and then they are off. He knows us by names.	Students conceived that recognizing and calling them by their names was a clear indication of taking keen interest in them. This goes to show that knowing and calling students by names is a motivation which should not be downplayed by any teacher.
Teacher as a role model	• Actually, the teacher had done, had had a positive impact on me and personally, I have adopted his method of teaching and I have made my mind to use his style in future. • I will use that method because it makes the understanding of the concepts very easy. Because when you get the picture, most of us are able to get concepts based on pictures and animations. And he	The students saw the teacher as their role model in teaching for them to emulate. They promised to adopt the teacher's style in terms of method of teaching in the near future when they also become teachers.

Table 6.10: Examples of some students' perceptions on themes

	these things in his lessons delivery. ... That is why I will go in for that method. • ...and with his teaching I have adopted it. If God permits and I am able to go through, I will behave like him.	
Barriers to applying interactive engagement (IE) approaches	• … Some of us have not got a very good physics background. • Some of us are enemies of the public, so since you are not in that mood to talk after writing you will be scared to go there. • Some of us, at times were not well prepared before coming, so when the questions come that way, you find it difficult to go and do it on the board. • Sometimes your will be ridiculed in class after saying something negative or incorrect, so you will be afraid to come out next time.	Students emphasized that some of them could not contribute well enough in class due to their poor physics background and ill preparation before the lessons. Some of them were also of the view that they found it difficult to talk in public or in front/ presence of their peers; hence could not contribute enough in class. They also claimed that ridiculing of students in class could serve as a means of inhibiting them to come out with their views in class.

6.4.1 Concept quiz on Newton's laws of motion

The aim of the concept quiz was to ask some questions that students could answer successfully if they had done their homework reading. In the previous year, some of the selected concept quiz questions on Newton's first law were either difficult to comprehend by students, not covered in the reading assignment or did not cover all the topics on Newton's laws of motion. For instance, question 3 of the previous year's quiz was not part of Newton's laws of motion and question 4a and 4b were difficult to understand by students and generated a lot of argument; hence they were changed to questions which were easy to comprehend and covered all of Newton's laws of motion. Some of the concept quiz questions were selected from Mazur (1997).

Question	Proportion correct score
(1) Which of these laws is not one of Newton's three laws of motion? (a) Action is reaction, (b) F=ma, (c) All objects fall with equal acceleration, (d) Object at rest stays at rest.	0.84
(2) The law of inertia (a) is not one of Newton's laws of motion. (b) expresses the tendency of bodies to maintain their state of motion. (c) is Newton's third law.	1.00
(3i) State Newton's second law of motion and explain.	0.79
(ii) Consider the interaction between a foot, and a ball, which interact simultaneously (at the same time). Identify the pair of action-reaction forces.	0.39

The questions did fit well with students' reading assignment, and probably as a result students had 0.72 mean proportion correct score. This is high in comparison with the results of other concept quiz scores and a considerable improvement compared to their score of 0.48 in the previous year. Students' low performance on question 3(ii) might be due to the difficulty in the correct description of action-reaction force pairs. They focused mainly on mentioning names of objects involved to represent the force pairs. Some fragments of how the discussion went:

1. **Teacher**: (*Teacher reads the question*) Which of these laws is not one …
2. **A student**: A
3. **Most students**: (*Chorus*) B.
4. […]
5. **Teacher**: The law of inertia is (*Teacher reads through the answers*)… Which is which?
6. **Students**: (*Chorus*). "B" (*expresses the tendency of bodies to maintain their state of motion*).

On Newton's second law, it was realized that students had fair knowledge of it, as they were able to state it correctly and in different forms. This leads to suggest that the question did fit well with the students' reading assignment. Another reason for easily stating Newton's second law could be that students are usually good at defining terms, stating laws and principles as well as quoting formulas.

7. **Teacher**: State Newton's second law of motion. Yes Isaac.
8. **Isaac**: It states that acceleration as produced by an object's net force is directly proportional to the magnitude of the net force in the same direction and inversely proportional to the mass of the object.
9. […]
10. **Frank**: Yes, … but I wanted to find out if somebody writes that the rate of change of momentum is directly proportional to the applied force and takes place in the direction of the applied force.
11. […]
12. **A student**: Sir what about the net force of an object is directly proportional to product of mass and acceleration.

On Newton's third law of motion, a student was able to identify the action-reaction force pairs of an interaction between a foot and a ball, as well as some students who just mentioned the names of the items involved. There was no challenge from the other students, as they were in agreement with the answer provided by their colleague. The fragment below indicates that:

13. **Teacher**: (*Reads the question*). Identify the pair of action and reaction forces?
14. **Some students**: (*Some said*) The foot, (*others also said*) the ball.
15. [...]
16. **Teacher**: Yes Frank.
17. **Frank**: The action is from the foot. That is the force exerted by the foot on the ball and then the reaction force is equal force exerted by the ball on the foot, but opposite direction of that of the foot.
18. **Teacher**: Do you all agree?
19. **Some students**: Yes sir.

From the answers given by the students in discussing the questions of the quiz, it was realized that students did their reading assignment and the questions did fit well with its purpose. The questions were more understandable to students with exception of 3(ii), where they identified the force pairs by mentioning names of objects involved (foot and ball). There was no occurrence of confusion and no extension of time.

6.4.2 Newton's first law of motion

The first law of Newton was the first topic to be taught in the sixth lesson after the discussion of the concept quiz and it took about fifty minutes to accomplish.

For this revised version of the lesson the main revisions were to make the teaching more interactive, to make the contexts more meaningful by the use of more examples relevant to daily life activities and to be more efficient in terms of time.

The lesson on Newton's first law had been revised in several respects for the second round of evaluation. As it turned out from the analysis of learning results presented above, the revised lesson seemed to achieve the intended learning outcomes. In this section we will provide a chronological account of the classroom processes, in order to evaluate how far the intended improvements were realized.

Conceptual reasoning question (CRQ)

The conceptual reasoning question was intended to give the teacher insight into students' current understanding of Newton's first law and to create the need for further learning. In the first evaluation, the CRQ included two questions, one of which was quite ambiguous. Discussions about the answer diverged as expected. However, it took much time, which led to planning problems in the rest of the lesson. In this round, the less ambiguous question of the two had been selected and revised to make sense to students. During evaluation, we will check if there was productive disagreement among students.

> To dislodge ketchup from the bottom of a ketchup bottle, it is often turned upside down and thrust downward at high speeds and then abruptly halted. Which of Newton's laws of motion explains the reason why the ketchup would still continue in motion when the bottle was halted? Explain.

In line with the aim of CRQ, it did evoke different understandings or interpretations. Though the question relates to the motion of the ketchup, students creatively invoked all the three laws, but often it was hard to trace the specifics of their reasoning. They might have difficulty in discerning different parts of a system and/or parts of the motion. The following data are from the plenary discussion that followed the groups' work:

20. **Bismark**: Sir, we chose all the three laws.
21. **Teacher**: … Why?
22. **Bismark**: In the first law, a body will remain at rest unless external force is applied to it. The ketchup was inside the bottle and it was at rest. So when you turn it like this (*demonstrating upside down*), that means the first law has taken place. And then you shake, then you give the ketchup force… you have exerted force on the ketchup for the ketchup to come out. So in this case we think the first law can apply here. And the second law too, action and reaction are opposite.
23. **Students**: It's the third law.

24. **Bismark**: Okay. … And the second law … since there is a high speed and then it stops, there is a change here, so the second law the rate of change of momentum ... can be applied here. And when we come to third law ..., since we are applying force, force that we apply, the ketchup will also react by coming out of the bottle.

Others also thought the first and the third law could be applicable. They seemed to apply their previous knowledge in physics, but it did not appear to connect well, especially with the use of the third law. Frank who seemed to understand the process did invoke the wrong law:

25. **Victus**: Sir, actually we had two ideas. It's like the ketchup when it is in the container and you try to move it down (demonstrating the process), and it doesn't want to come out. It's like the tendency not to move. But when you suddenly stop it, it jerks forward so comes out. So I concluded that it's the first law.
26. **Teacher**: What is the other one? You said you had two reasons.
27. **Frank**: That is the third one. In the course of the third one, we said action and reaction is equal and opposite in that, eh, when we were trying to dislodge the ketchup, you realized that as it was turned down and we exert, we move it suddenly, the bottom of the container will exert force on it, and the ketchup will also exert upward force on it. But the moment you suddenly stop, the ketchup will get dislodged. So…
28. […]
29. **Frank**: And when you stop, all of a sudden it will move down. The ketchup will get dislodged.

Although the original question had been focused on the moment of halting the bottle - "why will the ketchup continue its motion?" - some students extended the discussion to the entire motion, thus making the discussion more confused.

However, one of the groups was able to connect the phenomenon to Newton's first law of motion. One student in the group did initially connect the explanation to the first law, but failed to give a clear explanation of the effect of the continuous movement of the ketchup when the bottle was halted. A colleague from the same group gave a meaningful explanation to that effect. The fragments below did indicate that:

30. **Isaac**: I said a body that is at rest, will stay at rest, and a body that is in motion will continue in motion in the same direction unless external force acts on it. So here when they dislodge, when they turn the bottle upside down, it will move in the same direction at constant speed. So when it is being halted it will continue to be in the same direction but the speed will not change.
31. […]

32. **Sam**: As he was saying, so we took Newton's first law. The ketchup in the bottle will be moving with the same speed with the bottle. So when the bottle is halted, the ketchup will continue with the same speed that is why the ketchup gets out of the bottle to the…

From these observations it could be concluded that this CRQ was better than in the first round in the sense that there was less confusion about the target of the question and a student gave a correct explanation. However, the majority of the students did not indicate that the question was related to Newton's first law and could also not give the correct explanation. Misconceptions were not really displayed, but fuzzy reasoning was. Maybe the situation was still too complex for the students. By the end, the correct answer is not evident to all (20, 22, 24, 27, 29 & 30). The CRQ also revealed some misinformation from students from their senior high schools. The time limit was not exceeded.

Interactive teaching

In the previous year, the lecture was quite traditional with no interactive questions. It looked a bit abstract, as there were no situational examples to allow students to express their views. For the revised version, the teaching was more interactive; hence the name of the activity, interactive teaching. Selected and planned questions were inserted at strategic points during the teaching process for students to answer. The aim was to enhance students' involvement. Questions on real world examples that would make students apply reasoning and theory to meaningful contexts were selected. About five questions were chosen with an average of two minutes spent on each. About twenty (20) minutes were used for interactive teaching on Newton's first law of motion.

The interactive teaching started with an interactive question, asking students to state Newton's first law, which one student did easily (33 & 35). This was not surprising because students are used to memorizing definitions, stating of laws and principles, quoting and manipulating formulas to solve for unknown variables:

33. **Amoah**: It states that an object which is at rest will always remain at rest, and then an object which is in motion will always continue in motion when a net force is not applied to it. So an object will remain at rest or continue in motion in a straight line when no external force acts on it.
34. **Teacher**: Yes, it's an object being stationary or moving, but moving with what?
35. **Amoah**: With constant speed.

The teacher showed an animation of a driver who was thrown from his car for failing to wear his seat belt, after hitting the car against a wall. The teacher built on this to explain Newton's first law (inertia) of motion to students.

In the next question, some of the students could develop a clear idea of what would happen, but could not apply the physics vocabulary correctly (36, 38 & 40); there was also no explicit connection to the first law:

When you fill a cup of water to the brim, put it on a cart and move around an oval track making an attempt to let it complete a lap in the least amount of time. (i)What will happen to the water in the cup?

36. **David**: When you are going round the track, since it is curved, the water will fall (in a low voice), maybe some of the water will split (wanted to say spill)... Water will split, since you are changing direction, since we are changing the acceleration... Some of the water may fall.
37. […]
38. **Victus**: When you are accelerating, maybe the cup, the water does not want to come out, it wants to stay where it is, so that when you move the cup, the cup moves forward and the water stood behind you... The water will try to move to the other side of the....
39. **Teacher**: … Yes Isaac.
40. **Isaac**: Sir, I learnt since you are just moving round it and you haven't attempted to push the cup with the water, it will still remain in the cup.

However, there was one student who could correctly say what would happen to the water in the cup:

41. **Chris**: As you keep moving round the circle, the water will be spilling on the other side of the track (*using his hand to point towards the direction of a tangent*). …

On asking some daily life occurrences, students could connect the knowledge gained in understanding Newton's first law to explain both situations (42, 44 & 46):

i. Why is it that the head of a hammer can be tightened onto the wooden handle by banging the bottom of the handle against a hard surface?
ii. Why is it that blood rushes from one's head to one's feet while quickly stopping when riding on a descending elevator ("lift")?

42. **Bright**: We are always trying to tighten the head.
43. **Teacher**: How does it get tight? I mean ... what makes it so tight? ...
44. **Frank**: Newton's first law is implied, being that as you move it, and you are moving it downwards, both of them (*referring to the metallic part and the wooden part*) in motion, that is the same velocity, the moment it strikes the hard surface, the wood itself stops but the head would like to continue, so it moves down ...
45. […]

46. **Chris**: The body contains the blood and they were all in motion with the lift at first. When your body and the elevator suddenly stop, the blood still being in that motion will try to push down as you were going downwards, so it will come down...

Here, it was realized that students had the idea, but how to put it into convincing statements was the problem. They were trying to link their previous knowledge to the situation, but it hardly connected (47 & 49):

> A man is being chased by an elephant in the forest, who attempted to photograph it. The man makes a zigzag pattern to his advantage. How does this zigzag movement help the man for not being caught by the elephant?

47. **David**: … Because the elephant is too big, since the man doesn't have mass like the elephant, he can move in that zigzag.
48. […]
49. **Dan**: He did so because as he moves this way (*demonstrating with his hand*) in a zigzag manner, the force that it will need to stop, or the time it will need to stop and change direction, he would be able to double the gap. Because the elephant will need a greater time to stop and then change...

Meanwhile one of the students was able to connect his previous knowledge on inertia to give a correct explanation:

50. **Sam**: So as we are dealing with inertia, because the elephant is more massive it will resist the change so it will move with a constant speed in a straight line, so as the man is changing its this thing (*using his hand to demonstrate the zigzag direction*), the elephant will not be able to move in that way, because of its massive mass.

At the end of the interactive teaching, it was evident that students were showing signs of conceptual understanding of Newton's first law and could apply their understanding in solving some daily life occurrences (42, 44, 46 & 50).

The interactive teaching material was good in helping students to explain some real life occurrences in relation to Newton's first law. It brought more teacher-student interactions, and students appeared to gain a good understanding of the law. The questions in the teaching served as a guide to the teacher to see how students were following and understanding what he wanted to impart to them. In some instances, students were finding it difficult to put their ideas into convincing statements. An approach for improvement might be to give students more practice in using physics language.

Reflection

The aim of the reflection was to give students another chance to either discuss the CRQ in groups or provide individual answers depending on their conviction of the knowledge gained in the interactive teaching to polish up the initial answers, especially after they had failed to provide a reasonable answer to the CRQ at the beginning.

In the first round, reflection did not lead to clear answers, because the CRQ had been confusing. With the improved CRQ, Dan realised that the question could be explained by Newton's first law of motion (inertia), though he could not support the answer with a correct physics explanation (51 & 53):

51. **Dan**: Sir, first law.
52. **Teacher**: First law, initially you said all the three laws, your group in particular; you said all the three laws. Now why are you saying it is the first law?
53. **Dan**: Sir, because the first law is saying that the body continues to be at rest and then it also,..., it will be at rest when it is at rest and then moves in a straight line if it is moving in a straight line. It will change if only an external force is acted upon it. The ketchup was initially at rest, which means it has obeyed the first law. And it only changed the direction when the external force was acted on it that is when it was turned upside down. It followed the direction that the external force acted on. That also obeyed the first law. So I think it is the first law.
54. […]
55. **Bismark**: The ketchup is inside the bottle and it is at rest, so it needs external force to exert, to force it to move.
56. […]
57. **Bismark**: As it is moving, it moves with the bottle. To cause it to move it has obeyed the first law. Moving from rest to another position, the changes here...

The teacher had to use leading questions to guide (scaffolding) one of the students to come up with the reasons for the ketchup to come out when the bottle is halted abruptly (58-70):

58. **Fred**: Sir, you were pushing it down, but as you stop the ketchup in the bottle will still be in motion.
59. **Teacher**: What is in motion with the bottle?
60. **Fred**: The ketchup in the bottle.
61. **Teacher**: The ketch in the bottle is in motion with the bottle?
62. **Fred**: Yes.
63. **Teacher**: So as you stop...
64. **Fred**: So as you stop the ketchup will still be in motion.
65. **Teacher**: Because of what?
66. **Fred**: Because of inertia…
67. **Teacher**: Inertia is saying what?

68. **Fred**: Inertia is saying that an object will want to resist anything that will..., if it is motion, the tendency for the ketchup to continue in motion.
69. **Teacher**: Do you agree to Fred's explanation?
70. **Students**: Yes sir.

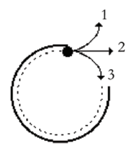
No major confusion occurred this time and less than the stipulated time was used. Though the activity was necessary to reveal to the teacher whether students would still hold on to their initial answers, he did not allow students to redress their incorrect explanations (line 53, 69-70). To improve the design, students should be given the chance to explain concepts and redress their initial thinking.

Application question

The aim of the application question was to allow students to try similar but new problems to see how effectively they apply the knowledge gained to solve problems.

The same question as in the previous year was used to sharpen students' minds on Newton's first law as regards motion in a circle. It is similar to a question in the force concept inventory (FCI). Similar responses during the first round were heard in the second round.

> A group of physics teachers is taking some time off for golf. The golf course has a large metal rim which putters must use to guide their ball towards the hole. Mr. Boakye guides a golf ball around the metal rim. When the ball leaves the rim, which path (1, 2, or 3) will the golf ball follow?



Most of the groups opted for path 2, and were able to use Newton's first law of motion to support their choice (71, 73, 77 & 81). The groups analysed the law correctly as the ball moved through the rim and the path that it took when it came out of the metallic ring:

71. **Smart**: We said 2.
72. **Teacher**: You chose 2. Why 2?
73. **Smart**: At the first instant when the ball was kicked, it would have moved in a straight line, but since there was something to guide it as it tries to move in a straight line, the, the ring tries to change the direction of the motion. At a point in time when it gets to the point where there is nothing to guide it, it is going to move in a straight line.
74. […]
75. **Bright**: We also chose 2.
76. **Teacher**: Okay. Ben, explain why did you choose 2?

77. **Ben**: We chose 2 because the body was moving with an initial, ... We said as it continues to move, because the ring was guiding the ball, it has to move in that same direction, but when it reaches the free range, the reluctance for it to stop or move in that circle, will not be so because the ring is no more there. It therefore continues in a straight line (*using his hand to demonstrate the straight path*).
78. […]
79. **John**: Sir we chose 2.
80. **Teacher**: Why 2?
81. **John**: This is because, you know at first the ball was moving on a circular path, so it was being guided by that circular ring to have that motion. But the moment that it will reach where the ring had been cut, there is no circular ring, then it means it must move along a straight line because of that empty space over there.

However, one of the groups applied Newton's first law wrongly during the group discussion. They assumed that circular motion was part of Newton's first law of motion (83-94):

82. **Obed**: Looking at this, the golf ball was played in a circular motion, it will continue with the same circular motion. And since it was in the same motion, and even as it is in the ring it keeps on changing direction.
83. **Dan**: Is the ring guiding it? Is the ring guiding it to be in the circular motion?
84. **Other members**: Yes.
85. **Dan**: If the ring is helping it to be in the circular motion, now the ring is not there, so what is going …
86. **Fred**: Eeh, but since it wants to obey the law of inertia, so it will continue to be in this motion. Because, it wants to obey the law of inertia.
87. **Dan**: Really, eeh, theoretically, but practically I think it doesn't happen.
88. **Obed**: Looking at the athletics game, those who throw …
89. **Fred**: Discus.
90. **Obed**: Yeah, they go round, round, round and then they release it.
91. **Dan**: But when they release it, the thing doesn't go round, or does it go round? It goes straight. It will be turning this way but it moves straight.
92. **Fred**: Yes, you see, it is still on the "round motion". When it is going…
93. **Dan**: So it is round and it will be moving down.
94. **Bismark**: Yes, so it will still be on that motion.
95. **Obed**: Or you are still arguing (*all of them laugh*).
96. **Dan**: We are not arguing, this one we are discussing.
97. **Obed**: (*Trying to explain using local language*). This is different from shot put.
98. **Fred**: Because as for shot put it goes straight.
99. **Dan**: The shot put will go straight even though you can be doing your …
100. **Obed**: The intention is that they want it to go a longer distance…

101. **Dan**: That is why they move round?
102. **Other** members: Yes.

From the group of Obed, Dan, Bismark and Fred.

So they understood the first law to mean "the continuation of motion as it has assumed earlier" without considering the "… in a straight line in the absence of the external force" of the law (105). Below is the response of Obed's group during the plenary discussion:

103. **Dan**: Sir, we chose 3.
104. **Teacher**: You chose 3, why 3?
105. **Dan**: We are looking at the fact that it will like to continue in the circular motion.
106. […]
107. **Teacher**: … when they hit the golf ball, it should have moved in a straight line with a uniform speed but because that circular ring was there it would make it move in a circular form. But when it gets to the portion where there is no ring, then in that range it continues to move in a straight line, as has been explained by the other groups. Theirs go in line with what Newton said in his first law that the object will continue to move in a straight line, when there is no external force to act on it. I hope it is clear.
108. **Students**: Yes sir.

The fragment here is informative to teachers who may expect this kind of thinking from their students. The teacher realizing that some students were including circular motion in Newton's first law, compared the views of Ben (77) and John (81) to those of Dan (105), and used their ideas to explain, emphasizing the straight line movement in the first law in the absence of force.

Students' response to the application question was better than in the first round as this time most of the students could choose the right path for the golf ball when it came out of the metallic rim, and could give a meaningful explanation for their answer. Only one group had it wrong. This shows that a majority of the students could apply or transfer the knowledge gained in the interactive teaching to solve similar but new problems.

The material is good in revealing how students used their understanding of Newton's first law to explain situations when something comes out of a circular motion. This idea could be transferred to explain such occurrences in real life activities, for example, the direction of motion of an object, when the rope which is used in whirling is cut.

Conclusions on teaching Newton's first law of motion

Our prior finding was that the CRQ did not create the need for further learning in students due to the ambiguity of the questions, that teaching was teacher-centred, that students still maintained their original answers to the CRQ during reflection, that about three-fourth of the class were not able to explain correctly the application questions and that the stipulated time was about fifteen minutes in excess. Now our aims were to use one unequivocal question with a definite target for the CRQ, make the teaching more interactive and meaningful by using real life examples and activities within students' environments, and to work within the stipulated time. In summary we found:

The CRQ made students voice out their preconceptions. The need for further learning was created as students gave different interpretations. There were more interactions in this activity. The material created room for learning.

Teaching was interactive. Interactive questions and examples were based on daily life activities. The animation used on the motion of the driver who did not wear his seat belt after hitting a wall and what happens to passengers when a vehicle stops, moves or suddenly negotiates a sharp curve, helped students to understand the meaning of Newton's first law of motion. More questions on real life activities and interactions guided students in relating the law to everyday life occurrences.

Though most students were able to revise their answers with regard to the type of law which explains the phenomenon of the CRQ, they could not link the explanation well to inertia. However, one student was able to do that with the guidance of the teacher and his reasoning was also understood by his colleagues. The activity was useful in helping students to understand how to solve similar problems by relating it to Newton's first law of motion, but students were not given the opportunity to correct their wrong explanations.

Though most students were able to apply the knowledge gained during teaching to support their answers in the application question, some could not connect it to Newton's first law. The material was successful in showing students how to use Newton's first law to explain the direction of motion of an object that comes out of a circular orbit.

6.4.3 Newton's second law of motion

The second block of the sixth lesson was devoted to Newton's second law of motion. It took about fifty-five minutes to go through the various activities with the students. Similar activities as observed in Newton's first law were followed. Thus the use of conceptual reasoning question, interactive teaching, reflection and application question were followed. The aims and purposes of the activities were similar to those for Newton's first law.

The main problem with the previous year's conceptual reasoning question was that it did not extend to include the effect of the presence of air on a falling parachutist's velocity and acceleration, and the force on her. As a result the students could not answer the question well enough with good reasons to support their answers. To avoid confusing students, two scenarios were given to improve the question: the effect on a falling parachutist of (i) absence of air and (ii) presence of air.

Conceptual reasoning question (CRQ)

The conceptual reasoning question was revised to include more physical quantities that would provoke students' thinking in the second round. The two different scenarios (absence and presence of air) have to make the question clear in terms of its demand to students. The question was adapted from Hewitt (n. d.).

(1a) As she falls faster and faster in the absence of air; what happens to her (i) velocity, (ii) acceleration and (iii) the force on her?

(b) As she falls faster and faster through air (air resistance), what happens to her (i) velocity, (ii) acceleration and (iii) the force on her?

The first question revealed students' misconceptions on free fall motions. In the group discussions, one of the groups had this to say:

109. **Dan**: I am falling, there is no air resistance, free fall, acceleration will be constant.
110. **Fred**: Constant velocity.
111. **Dan and Bismark**: (*Dan*) That is in a free fall, when there is no air resistance, (*Bismark*) acceleration is constant.
112. **Fred**: That means velocity will be changing. Constant acceleration, that means velocity will be changing.
113. **Dan**: As he falls faster and faster in the absence of air, … so what happens to her velocity, acceleration and the force on her (*Dan is reading the question*). In the absence of air, what will happen to her velocity? You are falling, no air, what happens to your velocity?
114. **Obed**: It means there is no resistance?
115. **Other members**: Yeah.
116. **Dan**: There is no air resistance. The air will not resist you, so you will fall with a constant speed, is that not? … If you are falling with a constant velocity…
117. **Fred**: The acceleration is zero.
118. **Dan**: The acceleration is zero. What then happens to the force on her?

119. **Bismark**: There is no force.
120. **Dan**: There is no force on you. We now come to (b). Okay, through the air. So what is the effect of increasing air resistance on the velocity if there is air resistance? Then it means that your velocity will be reducing. Is that not it?
121. **Other members**: Yes.
122. **Bismark**: When you are falling.
123. **Dan**: Yes, there is air resistance. If there is air resistance, your velocity will be reducing, it means that there will be acceleration, but this one negative form of acceleration. ... If the air is resisting, it means that your velocity will reduce, so there will be acceleration, and there is a force.
124. **Other members**: Yes.

From the group of Obed, Dan, Bismark and Fred.

In line with the aim of CRQ of evoking students' misconceptions, Fred and Dan were giving a wrong interpretation to what will happen to the velocity of a body falling in the absence of air (lines 110 & 116).

Theo and Obed used "change" to imply increase or decrease. Fragments below show such confusion in lines 126 and 130:

125. **Teacher**: …, Theo, yes…
126. **Theo**: In the absence of air, velocity will increase, acceleration will remain constant, 9.8 m/s^2, and the force will also remain constant. But in the presence of air, the velocity will reduce, acceleration will change and the force on her will change.
127. […]
128. **Chris**:... When there is air resistance, velocity will still be increasing, then acceleration will remain constant, then the force on her will remain constant …
129. […]
130. **Obed**: When there is air resistance, velocity will be changing.
131. **Teacher**: What happens to her acceleration?
132. **Obed**: Constant acceleration.
133. **Teacher**: Constant acceleration, then what happens to the force on her?
134. **Obed**: Then maybe the force will be constant.

However, one student made a good attempt but it was not entirely correct. Instead of force of gravity he used mass, in answering the effect of increasing air resistance on the velocity of the body.

135. **Teacher**: What is the effect of increasing air resistance on the velocity of the body?
136. **Frank**: I think the velocity will continue increasing, until the effect of air resistance is equal to the mass of the body, then it becomes stationary. But then…

137. **Teacher**: Stationary?
138. **Frank**: Yes, assuming it is falling, but because the air resistance is increasing, then at a point in time, eh, eh, sorry, there will be a net zero force, and when that occurs, then the velocity will become constant.
139. **Teacher**: But it doesn't mean it is going to be stationary.
140. **Frank**: Yes, it will become constant, and there will be a decrease in the acceleration.
141. **Teacher**: A decrease in acceleration...?
142. **Frank**: Oh no, sorry, acceleration will become zero, because… (video became full)

The CRQ was framed better than in the first round. From the protocol, there was no apparent confusion shown by the students at this stage. Thus the confusion was not too explicit for students to create the awareness of the need to learn. To improve the didactical function, the teacher at this stage could come in to create constructive confusion amongst the students, either by taking a different stand, or bringing in questions to cause some students to have some disagreement.

Interactive teaching

In the revised version, there were four planned questions inserted at various points in the interactive teaching to ask students for their view. Insertion of such questions should increase students' involvement and also enable them to see real life applications of the second law. Two to three minutes was the average time spent on each interactive question. About twenty-five minutes were spent on interactive teaching.

In answering one of the interactive questions, a student saw mass as a varying quantity:

> Suppose that a toy car is accelerating at a rate of 2 m/s^2. If the net force is tripled and the mass is halved, then what is the new acceleration of the toy car?

143. **Theo**: If the net force is tripled, times the acceleration, the 2 m/s^2, so the net force is 6 N. And from the law, acceleration is directly proportional to the force, so if the net force is 6 N, then the acceleration too will be the same. But the mass is inversely proportional. So if the acceleration increases the mass will decrease.

This answer could be of educational importance to teachers. More students may think the way Theo thought (143). The way the question was put could be confusing to students because it suggests that the mass is changing. This might be due to the fact that a comparison between two distinct situations was not explicit in the question. Teachers should make students aware of the fact that here mass is constant, not a varying quantity; it should be emphasized that mass will only decrease when it is reduced or halved as stated in the question. The increase of acceleration in this situation cannot decrease the mass, as suggested by the student. The teacher could make the comparison to be distinct by using illustrative diagrams to depict a bigger body of mass m, with a net force F, and a smaller body of mass ½m with a net force of 3F, or the question should clarify the fact that there are two distinct situations.

One student analysed the question wrongly to get the correct answer (144). The teacher guided the student on his analysis to explain to his colleagues the solution to such problems:

144. **Sam**: Me I think, acceleration is proportional to force and if the force is tripled, we have 6 m/s2 over half of the mass. The mass is halved, so that shows that will also have an effect on the force, then this thing, the net force will increase to 12.
145. **Teacher**: So when the mass is decreased by half, what happens to the acceleration?
146. **Sam**: The acceleration increases.
147. **Teacher**: Yes it will increase, but to what extent. I mean by what value?
148. **Sam and some students**: Double.
149. **Teacher**: If it decreased by one-fourth, what will be its effect on the acceleration?
150. **Sam**: It will increase four times.
151. **Teacher**: So if it is decreased by half, what will be its effect on the acceleration?
152. **Sam**: It will increase twice.
153. **Teacher**: It will increase twice, and then, so you have two times the acceleration. So if the force is increased, tripled, what will happen to the acceleration?
154. **Sam**: The acceleration will increase by three times.
155. **Teacher**: three times, so if the acceleration is 2, what will it be?
156. **Sam**: Six.
157. **Teacher**: And if the mass is halved, what will be the new acceleration, ... in all?
158. **Sam**: Twelve.
159. **Teacher**: Do you agree?
160. **Some students**: Yes.

Another example concentrated on the use of the formula of Newton's second law of motion $(a) = \frac{F_{net}}{m}$:

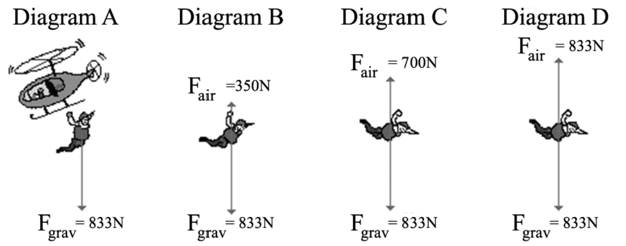
(i) *Doubling* of the net force results in …… (if mass is held constant). (ii) Similarly, *halving* of the net force results in a ……(if mass is held constant). (iii) Furthermore, *doubling* of the mass results in ………(if force is held constant). (iv) Similarly, *halving* of the mass results in …… (if force is held constant). Acceleration is inversely proportional to…, but directly proportional to……

161. **Fred**: Doubling the acceleration.
162. **Teacher**: Doubling the acceleration. Why?
163. **Fred**: Because the net force is directly proportional to acceleration, so as the net force increases, double, the acceleration also doubles.

164. […]
165. **Bright**: … halving the mass results in doubling the acceleration.
166. **Teacher**: Why?
167. **Bright**: Because the mass is indirectly proportional to the acceleration.
168. **Teacher**:… Furthermore, doubling of the mass results in..., if force is held constant.
169. **Ben**: It results in halving the acceleration.
170. **Teacher**: The 4th one, similarly, halving of the mass results in..., if force is held constant. Bismark, halving of the mass results in ...
171. **Bismark**: (*Bismark remains silent*).
172. **Teacher**: Acceleration and mass, what do they do? Are they directly proportional or indirectly proportional?
173. **Bismark**: Is indirectly proportional.
174. **Teacher**: So when mass is halved, the other does what?
175. **Bismark**: The other doubles.
176. **Teacher**: Halving of the mass, results in...
177. **Bismark**: Doubling of acceleration.
178. **Teacher**: … Okay, acceleration is indirectly proportional to... Bright.
179. **Bright**: Mass
180. **Teacher**: But directly proportional to ...
181. **Bright**: Force.

The teacher used an example of a falling parachutist to explain the effect of increasing air resistance on a falling body's velocity, acceleration and the force on the body.

182. **Teacher**:... (*Teacher displaying another slide with a parachutist falling out of a helicopter to explain the effect of air on the parachutist's velocity, acceleration and the force on him*). …



In conclusion, the explanation on the falling parachutist used by the teacher led to the same situation as the CRQ (182), hence it was not suitable for interactive teaching. The teaching did not improve students' understanding, as they were not given the opportunity to explain their initial response and why they were wrong. As a way to improve the design, interactive teaching should not address the same problem as the CRQ.

Reflection

Students' answers were better with the question which involved "… in the absence of air" during reflection (183-188). Explanation on free-fall motion using the elephant and the mouse might have improved students' understanding. They had this to say:

183. **Teacher**: As she falls faster and faster in the absence of air… What did you say would happen to the velocity?
184. **Students**: Velocity will increase.
185. **Teacher**: Acceleration?
186. **Students**: Acceleration will be constant.
187. **Teacher**: Constant. And then the force on her?
188. **Students**: Will also be constant.

Some of the students still exhibited the same kind of confusion they initially had, especially with the second part of the question (190), which involved the presence of air, whereas others showed some improvement in their understanding (192-201):

189. **Teacher**: Okay, in the presence of air as he falls faster and faster, what happens to her velocity?
190. **Some students**: Increasing velocity.
191. […]
192. **Chris**: I said it increased to a point and it becomes constant.
193. **Teacher**: What will increase?
194. **Chris**: The velocity. It will increase to a point and then it becomes constant.
195. **Teacher**: And then becomes constant. What about the force on her?
196. **Chris**: The force on her will remain constant to some point.
197. […]
198. **Teacher**: When the velocity is constant, what happens to the acceleration?
199. **Chris**: The acceleration becomes zero.
200. **Teacher**: And the force will be...
201. **Some students**: Zero.

There was some conceptual improvement in students understanding of Newton's second law of motion in the second round, as regards the use of the equation and relating it to a body falling in the presence of air. Though there was slight confusion with some of the students on "the body, falling in the presence of air", Chris and some students improved in dealing with relational problems involving acceleration, force and mass (192-201).

Application questions

Some additional questions were added to the application question used during the first round, and the question was slightly changed; the net force, which was tripled in the first instance, was changed to quadruple.

Sam could solve the first part of the application question easily, as it required manipulation of the equation of Newton's second law of motion (203-207):

(1a) Suppose that a sled is accelerating at a rate of 6 $m/s^{2.}$ If the net force is quadrupled and the mass is halved, then what is the new acceleration of the sled?

(b) A net force (i.e., an unbalanced force) causes an acceleration. Combine your understanding of acceleration and the newly acquired knowledge that a net force causes an acceleration to determine whether or not a net force exists in the following situations.

Description of Motion — Net Force: Yes or No?

202. **Teacher**: Yes, who will go to the board and solve it for us to see?
203. **A student**: (*Sam has gone to the board to solve the problem, others look at him to see what he is doing and others also try on their own*).

$$a_1 = \frac{F_{net}}{m} = 6m/s^2$$

$$a_2 = \frac{4}{\frac{1}{2}}\left(\frac{F_{net}}{m}\right) = 8\left(\frac{F_{net}}{m}\right) = 8(6m/s^2) = 48m/s^2$$

(After the solution)

204. **Teacher**: Have you finished?
205. **Sam**: Yes sir.
206. **Teacher**: What did you get?
207. **Sam**: 48 m/s^2.
208. **Teacher**: Do you all agree?
209. **Students**: Yes sir.

However, there was a problem with the second part of the question despite the fact that they had experience with dot diagrams in determining velocity and acceleration in the earlier lessons; some students found it difficult to comprehend (210-221). Students could not combine their understanding of acceleration and the newly acquired knowledge that a net force causes an acceleration to explain why there should be a net force or not:

210. **Teacher**: This is the dot diagram. (*Teacher reads the question to the students*). Do we have a net force in this situation?
211. **Some students**: Yes sir.
212. **Teacher**: Bright, do we have a net force here? (*Teacher pointing to the first dot diagram*).
213. **Bright**: Yes.
214. **Teacher**: Why?
215. **Bright**: (*Bright remains silent*).
216. **Teacher**: (*After a while*). Bismark do we have a net force? (still referring to the first dot diagram).
217. **Bismark**: (*After a while*) Yes sir.
218. **Teacher**: Why?
219. **Bismark**: As the acceleration increases the net force increases.
220. **Teacher**: Isaac, why? Do we have a net force?
221. Isaac: No.

At the same time, an answer provided by one of the students with some guidance from the teacher helped the others to understand (225-239):

222. **Teacher**: … Chris, do we have a net force?
223. **Chris**: Yes.
224. **Teacher**: Why?
225. **Chris**: Because from the dot diagram the velocity changes. Since the velocity changes there will be a net force.
226. **Teacher**: You see, when you look at this (*referring to the first dot diagram*) ... Is it accelerating?
227. **Students**: Yes sir.
228. […]
229. **Teacher**: The second one, is there any acceleration?
230. **Students**: (*Chorus respond*). No.
231. **Teacher**: Why?
232. **Students**: (*Some said*) the same interval, (*others also said*) the same speed.
233. **Teacher**: No acceleration: So what happened? Is there going to be a net force or...
234. **Students**: No. (*A student added*) The net force will be zero.
235. **A student**: Because the velocity is constant.
236. **Teacher**: Third one, is there any acceleration?
237. **Students**: (*Chorus answer*). Yes.
238. **Teacher**: So, net force or no net force?
239. **Students**: Net force.

Though the application question was better than in the first round due to the additional question which required students to think and analyse dot diagrams to determine the relationship among velocity, acceleration and force. The students were finding it difficult to comprehend initially. With some guidance, they were able to understand what was required in the question (225-239). This illustrates that scaffolding is sometimes needed in students' learning.

Though the analysis suggests that the material had been improved in the second round, there is still room for improving the material to foster students' learning. For example, a demonstration of the motion of the pebble in a long cylinder to explain the effect of friction in liquid on an object's velocity, acceleration and force on it, as measured by the Coach 6 instrument and motion sensors, might help students to get a clear picture of the situation of the falling parachutist. Students will get the opportunity to discern the motion, especially at the point where the object no longer accelerates, when it is converted to a dot diagram through the use of Coach. The motion of the bicycle might not be a better alternative because its use is not common in the Ghanaian community.

Conclusions on teaching Newton's second law of motion

In our first field test, we saw that the CRQ did not allow students to fully express their prior ideas on how to relate the motion of a falling parachutist to Newton's second law of motion: the need for further learning was not created in them. The method of teaching was about 70 % traditional lecture, the example of the falling object used to explain the relation of variables in Newton's second law of motion did not follow a step by step approach and students found it difficult to identify whether the motion was in the presence or absence of air resistance. In the revised design for the second field test, our major aim was to improve the materials used in the activities of the Newton second law of motion. Though the question on the falling parachutist was repeated it was enhanced by including what will happen to the falling parachutist's velocity, her acceleration and the force on her, when she falls in the absence or presence of air. Also, a step by step approach of a falling object in the absence and presence of air was used to make the two situations distinct to students. The teacher was to ask students more questions to improve teacher-student interactions. In summary we found:

The two scenarios in the CRQ, (i) absence of air and (ii) presence of air, did allow students to understand what the questions were demanding, but most of the students could not predict the possible outcome of the situations. There was no apparent confusion shown by the students to create the need for learning as expected. To improve the design the teacher could come in to make the confusion more explicit to students.

The questions on situational problems helped students to also understand the relationship between mass, acceleration and force. The explanation on the falling parachutist used by the teacher was the same as the CRQ. Teaching did not improve students' understanding so much because they were not made to explain their initial response and why they were wrong. As a way to improve the design, interactive teaching should not address the same problem as the CRQ, so that students could use their understanding gained here to improve their answers during the reflection stage.

During reflection, students could revise their initial answers, especially with the situation in the absence of air. Though most of the students still exhibited the same kind of mistakes, some showed an improved understanding of the possible effect of increasing air resistance on a falling body's velocity and acceleration, and of the force on the body. This might be due to the fact that the same situational example was used by the teacher during the interactive teaching.

Most students could apply their understanding of the equation of the second law to solve the first part of the application question. Initially, students were not getting the clue to solve the second question which involved the dot diagram. With some guidance they were able to connect the relation between velocity, acceleration and force.

6.4.4 Newton's third law of motion

The lesson about Newton's third law had been revised for the second round of evaluation. For example, in the first round there were two conceptual reasoning questions. The first question did not cause any confusion among students, while the second one did. The illustrative picture of the second question was not clear to students and as a result generated some confusion. In the second round the first question was repeated, as that question alone could evoke students' misconceptions and generate room for learning.

In the interactive teaching of the second round, many interactive questions which would enable students to relate Newton's third law to real world experience were included, unlike in the first round. The use of a microcomputer based laboratory (MBL) tool to validate Newton's third law was maintained, as it was quite helpful in making students appreciate the meaning of the law. The application questions were improved by increasing the number of items, to ensure more practice in action-reaction force pairs for students.

For this revised version, the main revisions were to make the teaching more interactive, to make the contexts more meaningful by the use of more examples relevant to daily life activities and to be more efficient in terms of time.

Conceptual reasoning question (CRQ)

This activity started after students had a twenty-minute break. It took about sixty minutes to accomplish. The conceptual reasoning question motivated students to express with their views. One of the groups had this to share:

> While driving down the road, a fly strikes the windscreen of a bus and makes a quite obvious mess in front of the face of the driver. (i) This is a clear case of Newton's … law of motion. (ii) The fly hits the bus and the bus hits the fly. Which of the two forces is greater: the force on the fly or the force on the bus? (iii) Identify the action and the reaction force pairs.

240. **Ben**: I think Newton's third law is occurring. It's the third law; every action there is equal and opposite reaction.
241. **Chris**: They collide then, they will stick together, but when they are not equal they collide and …
242. **Bright**: What shows they stick together?
243. **Chris**: They said it created a mess… So let's decide on one.
244. **Bright**: Me, I think based on the law, we must use equal but opposite... according to Newton's third law.
245. **David**: So you are saying that none of them will exert a greater force?
246. **Chris**: We are assuming the bus, but he is saying that according to the law, it should be equal and opposite, so now argue out and then tell us, because I am confuse. I know that of the car (*bus instead*) to be greater…
247. **Ben**: I think that one is from our own human idea, (*one of the members interrupted by asking which should be the action* …) but as for the law action is from the car and reaction from …
248. **Chris**: Action can be from any and the reaction can be from any, so the action can be that of the fly and the reaction can be …
249. **Bright**: But, from the question which one is the action and which one is the reaction, based on the question?
250. **Chris**: They are all action and they are all reaction.
251. **David**: The action is the bus while the reaction is fly.
252. **Bright**: Fine, … I think it's like that.

From the group of Chris, Ben, Bright and David.

During the plenary session of the conceptual reasoning question, it was realized that all students could affirm the collision of windscreen and fly to be an example of Newton's third law of motion (254, 258, 260 & 262):

253. **Teacher**: ... Bismark your group.
254. **Bismark**: Newton's 3rd law of motion.
255. **Teacher**: 3rd law of motion. Are you sure?
256. **Bismark**: Yes.
257. **Teacher**: What about Sam your group?

258. **Sam**: Newton's 3rd law of motion.
259. **Teacher**: Chris (*referring to Chris' group*).
260. **Chris**: 3rd law:
261. **Teacher**: Frank (*referring to Frank's group*).
262. **Frank**: 3rd law.

Though students could relate the interaction between the bus and the firefly to Newton's third law, it was realized that, conceptually, some of the students had difficulty with the understanding of the third law (263-268). They did not see the forces involved in the interaction to be equal in size. They assumed that the higher the mass the greater its force would be. The dialogue below shows that:

263. **Teacher**: The fly hits the bus and the bus hits the fly. Which of the two forces is greater: the force on the fly or the force on the bus? Bismark your group, which one did you choose?
264. **Bismark**: Sir the bus.
265. **Teacher**: The force from the bus is greater? Yes Chris.
266. **Chris**: The one from the bus.
267. **Teacher**: The one from the bus. Sam your group?
268. **Sam**: The force on the fly is greater.

As the discourse continued, some of the students became conscious of the fact that if action and reaction are opposite and equal in Newton's third law then the forces should be the same (269 & 273):

269. **David**: So sir, on the third law can we say that one of the force is greater? … Because if the force of the bus is greater than the fly, which means the fly will fall down and the bus will just run on it.
270. **Teacher**: No it created a mess, it means the fly splattered on the windscreen. If you are driving and you hit an insect, you would see that they really create a mess in front of the windscreen. Have you seen that before?
271. **Students**: Yes sir.
272. **Teacher**: And we are asking which of the two forces is greater? Is it the force of the fly on the bus or the force of the bus on the fly? Which one is greater?
273. **David**: Sir, are they not the same, since action and reaction are opposite and equal?

One of the students was able to mention that the windscreen of the bus and the fly would exert equal forces, perhaps after he had intuitively understood "action and reaction are equal…" of Newton's third law of motion (275):

274. **Teacher**: … Yes Frank (referring to Frank's group)?
275. **Frank**: We said both are equal.

Some students did not see action and reaction as forces. They saw action and reaction as two objects involved in the interaction (276 & 278). Possibly, the style of the question by the use of "which one is the action and which one is the reaction" by the teacher might have led the students to think that way. The discourse below shows that:

276. **David**: (*In a low tone*). The action is the bus and the reaction is the fly…
277. […]
278. **Fred**: The fly hits the bus, so he caused the action. And the bus responded the reaction. It reacted back.
279. **Teacher**: Okay, it doesn't matter. You can take any of them, but once you make the force of one of them on the other as the action, then the force also exerted by the other is the reaction. Or vice-versa.

Looking at the fragments under CRQ, it was realized that the question did serve the same purpose of evoking students' misconceptions and creating room for learning as occurred in the first round (263-268). There was less confusion with this question and the students' response was relatively better than in the first round. The misconception of the students that when two objects collide, the bigger one always exerts the greater force was displayed (264, 266 & 268). This wrong idea of the students calls for the need for further learning.

Interactive teaching

One of the major aims of teaching was to improve teacher-students interactions in class. More questions and examples were given to students to relate Newton's third law of motion to everyday activities in their community. Students are very fluent when it comes to definitions of terms, especially with that of Newton's third law of motion due to its conciseness, though they might not fully understand it. In most cases, their lack of understanding could make them use different words. Teachers need to be critical with students' choice of words in defining or explaining laws, as a different word used could imply a different meaning.

In defining Newton's third law of motion, a student used different words to imply Newton's third law; "different direction" to imply "opposite direction" (281). This changed the entire meaning of the law. For two objects to move in opposite directions could mean they have moved in different directions, but to move in different directions does not necessarily mean that they have moved in opposite directions. The protocol below shows such a situation:

280. **Teacher**: Newton's third law. What is Newton's 3rd law? Yes Fred.
281. **Fred**: When an object acts on another object, acts on the second object, the second object also acts with the same force on the first object but in, the same magnitude but different in direction.

282. **Teacher**: But different in direction…
283. **Frank**: Sir, is it in different direction or opposite direction?
284. **Teacher**: It's not, well I understood his different direction. Anyway, it's opposite direction but not different direction. Okay?
285. **Fred**: Yes sir.

Some students were able to give some examples of everyday life applications of Newton's third law of motion (286, 287, 290, 294, 297& 301). These show how students could relate and explain phenomena in their environment with what they are learning in the classroom. This emphasizes that real life examples are useful for the application of physics knowledge:

286. **Fred**: Sir, nailing. If you are nailing a nail into a wood. As you nail, the nail also exerts the same force on the hammer.
287. **Victus**: Sir, kneeling on the wall.
288. **Smart**: When you throw a ball to hit the wall. It bounces back.
289. […]
290. **Isaac**: When one fires a gun.
291. **Teacher**: What happens to the gun?
292. **Isaac**: The recoil force that is the reaction…
293. **Teacher**: Yes, the bullet moves forward, but the force that the bullet used to move forward, there will be the same force that will act on the rifle to move backwards…
294. **Chris**: Paddling a canoe.
295. **Teacher**: Paddling a canoe. Yes, what happens?
296. **Chris**: When you insert the paddle into the water you push it backwards, that is the action and the reaction is the force of the water on the paddle to move the canoe forward.
297. **Bismark**: Sir, swimming. As you are swimming you pull the water backwards and the water will also push you back (*forward instead*).
298. […]
299. **Frank**: Birds flying.
300. **Teacher**: Birds flying. You see, what do they do to the wind?
301. **Frank**: They push the wind (*demonstrating with the hands*) and the wind pushes them.
302. **A student**: When a rocket is moving up.

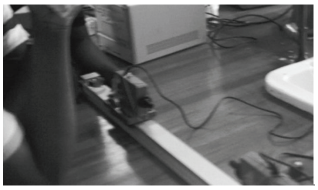
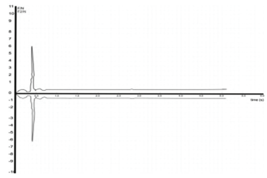
The teaching was more interactive, and students participated fully by giving many examples from everyday life which relate to Newton's third law of motion (286, 287, 290, 294, 297& 301). It made the teaching lively. This confirms that students' minds are not blank slates for information to be added.

Though students could state Newton's third law accurately, it is still a problem for them to believe how a collision between a heavier object and a lighter object will exert the same size of force. The use of MBL was quite helpful in explaining this to students.

Demonstration of Newton's third law of motion using MBL

The demonstrations below deal with two objects having (i) the same masses and (ii) different masses. The demonstration was done as part of the interactive teaching.

303. **Teacher**: …, what explanation can you give to this (*referring to diagram displayed on the screen of the computer after students have collided two carts of the same mass together*)? … Chris, can you explain, can you give us what you did?

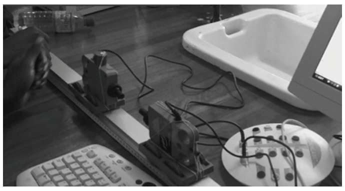
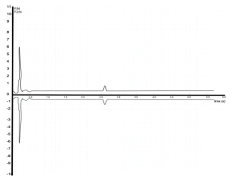



304. **Chris**: Yes sir, we collided two of the… We are trying to…
305. **A student**: Verify Newton's third law.
306. **Chris**: We are trying to verify Newton's third law, that in a collision, two forces, the reactant force, the reaction force and the action force, are equal.
307. **Some students**: And opposite.
308. **Chris**: But opposite. It's independent of the masses in the reaction (*interaction instead*).
309. **Teacher**: So are the masses that you have here, different or the same?
310. **Some students**: The same.
311. **Chris**: These ones are the same.
312. **Teacher**:… So these ones, you are trying to find out what, what will happen between equal masses, when collided?
313. […]
314. **Chris**: (*Explaining F-t graph on the screen*). We could see that, the graph shows in terms of magnitude that forces are equal. That is it, so now we will erase this and then collide a heavier mass with a smaller one.

The demonstration below is when the two objects involved have different masses:

315. **Teacher**: So by adding a heavier mass to one of them …? What do you want to show?
316. **Chris**: We want to show different masses, and find out if they will still give us equal and opposite forces after the reaction.
317. **David**: After the collision (*David trying to correct Chris' statement*).
318. **Chris**: That is after the collision.
319. **Teacher**: Whether you will have the same graph, like what you have here.

320. […]
321. **Teacher**: So why are you adding that mass?

322. **Chris**: To increase this one's mass.
323. **Teacher**: So they are no longer of the same mass?
324. […]
325. **Teacher**: … So what is happening? No, not Chris, another person from the group. Anybody?
326. **Ben**: What we did this time round was to increase the mass in one of the …
327. […]
328. **David**: The mass in one of the bodies that we are putting in motion. So we brought them together, we collided them and we realized that the action and reaction are still the same.
329. **Teacher**: Why are you saying that the action and reaction are the same?
330. **Ben**: Because the law states that irrespective of the mass, the motion after collision will still be equal.
331. **Teacher**: (*Teacher helps students to enlarge diagram*). So what can you say about this on Newton's law? (*Teacher and students observing an F-t graph from a computer screen*).

332. **David**: That both F-t graphs are the same and in opposite directions. That means to every action there is equal and opposite reaction.
333. **Teacher**: So which one is the action and which one is the reaction?
334. **Bright**: Sir, we can take the force of this to be our action and the force of that to be our reaction (*pointing to the diagrams on the screen*).
335. **Some students**: Any of them can be the action and the reaction.
336. […]

The use of MBL to demonstrate Newton's third law to students convinced them that irrespective of the masses involved in the interaction, the size of the forces on each other will be the same. The dialogue below shows this:

337. **Teacher**: … Initially some of you were doubting.
338. **Some students**: Yes.
339. **Teacher**: …, is it true that some of you were doubting?
340. **Some students**: Yes. (*A student said, even me*).
341. **Teacher**: What about this? Has this been able to convince you that Newton's third law is true?
342. **Students**: Yes sir.
343. **Teacher**: That is beautiful. At least it is known that action and reaction are opposite and equal. Okay, it is good, you have done well.

The demonstration on Newton's third law through the use of Coach 6 and force sensors connected to a computer was a good activity to make students conceive the law. They were fully convinced that the law is true (330 & 332). However, from the protocol fragment (line 337 to 343) it could be realized that the conclusion drawn by the teacher was too superficial. He should have asked more questions to be convinced that students truly understand the third law conceptually. As a way to improve the design in future, especially on checking the understanding of students, the teacher has to check more whether the students comply or not.

Reflection

During reflection, students were very confident in responding to the conceptual reasoning question. They were now convinced from what they perceived from the demonstration using the MBL. This is also shown in the chorus response they made in the protocol (345, 347 & 349):

344. **Teacher**: (*Teacher reads the conceptual reasoning question again*)… This is a clear case of Newton's…
345. **Students**: (*Chorus answer*). Third law.
346. **Teacher**: It's accepted. (*Teacher reads the second question*). The fly hit the bus and bus hits the fly. Which of the two forces is greater; the force on the firefly or the force on the bus?
347. **Students**: (*Chorus answer*) Equal force.
348. **Teacher**: There will be…
349. **Students**: Equal force.
350. **Teacher**: No longer the force of this or…
351. **Students**: Yes sir (*to indicate no*).

There was no major confusion during the reflection, hence the reflection took less time. Looking at the protocol (lines 344-351), it could be seen that the teacher concentrated only on the right answer, but did not allow students to redress their initial ideas. To improve the design the teacher should give the students more opportunity to explain their initial ideas.

Application questions

In answering the application questions, some students stuck to the use of mentioning objects as action and reaction instead of "force with which one object acts or reacts on the other". Teachers need to emphasize that it is not the object which is the action or the reaction, but the force of the object on another. The fragment depicts that:

(1a) Identifying Action and Reaction Force Pairs in the following

The ball pushes the stick rightwards.

(1b)

Baseball pushes glove backwards.

(1d)

Enclosed air particles push balloon wall outwards.

(1d)

Bowling ball pushes pin backwards.

352. **Dan**: …, so throwing of the ball is the action and the hitting of the ball will be the reaction.
353. **Teacher**: The throwing of the ball. It is not the throw. The action and reaction come into play when the two come into contact.
354. **Dan**: So the ball is the action.
355. **Teacher**: The force of the baseball on the stick to the right is the action and which is the reaction.
356. **Dan**: The stick on the…
357. **Teacher**: The force of the stick on the ball to the left.
358. **Dan**: The force of the stick on the ball to the left is the reaction.

The teacher made an effort to guide students on how to explain action and reaction:

359. **Teacher**: A baseball pushes gloves backwards. So which should be the action and which should be the reaction? Yes another person, Bismark.
360. **Bismark**: The force of baseball is the action.
361. **Teacher**: The force of baseball on what?
362. **Bismark**: On the gloves backward is the action, …, while the force of the gloves forward is the reaction.
363. **Teacher**: On what?
364. **Bismark**: On baseball is the reaction.
365. **Teacher**: Okay, the third one. Enclosed air particles push balloon wall outwards. So which is the action and which is reaction? Yes Fred.
366. **Fred**: Sir the force of the enclosed air particles is the action and the..
367. **Teacher**: The force of the air particles on what?
368. […]
369. **Fred**: Force of the enclosed air on the balloon.
370. **Teacher**: On the wall of the balloon.
371. **Fred**: Force of the enclosed air particles on the wall of the … balloon is the action, and the force of the wall of the balloon, towards the enclosed air particles is the reaction.

After the teacher's effort, one of the students answered the fourth question as they had been taught:

372. **Teacher**: … The bowling ball, yes Bright.
373. **Bright**: The force of the bowling ball on the pin backwards is the action and the reaction is the force of the pin on the bowling ball forward.
374. **Teacher**: … You have to explain, the force of this on that and the direction, remember the directions should be opposite, and this on that …will give you the action and reaction. I hope it is clear?
375. **Students**: Yes sir.

Dan was still identifying objects as the action-reaction force pairs when he answered the application questions (354 & 356). The teacher guided the students to the correct way of interpreting Newton's third law (361-371, 372-375). There was less confusion and the task was accomplished within time.

Conclusions on teaching Newton's third law of motion

In the field test of the first design, we found that the awareness of the need for further learning was not created in students by one of the CRQs, due to its ambiguity. Teaching was basically a traditional lecture and almost all students found it difficult to correctly describe the application questions which were on action-reaction force pairs.

In the revised design for the second trial, our aims were to use the CRQ to create the awareness of the need for further learning in students, to improve teacher-student interactions in the lecture and to include more real life examples on Newton's third law of motion. More examples on identification of action-reaction force pairs were included in the application question to improve students' understanding. In summary we found:

- Students' response to CRQ in the second round was better than in the first round. The material used did evoke students' misconceptions and created awareness of the need to learn in students.
- More examples and questions used in the interactive teaching gave students the opportunity to relate Newton's third law of motion to everyday activities in their community. The demonstration aspect, using MBL, was still meaningful in illustrating the third law.
- During reflection, students revised their initial ideas. The interactive teaching was useful in clarifying and explaining Newton's third law.
- In the application questions some students could not properly identify action-reaction force pairs. They had some idea, but found it difficult to put their idea in correct physics language. They were able to correct themselves after some guidance from the teacher. This activity has been successful in polishing students' way of answering action-reaction force pair questions.

6.4.5 Problem solving session

In the problem solving session students had to solve selected problems on Newton's first, second and third laws, with both qualitative and quantitative questions.

We analysed three aspects of the problem solving session: (1) the quality of the teacher-student interactions, (2) the level of mastery improvements in relation to the teaching sections, (3) and remaining difficulties in learning of the students. Note that in traditional problem solving sessions the lecturers were solving selected questions in their entirety for students to copy.

To make it more interactive, students were made to work on the questions in the week before the session and present their solutions verbally or on the whiteboard for their peers to ask questions, especially if they do not agree. The teacher remained as an observer and came in to clarify situations where necessary, to scaffold students' ideas, when he realized "bankruptcy" in their ideas, or to ask important questions when relevant.

The problem solving session was also used to supplement interactive teaching: students who had questions during the interactive teaching period, but could not get the opportunity to ask, could bring them to the problem solving session to be discussed.

During the second round of the problem solving session, some of the questions which were used in the first round in CRQ and application question activities, but which were no longer used in the second round, were added to the problem solving questions. It was expected that students would have more time to deliberate and grab the central idea of the questions.

About 25 questions were used. Most problem solving questions from Hewitt (2010) and The Physics Classroom (n. d.) were used due to their interactivity evoking nature. The questions discussed here are some selected questions which students answered on Newton's three laws of motion. The selection of the questions used in the analysis was based on the added value of the protocols as compared to the teaching session and last year's performances, for instance in their reasoning on the CRQ. For example, fragments with vivid and productive discussions where students were going in the right direction, in contrast with some performance on the conceptual reasoning question, are highlighted. Remaining difficulties of students will be identified.

Selected questions on Newton's first law of motion

The aim of the first question was to give students the opportunity to relate a real life situation to inertia:

> Q1. A coin was put on a card and placed on a glass. Why will the coin drop into the glass when a force accelerates the card?

A student applied his own understanding, but did not relate it to inertia:

> 376. **Isaac**: I am saying, if the upward force is taken away then acceleration will act on the coin to fall.

However, the answer was improved by another student by applying Newton's first law of motion:

> 377. **Chris**: To add to that, the coin will like to retain its state of rest since the acceleration is applied to the card. The coin will like to remain at that state. So while it still remains here

because the other force is going the other way, it will drop because the force of gravity is pulling down on the coin.

378. **Teacher**: And why will it like to stay in that position?
379. **Chris**: Because of Newton's first law, inertia. The tendency to resist change of motion.

As expected, Chris gave a correct response to the answer (377 & 378). This might be because of being at a later stage in the learning process. At this point the problem seems more productive than when it was used last year as one of the conceptual reasoning questions.

Question 2 was to see how students could apply the relationship of mass and inertia (tendency of an object to resist changes in motion) to determine a more massive object:

Q2.Two bricks are resting on edge of the lab table. Victoria stands on her toes and spots the two bricks. She acquires an intense desire to know which of the two bricks are most massive. Since Victoria is vertically challenged, she is unable to reach high enough and lift the bricks; she can however reach high enough to give the bricks a push. Discuss how the process of pushing the bricks will allow her to determine which of the two bricks is most massive. What difference will Victoria observe and how can this observation lead to the necessary conclusion?

A student applied his knowledge on the relationship of mass and inertia:

380. **Rex**: So in order for her to determine the most massive one, when she gives them the slightest push,… The slight push, the one that will rise with the most opposing resistance. That will be the massive one.
381. **Teacher**: The one that will do what?
382. **Rex**: That will, eh, resist the greatest change in movement, that will be the massive one.

Rex was able to extend his understanding in Newton's first law of motion to solve a problem that requires an application of the law as expected. His deductions to arrive at the answer signify his understanding of inertia (380-382).

This aim of this question 3 was to find students' appreciation of the fact that irrespective of the environment, a stationary object would require a force to set it into motion. Thus to find out whether students see Newton's first law to rule everywhere:

Q3.Supposing you were in space in a **weightless environment**, would it require a force to set a stationary object in motion?

A student who understood "weightlessness" to mean a body without weight, answered the question wrongly. He was, however, salvaged by another student:

383. **Ben**: Sir I think weightless bodies are not affected by force of gravity.
384. **Teacher**: No, it says, supposing you were in space in a *weightless environment*, would it require a force to set a stationary object in motion? That is the question.
385. **Ben**: My answer is no.
386. **Teacher**: Yes who has got a different answer? (*Some students raise their hands*). Yes.
387. **Isaac**: I will say, yes, because even in space bodies have mass. So if it has mass, it will have inertia and it will require a force to set it in motion once it is stationary.

Ben did not answer the question as expected. He seems not to apply Newton's first law universally (383 & 386). However, Isaac applied the law everywhere and was able to support his answer with a better reason (387). Though the answers provided by students to this question in both first and second rounds were similar, Isaac was able to argue in line with Newton's first law of motion, in contrast to students in the previous year.

Question 4 was to find whether students acknowledge the fact that, when the forces acting on an object are balanced, either it does not move or it moves with a constant velocity. This is because often students think in such circumstance that the object will not move:

Q4. If the forces acting upon an object are balanced, then the object could (a) not be moving. (b) be moving with a constant velocity. (c) not be accelerating. (d) none of these. (*Choose those that could be possible*).

Students could identify the effect of balanced forces on an object:

388. **Victus**: Sir if the forces acting on the object are balanced then the object could not be moving and I say for "a" it can be moving but not always moving. Because when you consider an object on a table, when the forces are balanced the object can be, the object would be at rest. But when you consider an object falling, when the object reaches a point when the forces on it are balanced but it is moving with a constant velocity but it is still moving. Could not be accelerating. So it is not necessarily "d". So sir, could be moving with a constant velocity.... "a", "b" and "c".
389. **Teacher**: "a", "b" and "c". Do you agree to that?
390. **Students**: Yes sir.
391. **Teacher**: Hei Evans, do you agree to that?
392. **Evans**: The "b" is correct alright, but I also think the "a" is also correct. (*He waited for a while*) Yes a, b and c.

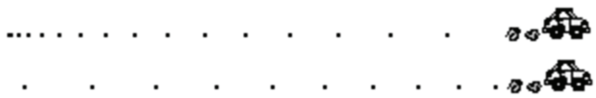
Students could now appreciate the fact that when the total force acting on an object is balanced, the object could move with a constant velocity (388 & 392), which was a bit difficult for them to understand during the CRQ and interactive teaching. From Victus' explanation, it might be that further discussions with colleagues before the problem solving session might have improved their understanding of such problems.

Students were mostly able to argue in line with Newton's first law of motion. However, some conceptual difficulties still remained. For example, some students found it difficult to apply Newton's first law of motion universally (everywhere), especially in a "weightless environment".

Selected questions on Newton's second law of motion

The aim of question 5 was to see how students could transfer their knowledge in dot diagrams to establish the relationship between velocity and acceleration, and between acceleration and net force on a vehicle:

Q5. Consider the two oil drop diagrams below for an acceleration of a car. From the diagram, determine the direction of the net force which is acting upon the car.



Students might have transferred the knowledge gained in answering the dot diagram application question to solve this. This is shown in this fragment:

393. **Teacher**: Yes. Is it your turn Obed?
394. **Obed**: Question 14, we are to determine the direction of the net force acting on the car. So for diagram 1, I can see that the car is accelerating from left to right. So the acceleration is in the rightwards direction. And if the acceleration is in the rightwards direction, then the force will also be in the rightward direction ... And for the 2nd diagram, the car is slowing down. That means, it started with a higher velocity and is slowing down from left to right. And if it is slowing down from the left to the right, that means the acceleration is in the leftwards direction. So therefore the net force will also be in the leftwards direction.
395. **Teacher**: Do you agree?
396. **Students**: Yes sir.

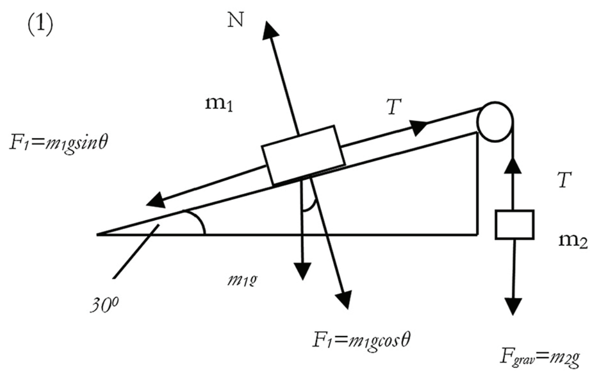
Obed could transfer his understanding of the relationships of the variables (acceleration, mass and force) of the equation of Newton's second law of motion to solve qualitative problems in real life activities as expected (394).

The aim of Q6 was to find out how students could apply their conceptual understanding of Newton's second law of motion to solve a two-body question on an inclined plane:

Q6. A block of mass m_1 = 3.50 kg on a frictionless inclined plane of angle 30.0° is connected by a cord over a massless, frictionless pulley to a second block of mass m_2 = 2.30 kg hanging vertically. (1)Draw a free body diagram to represent this.(2)What is the magnitude of the acceleration of each block? (3) What is the direction of the

> acceleration of m_2? (a) m_2 accelerates downwards (b) not enough information (c) m_2 accelerates upwards (4) What is the tension in the cord? (Take g=10 m/s^2).

Students failed to answer this question correctly as expected. They claimed it was completely new to them. However, there was a good attempt made by one of the students on the sketching of the body diagram, though ultimately his solution was wrong:



The student first calculated acceleration for body one, without taking into account the effect of body two:

$$F_1 = m_1 a_1 = m_1 g \sin\theta$$

$$\Rightarrow m_1 a_1 = m_1 g \sin\theta$$

$$a_1 = \sin\theta$$

$$a_1 = 9.8 \sin 30$$

$$a_1 = 4.9 \text{m/s}^2$$

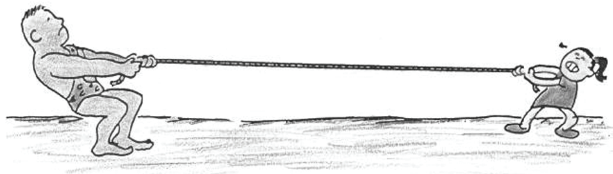
He continued with the same trend and calculated the acceleration for body two without considering the fact that it was connected to body one. In effect, his solution was wrong, because he considered the acceleration of the two bodies separately. The teacher recognized this, and worked out the problem with students in the classroom.

Students were able to reason well with the transfer of Newton's second law of motion to solve the first qualitative problem. They, however, failed in solving the quantitative problem, which was earlier thought to have been easier, due to students' interest in solving quantitative problems. The reason might be that the question was too difficult and was misplaced in the problem solving session. If such problems could be used in this session, students should be introduced to how to solve a two-body diagram in the interactive teaching.

Selected questions on Newton's third law of motion

The aim of question 7 was to find how students could apply their understanding of the demonstration of the Newton's third law of motion with Coach and force sensors during the interactive teaching to answer a real life activity in a tug of war contest:

Q7. Paul and Josephine pull on opposite ends of a rope in a tug of war. The greater force exerted on the rope is by (i) Paul (ii) Josephine (c) Both the same.



Students could apply Newton's third law to choose the correct option of the force that is exerted on the rope by both people pulling on the rope:

397. **Teacher**: Okay Frank, your question.
398. **Frank**: It's "c".
399. **Teacher**: It's "c".
400. **Frank**: Action and reaction are opposite and …
401. **Teacher**: Equal, do you agree?
402. **Students**: Yes sir.

Students answered this question better than the previous year's students when it was used as one of the conceptual reasoning questions. This might be because of the later position of the problem in the learning process.

The aim of question 8 was to find how students could apply their understanding of Newton's third law of motion to the acceleration of a bullet and a rifle when fired. It was expected that the students would say acceleration was equal for both the gun and the rifle:

Q8. Many people are familiar with the fact that a rifle recoils when fired. This recoil is the result of action-reaction force pairs. A gunpowder explosion creates hot gases which expand outward allowing the rifle to push forward on the bullet. Consistent with Newton's third law of motion, the bullet pushes backwards upon the rifle. The acceleration of the recoiling rifle is...

a. greater than the acceleration of the bullet.

b. smaller than the acceleration of the bullet.

c. the same size as the acceleration of the bullet.

In this question, it was realized that some of the students thought both objects, with different masses, will have the same acceleration as expected, due to the fact that acceleration is directly proportional to force (Newton's second law), thus extending the application of Newton's third law wrongly (403, 406 & 408):

403. **David**: The acceleration of the recoiling rifle is the same size as the acceleration of the bullet.
404. **Teacher**: Do you agree?
405. **Students**: Yes sir.
406. **David**: Sir, because the forces are the same, and since…
407. **Teacher**: If forces are the same, it doesn't mean that acceleration should be the same.
408. **David**: Since force is directly proportional to acceleration.

The teacher capitalized on this question to explain to students why the acceleration would not be the same for cases where the masses are different:

409. **Teacher**: … Even what I have explained here should have given you the clue (*Teacher was referring to an earlier explanation, so he moved to the board*). Bullet and the rifle which one is heavier?

Force of rifle = Force of bullet

$$(mass_{bigger} \times accel_{smaller})_{rifle} = (mass_{smaller} \times accel_{bigger})_{bullet}$$

410. **Students**: The rifle.
411. **Teacher**: The rifle is heavier. (*Teacher writes on the board*). The mass of the rifle is bigger, so it accelerates very, very ….
412. **Students**: Small.
413. **Teacher**: And the mass of the bullet is…
414. **Students**: Small.
415. **Teacher**: Very small, hence its acceleration is very, very fast. Do you get it? (*Teacher explains it on the board*).
416. **Students**: Yes sir.
417. **Frank**: Even in reality it happens, you will see the bullet moving fast, while the gun moves slowly.
418. **Teacher**: The "b", smaller than the acceleration of the bullet, will be the correct answer.

Students failed to answer the second question on "acceleration of rifle and bullet" correctly. The reason for their failure might have been that such examples were not used in the interactive teaching. Such examples should be considered earlier in the learning process, for example, the question on the collision of equal forces between the bus and fly (different masses) could be extended to include different effects on objects' acceleration.

Conclusions on problem solving

In the first round analysis of the problem solving session we found that it motivated students to come to the session prepared and that this improved peer discussions. Our aims now were to encourage students to be better prepared the session, share ideas and do more discussions with their peers, and answer questions that seemed difficult in the activities during the first round. In summary we found:

- Most students could answer the majority of the questions, indicating that they came to the problem solving session prepared and could also answer similar questions which were initially difficult, through sharing ideas with their peers.
- More teacher-student interactions occurred during this session. The teacher subjected students to many questions, as a way to be sure of their understanding.
- The materials contained good practice questions for students. The quality of the students' reasoning was better than experienced in the previous year and the level of teacher-student interactivity was quite remarkable in the problem solving session. The questions were good to identify students' remaining difficulties to provide the necessary solutions. However, there is still room for improvement. Examples that are similar to questions that students find difficult to solve in this session should be discussed earlier in the interactive teaching. Also, misplaced questions should be changed to those that will be suitable for students.

6.4.6 Conclusions of the sessions on Newton's laws of motion

Evaluation of students' in-depth analysis of classroom episodes showed that improved measures and conditions adopted in the materials and activities of the design led to an improvement in the second round answers compared to the first round. Classroom interactions had been enhanced, mastery of content and quality of reasoning in solving qualitative problems had improved compared to the first round. This is not to conclude that everything was perfect. We will give some examples and suggestions for improvement in the next section.

6.5 Conclusions about the second round of teaching

In this revised design, we had aimed to improve the quality of the classroom discourse, and thereby improve the effectiveness of the course. As in the first round, the learning gains (insofar as these could be assessed using the FCI-test) were in line with the average for interactive engagement course, and much above the typical result for a traditional classroom. Although the post-test results were a bit better compared to the first round, the same applies for the pre-test, so that the learning gain is not significantly different for the first and the second round.

Still, the classroom process was the main focus for improvement, and the main interventions towards that end involved refining the concept quizzes and conceptual reasoning question, so that they would lead to productive discussion, and on inserting interactive elements in the lecturing parts. In our evaluation we found marked improvements in the amount of classroom discussions and the quality of reasons in the answers given by students. The positive judgment about the quality of the classroom process was confirmed by the comments from a colleague who had been observing all teaching sessions in her role as a "critical friend". The learning outcomes were also slightly better than in the first round of evaluation, but the difference was not significant. Students' opinions about the course were very favourable again, like they had been in the first round of evaluation. The difference between the two evaluations was not significant. A more remarkable, and perhaps disappointing, finding was that students were also equally positive about their experiences in high school. A caution when interpreting this finding is that the students' opinions about their high school experiences were gathered only before the start of the current course, so that the students never had an opportunity to compare the two. Looking back, an improvement could be to ask the students about the high school experiences at the end of the course as well.

For the concept quizzes, the number of questions had been reduced, the fit of the questions to the topic of the reading assignment had been improved, and ambiguous questions had been replaced or reworded. The joint effect of these improvements was that the time needed to discuss the questions in class was substantially reduced, and that students who had done their homework well could succeed in answering the questions. Students' scores on the concept quizzes seem to suggest that they did come prepared. Although we have no independent measure to confirm this, the discussion fragments sometimes seem to indicate this.

Likewise, for the conceptual reasoning questions, for each theme we kept only one question that was most successful to bring out student ideas. As a consequence, students' discussions were more focused on physics ideas rather than on confusion about the situation at hand. In a few cases, the conceptual reasoning question still needs further optimization. As an example, the conceptual reasoning question on Newton's second law of motion, on the falling of the parachutist, was too remote from daily life for many students to properly imagine. Our observations illustrate that, in order to have a productive conceptual reasoning question, it is crucial to have clarity of wording, a situation that is meaningfulness to the students, and a good fit to the physics principle at hand.

In the lecturing part, in order to promote students' engagement, some open reasoning questions about real world situations were inserted. In general, students made successful contributions towards answering these questions, and their answers indicated how their understanding progressed beyond the levels they had exhibited in the conceptual reasoning questions. In addition to keeping the students engaged, this approach yielded useful feedback for the instructor on students' understanding.

For some concepts it was observed that students had little concrete ideas or experiences to relate to. An example is the air friction on a falling object to relate its velocity, acceleration and the force on it. However, there is room for improvement, especially in making students visualize the effect of friction on a falling object's velocity, acceleration, and the force on it by a demonstrational activity of a pebble moving down in a liquid friction in a long measuring cylinder through the use of Coach and motion sensors. Students could be convinced when they see real situations happening, especially through the use of MBL tools. For example, a demonstration with the use of MBL tools cleared students' doubts about the application of Newton's third law in real situations.

The problem solving questions improved group discussions. However, sharing of ideas among students, cooperating with their peers and making students more responsible for their own learning could further be strengthened when appropriate problems/ questions, projects and assignments are designed for the students to solve on their own.

Aside from having a good educational design with a sound physics content, it is an essential requirement for an interactive classroom that students feel free and challenged to voice their opinions, and to alter their positions. From what we have seen, and from the critical friend's comments, it turned out that we have been successful in creating such a demanding and safe atmosphere. The teacher has been well aware of this, and was cautious to be inviting and respectful towards the students' opinions, while yet being critical about factual correctness.

In effect, classroom interactions had been enhanced and that led to the quality of reasoning in solving qualitative problems and mastery of contents that were experienced in the second round more than those in the first round. However, there were still some didactical functions, which needed to be sharpened. For example, the conceptual reasoning question (CRQ), interactive teaching and reflection should show coherence. That is to say, the CRQ should cause different opinions among students, so that awareness of the need to learn further will be created in students. In cases where all students agree on one particular answer or where disagreement among students' answers is not easily recognized, the teacher should use his skills to create some disagreement in students' opinions, either by suggesting a different opinion, which could be supported by some of the students or by himself. The interactive teaching should reflect on the discussion of similar situations of the CRQ, but not the same. The teaching should not reflect on examples that will relate directly to the CRQ, so that students could make deductions from the teaching to improve on their answer during the reflection stage.

Reflection should redress students' initial thinking or response. The teacher should not only concentrate on the right answers produced by students, but should ask probing questions to redress students' initial thinking. In that situation, students could improve their conceptual understanding.

In the next chapter, we will give conclusions of the entire study, discuss findings, reflect on what the researcher has come to realize during the period of his research work and make recommendations to improve interactive teaching and learning. Suggestions for further studies in this field will also be presented.

Chapter 7

Conclusions, reflections and recommendations

7.1 Introduction

In this chapter we will firstly give an account of the main results of the study. We will follow it up by discussing limitations of the research method used and reflect on what the researcher has come to realize over the four-year period of his research work. Next, we will give recommendations for further research, and for teachers setting up interactive engagement courses in similar contexts. The chapter ends with recommendations for teaching universities and agencies in Ghana.

7.2 Overview and overall conclusions

The predominant mode of physics teaching in most Ghanaian schools places a heavy emphasis on lecturing, memorising definitions and formulas, and applying them to standard problems. As a result, students are used to rote memorization of formulas and many of them try to avoid questions that require qualitative reasoning and verbal explanations. This traditional method of teaching by telling does not help students to grow in their reasoning ability, which was reflected in the low ranking in science of Ghana's eighth graders (JHS 2) in the international comparison studies TIMSS 2003 and 2007. The aim of this research was to investigate the potential of interactive engagement teaching for learning mechanics in the Ghanaian university context. The main focus was on how to improve students' conceptual understanding in a first year university mechanics course. This requires an approach where all students would get involved in the teaching and learning process, and would be responsible for their own learning. Interactive engagement teaching was introduced to see how it could offer students opportunities to interact more and participate fully in class, and develop scientific reasoning skills to analyse, argue and evaluate scientific problems, and to also acquire quantitative problem-solving skills. We wanted to find out whether the interactive engagement approach, which is a western cultural perspective of teaching, will fit with Ghanaian cultural practices and to also find out students' experiences with research-based instruction, such as whether interactive engagement teaching will affect them positively or not. Most Ghanaian students tend be conservative and it would be necessary to find out if they would prefer the use of the traditional lecture by showing resistance to the new interactive engagement approach in teaching. The major research question in this study was:

> *How could the understanding of mechanics be promoted through interactive engagement methods among undergraduate physics students in the Ghanaian educational and cultural context?*

In order to answer this question, a set of design guidelines has been identified from the international research literature. Based on these guidelines, a mechanics course has been redesigned and implemented at the University of Education, Winneba to evaluate how and whether interactive teaching practice could be effectively attained. In the evaluation, the focus was on answering the following questions:

- How does interactive engagement work in classroom practice?
- How do students appreciate interactive engagement teaching?
- Does the revised course lead to gains in conceptual understanding?
- What is the long term effect on students' ideas about interactive engagement teaching and learning?

7.2.1 How does interactive engagement work in classroom practice?

In order to promote interactive engagement we introduced a series of activities aimed at stimulating interactivity among students and students' maximum participation during class meetings. The major questions with regard to the classroom process were how to make sure that students come to the meeting prepared, ensure quality dialogue/ discourse among peers and with the teacher, relate and practice physics concepts to multiple real-world contexts, encourage students to reflect on their initial ideas and responses, scaffold students' constructive learning process and create a safe, inviting and ambitious classroom culture. We used the observational data of how students responded to the activities which were based on the design guidelines to assess these points.

The teaching necessitated the students to come prepared; the observation was that initially the students were not well prepared, and after a while they came to the meetings better prepared. The key element or explanation to that could be due to the quiz, which was part of their assessment. Also, with the tutorial/problem solving session, students did a lot of preparatory work before coming to the meetings because they were made to submit some of the questions as an assignment, which also formed part of their assessment, and they were called to provide answers or explanations to questions during the problem solving session.

Open high quality dialogue/discourse with peers and the teacher; the observation was that students did barely voice their opinions at the initial stages of the meetings, but as the meetings progressed they expressed their opinions with increasing clarity and justification. This could be due to the activities that motivated them to speak up. By using the method of interactive teaching the teacher could ask some questions that would cause students to think deeply to justify their answers. Also, the use of clear tasks enabled students to have open, high quality discourse among themselves due to the tasks being devoid of ambiguity which could call for divergent opinions and answers.

Relate and practice physics concepts to multiple real-world contexts; the observation was that initially students were not interested in some of the real world contexts. Some examples looked foreign and quite confusing. For instance, examples based on skating on ice and the use of a falling parachutist did not fit the common Ghanaian experience. With the use of real world examples that are found within the students' environment, it gave them a better understanding, especially when there was the need for them to solve problems. This was evident in the quality of the answers they provided.

Hands-on experience with real objects and/or computer tools; the observation was that in some cases students were still not showing a good understanding of concepts despite several examples relating to real world activities. The key element which made students have hands-on experience with real objects and/or computer tools was to let them verify a phenomenon to ascertain the truth or accuracy of a phenomenon or law by doing it themselves. For instance, some students did not believe that when two unequal masses collide the force that is exerted on each other should be equal. After they had hands-on experience with the use of an MBL tool to verify the situation, they did believe that unequal masses of vehicles exert equal forces on each other when they collide.

Students are encouraged to reflect on their initial ideas and responses; the observation was that students stuck to their original ideas (prior misconceptions) at the initial stages, but as the meetings progressed they revised their originally held opinions. The key element to the revision of their initial ideas could have been due to the way scaffolding was provided to promote students' learning in the answering of questions during the interactive teaching. Thus scaffolding by providing hints, clear explanation of questions/tasks and asking further probing questions during the interactive teaching made students understand concepts better and change their initial ideas at the revision level (during reflection). This was the main reason why we changed the traditional lecture approach in the first round of teaching into the interactive type of teaching during the second round.

Constructive learning processes are being scaffolded; the observation was that students found it difficult to work as planned sometimes, in terms of conceptual understanding and time limit. The key purpose of scaffolding students' ideas was the need to guide and enhance their conceptual understanding because of their failure to grasp concepts on their own and also to work within time.

Creating a safe, inviting and ambitious classroom culture; the observation from the critical friend was that the teacher was too harsh sometimes and students ridiculing their peers inhibited their maximum participation in class. The key elements that led to the creation of a safe, inviting and ambitious classroom culture were to make the teacher friendlier and allow students to express their opinions without any apprehension or fear of being ridiculed to encourage maximum cooperation and participation.

7.2.2 How do students appreciate interactive engagement teaching?

The major components of student appreciation were conceptualised as their acceptance of the new method, cohesiveness, cooperation, instructor's support and their attitude towards physics teaching and learning. To assess students' appreciation we used interview and questionnaire items. Students indicated that they did like the interactive engagement approach. They enjoyed all activities, and were of the view that the activities did help them to participate actively in class, which in their view contributed to their conceptual understanding of mechanics.

They further suggested that interactions (student-student, teacher-student and around the use of computer tools) in classroom had led them to improve in their cohesiveness and cooperation. They shared books and resources with other students when doing assignments, there was team work in group assignments and projects, and were committed to helping each other. On attitude towards physics and learning, students were affirmative that the interactions were fun and lively, and motivated their interest in physics. They further added that teacher-student interactions improved the instructor's support; made the teacher take a personal interest in them, that he helped them when they were in trouble, that he was interested in their problems and understood them, and moreover his questions helped them to understand concepts better. Though the anticipated risk was that students would be reluctant to participate and to voice their opinions with respect to their background of how they study in class, there was no objection by the students in practice, as they did accept the new approach and contributed effectively.

Before the course, students were asked to answer questionnaire items on their attitudes towards physics and learning environments in senior high school and after the course, reflecting on the new approach of interactive engagement which was used to teach them mechanics at the university. It had been expected that students would not like the traditional lecture approach at SHS and would rate it low at the beginning of the university mechanics course, and would like the interactive teaching, which they would rate high after the course. Comparing the questionnaires, it turned out that students rated their senior high school (SHS) traditional lecture method and the university interactive engagement teaching almost at the same level. This was also contrary to their views in the interview, in which they showed higher appreciation for the interactive engagement method in comparison to the traditional lecture method at the SHS. The lack of difference in the questionnaires could perhaps be due to the fact that they filled out the questionnaire about their high school experiences before they had experience with the interactive engagement approach.

Reflecting on the major research question, we were in advance not too sure whether the implementation of interactive engagement teaching would work well in the Ghanaian classroom, given the context of respect of elders, and the passive habits of students who are so used to the traditional mode of teaching, where they just had to listen to the teacher. However, the use of an interactive engagement approach in teaching in Ghana seems to be feasible, as students did contribute effectively and appreciated this type of teaching and learning.

7.2.3 Does the revised course lead to gains in conceptual understanding?

To assess students' gains in understanding, the main instruments were the force concept inventory (FCI), the test of understanding graphs in kinematics (TUG-K), the mechanics baseline test (MBT), the end of semester examination and the transcription of selected episodes of video. FCI and MBT are multiple-choice standardized tests designed to assess students' understanding of the most basic concepts and quantitative problem solving skills in Newtonian mechanics. TUG-K is also a multiple-choice standardized test designed to assess students' graphing abilities and their interpretation of kinematics graphs.

The study revealed that students had a significant gain in conceptual understanding of Newtonian Mechanics and fluency in problem solving skills. They had better understanding of concepts and could transfer the new knowledge acquired in solving new but similar quantitative problems. Students' gain in FCI did show that they had improved in conceptual understanding of Newtonian mechanics. Their scores in MBT signified that not only had they improved in conceptual understanding, but they were also fairly able to solve quantitative problems, which require a good grasp of concepts before one can solve these standard set of problems. Furthermore, students showed good conceptual gains in understanding of kinematics graphs especially in calculating the area under graphs, knowing the meaning of slopes of graphs, calculating their values, and describing graphs and graphs transformations.

Students' way of answering qualitative questions, in terms of reasoning, analysing and evaluating improved over time. Transcriptions of selected episodes of video revealed how students could apply their conceptual understanding of Newton's laws of motion to solve problems related to them.

In most instances, when convinced, students could reject their previously held belief and accept the more scientific and meaningful explanation that is applicable to all situations. This was an affirmation of the fact that they had declined their previously held misconceptions.

Students' interactions with microcomputer based laboratory tools made them visualize some concepts they found difficult to understand. Students could answer questions on "How do we know…?", "Why do we believe…?", and explain the outcome of a demonstration using qualitative reasoning without equations.

Though the classroom interactions did seem to contribute to improving students' conceptual understanding, there were still some topics/concepts which students found difficult to grasp. For instance, the concept of relating the equation of Newton's second law of motion to a falling parachutist was a bit difficult for students to understand. However, they showed good improvement in understanding Newton's first and third laws of motion.

7.2.4 What is the long term effect on students' ideas about interactive engagement teaching and learning?

This is to determine whether students would still maintain their positively held views about teaching and learning with the interactive engagement approach in teaching after some time. To assess the long term effect on students' ideas about teaching and learning, we used a retention interview. From the interview conducted six months after the study, it appeared that the students still had their initial positive reactions on the use of classroom interactions. They maintained that the interaction through the use of activities did help them to express their own ideas, gain confidence in doing their reading assignment, practicing and applying what had been learnt. They were of the view that it promoted their learning engagement, such as concentration, thinking, discussion and deep understanding.

Students reported that the course had made them take self-initiative in learning (learning without having to be told), discuss and share ideas with their peers in assignments and continue to use group discussions to solve textbook problems and to grasp the meaning of concepts. They attributed these positive qualities to the use of the interactive engagement approach in teaching. They could explain and solve conceptual physics problems, not just mathematics problems in physics clothing.

7.2.5 Concluding remarks

It could be concluded that interactive teaching is feasible and worthwhile in the University of Education, Winneba (UEW) mechanics curriculum. The use of design activities brings more interaction and participation to the classroom, students like it, the interactive teaching does promote conceptual understanding and it seems to change students' views on teaching and learning, which is particularly relevant in a teacher education programme.

However, it was realized students were doing well in understanding concepts in some topics, whereas in other topics they had problems to grasp the concepts properly. Also, some design principles were more strongly implemented than others. For instance the use of open high quality dialogue/discourse with peers and with teachers and a safe, inviting and ambitious classroom culture were applied in almost in every situation, whereas hands-on experience with real objects and/or computer were only used on one occasion.

7.2.6 Discussion

This study was conducted in the context of a Ghanaian university, where relatively little work has been done in this field. Given this situation, the researcher had to make certain decisions for the smooth and effective implementation of the mechanics course to achieve better results. Though the decisions used in the research seemed a good choice to improve classroom interactions and students' conceptual understanding in mechanics, there are, however, some limitations, which made it hard to draw conclusions about the optimum effect of the use of the approach. These could be useful to future researchers who would like to do similar studies. These are discussed as follows:

- The study covered the full redesign of an eleven-week course. The redesign of the entire course limits the attention that can be spent on optimizing every single detail of the teaching and learning process with respect to the topics treated. However, since the focus of the study was on implementing a radically different teaching approach, which the students would have to get used to, using a few weeks would have made it difficult for them to get into the mood.
- There is also lack of evidence of previous work done in this area of interactive teaching in the Ghanaian educational university context. In view of this, the study could not be compared with any other study or work to assess its effectiveness. The lack of comparison group made it impossible to conclude or draw a hard conclusion that the interactive engagement approach led to the optimum benefit of the students. The physics education unit had a limited staff capacity when the research was being conducted, and the lecturers concerned were already overloaded with many credit hours of teaching. This made it difficult to collaborate in an intensive way with other colleague lecturers, as regards the teaching of the mechanics course. This circumstance led to the researcher teaching the course by himself.
- The study was conducted in only one course, at one university, with one instructor. This of course limits the generalization of the results. However, given the situation at the outset of the research, both in terms of available knowledge and in terms of resources, this still seems a justified choice. Firstly, given the practical circumstances,

it would not have been feasible to conduct the study in both teaching universities in Ghana. The two teaching universities in Ghana are about 80 km apart, there is little institutional collaboration and they offer rather different programme structures. Secondly, if trying out an innovation for the very first time, in a very different fashion, it is quite reasonable to start with the proof of existence before extending a full scale evaluation in other institutions. Being both the researcher and the teacher might not be the best position to make an objective analysis of what the teacher and the students are doing, because one might see what one wants to see. To compensate partly for this, the researcher employed techniques such as involving a critical friend to critique his teachings and evaluate the opinion of the students, and analysing video- and audio- recordings of classroom sessions. The researcher also discussed transcriptions of the protocols with his co-researchers.

- There were some practical disturbances which occurred during the implementation of the interventions in the classroom. Unforeseen contingencies like strike actions by lecturers did not allow the entire completion of the eleven lessons as planned. Unexpected long power outages also led to an abrupt end and break in classes. Though extra teaching classes were arranged to continue from where they ended at different times, the disturbances might have created distortions in the continuous and systematic proceedings of the classroom teaching and students' learning.
- Students were made to answer the same questionnaire items on attitudes towards physics and their learning environments before the beginning and after the end of the mechanics course. They answered questionnaire items at the beginning of the mechanics course in retrospect of the traditional lecture method used in teaching them at the senior high school (SHS). Again, they answered the same questionnaire items after the mechanics course in which the interactive engagement method was used. If students had been given the opportunity to compare the two methods at the same time after the end of the mechanics course at the university, perhaps they might have given more different ratings to the SHS and interactive teaching situations, more in line with the interview. Another possibility that could have influenced students' answers to questionnaire items would be the positive cultural tendency of Ghanaians. For instance, the tendency towards politeness may have influenced the students to rate the items high, despite their freedom to come out with what was on their mind. Thus students might be polite towards the teacher and would like everything that he/she did, once they see him as a friend.

7.3 Recommendations

Recommendations have been grouped into three: (i) Recommendations for further research, (ii) recommendations for teachers who want to set up interactive physics courses in a similar context, and (iii) recommendations for teaching universities and agencies in Ghana.

7.3.1 Recommendations for further research

Reflecting on the study, there are some major questions which this research did not cover or answer due to the focus of the study and the prevailing situation in the period when it was being conducted. These questions mainly deal with scaling, teacher training and implementation of interactive teaching in Ghana.

- The number of students in the course that the study dealt with was about twenty, which was quite a small group. It would be worthwhile to also investigate how to deal with a large setting when using interactive teaching.
- The adoption of the use of interactive ways of teaching in secondary school and university settings will be worthwhile, especially if we want to extend the good attributes of the interactive engagement approach, as revealed by this research, into these levels of our educational hierarchy. It would be of great value to find out how the adoption of the use of interactive teaching could be made effective in the secondary school and university settings in Ghana.
- This study of using an interactive engagement approach in teaching revealed the improved learning results of students in a mechanics course. However, many teachers in Ghana still depend on the use of the traditional lecture approach, as there is no comparable evidence to prove the success or otherwise of their method. It would therefore be significant to all stakeholders in the educational setting if a comparison of the interactive teaching results with the results of the traditional lecture method in mechanics could be made.
- Lastly, though the use of the interactive teaching approach was studied in physics and had a good learning effect on students, it would be important to explore effective ways of applying this approach to different disciplines.

7.3.2 Recommendations for setting up interactive physics courses in a similar context

Extending the findings from our studies, we recommend the following guidelines to teachers who would like to set up interactive physics courses in a similar context. These suggestions apply to courses which make considerable use of interactive engagement approaches.

Activities to enhance interactions and learning

- It is a common experience for most physics teachers that students often come to class unprepared. In this study, we found that an effective measure that could promote students to do their preparatory assignment before coming to class is to adopt the use of concept quizzes at the beginning of every lesson and a problem solving session after the lesson, with the scores being part of the final assessment. In order to be effective, the questions on the quiz and the problem solving session should be answerable by any student who does the preparatory assignment well.

- To make students reconsider their misconceptions, it is important to activate students' prior knowledge, and this study showed that conceptual reasoning questions could be a good way of doing that. A good conceptual reasoning question should bring out different opinions from students. However, a caution is that the question itself should be very clear, because confusion about the question will interfere with the intended conceptual discussions.
- From the results of the study, it is recommended that everyday context and practical experience like the use of MBL tools and examples of real life activities that are within the environs of the learner should be used as much as possible. They help students to reach a clear understanding of concepts.
- Students could be made more responsible for their own learning through group discussions, sharing of ideas, cooperating with peers and with some guidance from the instructor when appropriate problems/questions, projects and assignments are designed for them.
- In order to make the most effective use of class time, the teacher should judge which questions from students need to be answered right away or by the end of the lesson; otherwise he would have to keep on answering questions, which would in effect be dealt with in the next activity.

Creating a safe, ambitious and inviting classroom atmosphere

- In order to encourage an open dialogue, where everybody voices his or her opinions, it is crucial that everybody's contributions are responded to with respect. Students ridiculing each other are detrimental to a safe, ambitious and inviting classroom environment. Teachers should take care that students refrain from such behaviours. Reasons should be given to students why they should desist from such practices.
- Students within a group who are perceived by most peers to be knowledgeable will usually do the talking most of the time. To promote a more balanced participation, the teacher could adopt the style of calling any member within a group to give the group's response. Doing so will create a need for all students to take an active part in the group's discussions.
- The teacher should show a personal interest in students, for instance by knowing their names. This would make them feel recognized as being part of the class and contribute their quota effectively to the class activities.
- The teacher should try to make students ambitious. He could do this by demanding students to discuss questions in groups and make presentations of their group findings afterwards for critique, but in such a way that they do not feel threatened.

7.3.3 Recommendations for teaching universities and agencies in Ghana

In the context of this research, it was seen that the interactive engagement approach could add value to teaching and learning. The following recommendations are provided for teaching universities and agencies in Ghana to explore the possibilities of implementing the use of interactive teaching in classrooms:

- It will be worthwhile to extend the usual teaching techniques with forms of interactive teaching, especially in the two teacher training universities in Ghana (University of Education, Winneba and University of Cape Coast). For example, physics trainee teachers could be helped to develop materials for some topics, to be implemented in their teaching practice. This could be done in steps, so that they are first given well-designed materials to use, and once they have gained experience, they can try to do it for themselves, using small topics in the text books. This will send a message to the trainee physics teachers that teaching with the book alone is not necessary, but that you can do something with the book and change it according to your view.
- In the context of this research, it was seen that interactive physics teaching requires a lot of time for good preparation, especially when you want to have a good classroom dialogue, fruitful discussion and good results. This is an arduous task to develop and implement by non-researching teachers especially, as this approach is quite different from what most of these teachers are used to. Meanwhile, in view of the positive outcome of interactive teaching on students' learning results from the study, it would be valuable if all teachers, especially non-researching teachers could be prepared to teach an interactive course. For instance, Deslauriers, Schelew and Wieman (2011) found about twice the learning in students taught by a postdoctoral fellow using research-based instruction such as active learning than in those taught by a faculty member with high student evaluations and many years of experience in teaching the course using a traditional lecture. This does not always seem to be the outcome, though, as the contrary had been shown by Andrews, Leonard, Colgrove and Kalinowski (2011). According to the latter authors, instructors who lack the rich and nuanced understanding of teaching and learning that science education researchers have developed in active learning might lack the elements necessary for improving learning. This goes to confirm the fact that non-researching teachers need to be trained to successfully teach an interactive course.
- It will be worthwhile for both universities to join forces to provide professional development courses on interactive teaching, especially to help those teachers who are dissatisfied with the learning results of their students and would like to explore alternative teaching strategies.
- Heads of schools could consider offering opportunities for their teachers to be trained in interactive ways of teaching. They could liaise with educational researchers

in both universities in Ghana, who are familiar with the techniques of interactive teaching to make them available to their teachers with requisite materials and teach them how to implement the techniques and materials in classrooms.

- It will be worthwhile if agencies like the Ghana Science Association (GSA), the Ghana Association of Science Teachers (GAST) and the Centre for School and Community Science and Technology Studies (SACOST), which function to support and improve science education in Ghana provide support in gathering and distributing exemplary teaching materials to teachers, as interactive physics teaching might be hard to implement by most teachers, due to the amount of time involved in developing such a course. It is recommended that these agencies provide a collection of more effective ways of using interactive teaching, such as reported in this thesis and distribute these materials to be used by teachers in classrooms. This supportive measure would be of great value to teachers who might find the preparation of interactive teaching materials to be an arduous task.

Science and innovation are crucial to helping revitalise the Ghanaian economy. It is therefore up to the Ghanaian scientific community, agencies in Ghana and the government to ensure that the teacher training institutions produce good science teachers, who can keep students informed, engaged in classroom interactions and enthused, and attract more students to study science at higher educational levels. By so doing they can help to improve the Ghanaian economy.

7.4 Reflection

Reflecting over the four-year period of this study, I have come to realize how it has changed my views and approaches to teaching physics. Since my starting position might be similar to that of physics instructors in many physics departments in Ghana, and around the world, the development of my thinking might offer some hints on how to improve interactions with students so that they feel more committed to learning and teachers will focus more attention on students' conceptual understanding in the teaching process than on quantitative problem solving.

Until I started on this research, my teaching habits had been shaped by the way I was taught myself, and by the usual practices of colleagues around me, which was all in line with the expectations of my students. Content mastery was held in high esteem around the department and skilful quantitative problem solving was regarded as the main indicator of that. The favoured instructional approaches were the lecture and problem solving practice. In my lectures I tried to explain clearly, to convey enthusiasm and to maintain good personal relations with the students. If I did ask questions, they mostly required only short true/false answers. There was little conscious deliberation about students' prior ideas, the relation between skilful performance and conceptual understanding, or the effects that different types of assignments might have on student learning. Professional and research literature on physics education was not prominently available within the department, and I did not consider such literature as a relevant resource for my own teaching.

Like most physics instructors around me, my initial research proposal was a source of reflection to where I stood previously. The initial proposal was based on an opportunity in computer technology. Thus the use of modelling to create direct experience to connect abstract formulas using MBL, without much consideration about the details of classroom processes (i.e. the didactics). I thought I was going to improve my teaching by using MBL. During my interactions with science education researchers, I found out that just the MBL was not sufficient, but had to broaden my whole view on teaching, in which MBL was a part.

I used to feel reluctant to change the traditional lecturing approach to experiment with the new research-based instructional approach which has been produced by physics education researchers. The major excuse was that research-based instruction might not enhance students' learning or achievement. The self-initiative to use a new, empirically validated instructional approach produced by physics education researchers in the classroom was virtually absent due to the fear of not succeeding, students' rejection of the new method and wasting students' learning time. My interactions with science educational researchers motivated me to give these educational innovations a try.

Trying out and having a systematic evaluation of what happened in the classroom after the teaching process was one of the major factors that helped me to gain confidence to try new things. This practice enabled me to see how misunderstanding arose and questions could be misinterpreted differently, which in a way served as feedback to improve on the clarity and understanding of questions in terms of their target. This type of feedback was not common with the regular traditional teaching practice.

It was quite rare to engage a colleague teacher in discussing issues about developing and improving lessons or quality of teaching practice formerly. The research climate in the Freudenthal Institute for Science and Mathematics Education (FIsme), University of Utrecht, has had the positive effect of sharing ideas and discussing lessons or working collaboratively with colleague teachers, science educators in general and researchers. Attending presentations every week, having talks with colleague researchers on research interventions, having discussions about the improvement among researchers in the corridors and during tea breaks, doing presentations myself and having reactions from the audience in FIsme was also one of the major factors in causing the shift from the use of MBL only to improve content into more details of the classroom processes.

Usually, when educational innovations depend on a single person or a few people, they easily break down, especially when the people involved are no longer with the institution. This is also true for universities in general, due to the lack of institutional memory, so if there is a successful educational innovation somewhere, it tends to remain with one person and when he or she retires, that might be the end of the innovation. To avoid this situation at the University of Education, Winneba (UEW), I will suggest to the authorities that they provide opportunities to form a team/community of staff with educational innovations to organize leadership training or courses to enhance the professional effectiveness of our colleague lecturers in order to improve the standard of teaching and learning at the university.

Appendices

Appendix 1

Interview guidelines

1. What new things have you gained from some of the lessons?
2. How did you participate in the interactive activities?
3. What is your opinion about the activities in the lessons? Difficult or not?
4. How could your learning be supported?
5. Given the list of interactive engagement approaches/activities,
   i Which one do you like best and why?
   ii Which one do you like the least and why?

Appendix 2

Questionnaire for students

"*All information is confidential and will be treated as such*"

(I) **Code: 1.** *Birthday* _ _ **2.** *Month* _ _ **3.** *Last 4 digits of your mobile phone number* _ _ _ _

4. Sex: ....

5. Age: ....

6. SHS or SSS attended: ....

7. Which city or town is the SHS or SSS you attended located? ....

8. Urban or rural: ....

9. What was your grade in physics (WASSCE or SSSCE)? ....

10. Or both ....

II. Items in students' opinions about the types of activities used in the meetings.

A five-point Likert scale questionnaire with responses ranging from strongly disagree-SD (1), disagree-D (2), not sure-NS (3), agree-A (4) and strongly agree-SA (5) is used.

A. Concept quizzes

	SD (1)	D (2)	NS (3)	A (4)	SA (5)
11. Helped me to do my reading assignment before coming for lectures.					
12. I enjoyed this activity.					
13. Helped me to participate actively in class.					
14. Helped me to understand mechanics concepts.					

B. Conceptual reasoning questions (CRQ)

	SD (1)	D (2)	NS (3)	A (4)	SA (5)
15. Helped me to express my own ideas.					
16. I enjoyed this activity.					
17. Helped me to participate actively in class.					
18. Helped me to understand mechanics concepts.					

C. Interactive teaching

	SD (1)	D (2)	NS (3)	A (4)	SA (5)
19. Helped me to get thorough understanding of the topics in "blocks".					
20. I enjoyed this activity.					
21. Helped me to participate actively in class.					
22. Helped me to understand mechanics concepts.					

D. Reflection

	SD (1)	D (2)	NS (3)	A (4)	SA (5)
23. Enables me to give a more satisfying and elaborate answer to the starting questions.					
24. I enjoyed this activity.					
25. Helped me to participate actively in class.					
26. Helped me to understand mechanics concepts.					

E. Application questions

SD (1)	D (2)	NS (3)	A (4)	SA (5)	
27. Helped me to gain confidence in practicing and applying what has been learnt.					
28. I enjoyed this activity.					
29. Helped me to participate actively in class.					
30. Helped me to understand mechanics concepts.					

F. Problem solving

	SD (1)	D (2)	NS (3)	A (4)	SA (5)
31. Helped me to understand deeply how problems/ questions in mechanics are solved and can solve questions on my own.					
32. I enjoyed this activity.					
33. Helped me to participate actively in class.					
34. Helped me to understand mechanics concepts.					

III. Items in attitude & learning environment scales (Martin-Dunlop & Fraser, 2007) (*Pre*- and *Post*-questionnaire)

G. Attitudes towards physics teaching

	SD (1)	D (2)	NS (3)	A (4)	SA (5)
35. I looked forward to (eagerly anticipate) physics lessons.					
36. Lessons in the class were fun.					
37. I disliked lessons in the class.					
38. Lessons in the class bored me.					
39. The class was one of the most interesting classes.					
40. I enjoyed lessons in the class.					
41. Lessons in the class were a waste of time.					
42. The lessons made me interested in physics.					

H. Students' cohesiveness

	SD (1)	D (2)	NS (3)	A (4)	SA (5)
43. I made friends among students.					
44. I knew other students.					
45. I was friendly to other students.					
46. Other students were my friends.					
47. I worked well with other students.					
48. I helped other students who were having trouble with work.					
49. Students liked me.					
50. I got help from other students.					

I. Instructor's support

	SD (1)	D (2)	NS (3)	A (4)	SA (5)
51. The instructor took a personal interest in me.					
52. The instructor went out of his way to help me.					
53. The instructor helped me when I had trouble with the work.					
54. The instructor considered my feelings.					
55. The instructor talked with me.					
56. The instructor was interested in my problems.					
57. The instructor moved about the class to talk with me.					
58. The instructor's questions helped me to understand.					

J. Cooperation

	SD (1)	D (2)	NS (3)	A (4)	SA (5)
67. I cooperated with other students.					
68. I shared my books and resources with other students when doing assignments.					
69. When I worked in groups, there was team work.					
70. I worked with other students on projects.					
71. I learned from other students.					
72. I worked with other students.					
73. I cooperated with other students on class on class activities.					
74. Students worked with me to achieve class goals.					

Fill in comments, hints, and suggestions

……………………………………………………………………………………..……
………………………………………………………………………………………
…………………………………………………………………………….…

Appendix 3

Interview guidelines

1. **Strengths of the interactive-engagement approaches used (e.g. the use of Microcomputer based laboratory tools (MBL), animation, group discussion, teacher-student interaction, student-student interaction, presentation, the use of whiteboard (for explanation or solving of problems), problem-solving session (tutorial), conceptual reasoning questions, application questions, etc.**

- *Cognitive processing*: That is how the interactive engagement (IE) approaches had promoted their engagement in thinking about mechanics concepts (physics concepts).
- How could they compare their thinking in mechanics concepts after the use of the interactive engagement approaches with their learning experience in secondary schools? What about Newton's laws of motion and understanding of graphs?
- *Concentration and retention*: That is how the interactive engagement approaches had been beneficial to concentration and retention of mechanics concepts in class. In what ways had the use of these IE approaches contributed to your concentration and retention of mechanics concepts in class?
- *Identification of misconceptions*: That is how the IE approaches had provided opportunities for them to understand some mechanics concepts (physics concepts) and helped them to identify the misconceptions. Students can give specific examples of their misconceptions and how the use of IE approaches had helped them to identify that they were misconceptions.
- *Shifting focus from teaching to learning*: That is whether the use of IE approaches had shifted the focus of teaching from the teacher and teaching materials to the learners (students) and learning outcomes.
- *Teachers as learning facilitators*: That is whether the students felt that the teacher (lecturer) was lazy by using the teaching time for students to work by themselves instead of teaching or lecturing them.
- Did they see the teacher to be committed in helping the students to learn? In what ways?
- Was the time giving to them to think was worthwhile? In what ways?
- *Harmful to content coverage*: That is whether the students saw the IE approaches could be harmful to content coverage or not (whether all the content in mechanics would be covered)? In what ways?
- *Teach less and learn more*: That whether the students felt that the IE approaches were making the teacher to teach less while the students think more or not? In what ways?
- Did the students see the interactive activity to be a waste of time? In what ways?
- How do students compare IE approaches with traditional lecture method in class?

Barriers to applying interactive engagement (IE) approaches

- *Insufficient physics background*: That is whether their insufficient physics background was not making them to contribute enough with their colleagues or to answer questions in class.
- *What about the reading assignments and short quizzes*: Were they not helping them to read ahead and contribute? In what ways?
- *Being afraid or being blamed or teased by the lecturer or peers*: That is whether students were afraid to expose their weakness in front of their colleagues/peers and the teacher. Was that the reason why they were not contributing in class?
- *Lecturers difficulty in understanding students difficulties*: That is whether students felt that because lecturers have high level of academic achievement, they could hardly understand where they are at, and that was why they were keeping things to themselves instead of asking the lecturer.
- *Time consuming*: Did the students see the IE approaches to be time consuming? Was the time consuming worthwhile? In what ways?

Appendix 4

"Critical Friend"

1. How did activity *concept quiz* work out?
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…………………………………………………………………………
2. How did activity *conceptual reasoning* question work out?
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…………………………………………………………………………
3. How did activity *interactive teaching* work out?
………………………………………………………………………………………
…………………………………………………………………………
4. How did activity *reflection* work out?
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…………………………………………………………………………
5. How did activity *application question* work out?
………………………………………………………………………………………
…………………………………………………………………………
6. How did you see students' participation and motivation throughout the lesson?
………………………………………………………………………………………
…………………………………………………………………………
7. Which aspect(s) of the lesson stand(s) out as attractive/promising?
………………………………………………………………………………………
…………………………………………………………………………
8. Which aspect(s) of the lesson stand(s) out as questionable/boring?
………………………………………………………………………………………
…………………………………………………………………………
9. (a) Did you notice any impasse?
………………………………………………………………………………………
…………………………………………………………………………
(b) How was it dealt with?
………………………………………………………………………………………
………………………………………………………………………………(c)
Could you suggest any possible alternative to deal with impasse?
………………………………………………………………………………………
…………………………………………………………………………
10. Any other good thing(s)/praise(s) you saw in the lesson that should be continued or encouraged?
………………………………………………………………………………………
…………………………………………………………………………
11. Any other unwelcome practice(s) you saw in the lesson that should not be continued?
………………………………………………………………………………………
…………………………………………………………………

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Summary

It has been reported from previous studies that the traditional lecturing approach to physics teaching has little effect on students' participation and attainment of deep conceptual understanding, and that interactive engagement approaches can be much more effective. Interactive engagement methods typically involve open and critical discussions in the classroom, with hand-on experiences and group work presentations. The question is whether such techniques can be fruitfully implemented in the Ghanaian setting, where classroom resources are limited, and where politeness and respect towards one's elders are highly esteemed values. In this research, we investigated how conceptual understanding of mechanics could be promoted through interactive engagement methods among undergraduate physics students in the Ghanaian educational and cultural context.

For the question to be answered, a series of studies was carried out and reported in chapters two to six of this thesis. Chapter two of the study reported on the Ghanaian educational system. It focused on the various levels of educational system as regards physics education, science and technology education and agencies that support the Ghanaian educational system. Light was also shed on the challenges that the Ghanaian education system faces, such as poor funding, inadequate staffing or teacher attrition, lack of rooms for lessons/lectures, poor remuneration for teachers, lack of equipment and materials, and little possibilities for career progression, though steps are taken by the government to fix these problems.

The next study was done on mechanics teaching and students' learning problems in this field of physics. We examined the major issues that inhibit learning. We further looked at the potentials and the need for Ghana's capability to improve teaching and learning physics by making use of the literature. These included creating an educational environment that promotes learning outcomes where students assume more responsibility for their own learning and develop and effectively use varieties of thinking and reasoning strategies, which requires from teachers to nurture students' motivation for learning with learning tasks derived from real life activities, to create an environment that stimulates their curiosity and use a planned pedagogical approach with technology. This constituted chapter 3.

Chapter four reflects on the need for developmental research, possible solutions based on the literature and describes the development and testing of a design that is supposed to address the problem. It results in a series of design guidelines that have prospects for improving learning and promoting interactions in the classroom. These design guidelines formed the basis of a series of activities that were expected to stimulate

interactivity during lessons. A lecture series was then designed for a mechanics course to be taught in a first year teacher education programme.

Chapter five describes how the lecture series was tested for the first time in practice and presents the findings. The lecture series comprised interactive engagement activities aimed at interactivity among students, between students and teacher, and between students and computer. Standardized tests such as force concept inventory (FCI), test of understanding graphs in kinematics (TUG-K) and mechanics baseline test (MBT), and scores from end of semester results, concept quizzes, assignments and projects were used to determine learning outcomes of students. Students were interviewed intermittently throughout the period of implementation of the design to get their views of the interactive engagement approach being used. They also answered questionnaire items to find out their perceptions of the activities used in the lessons. Classroom proceedings were videoed and some discussions among students were recorded by audio devices, which were analyzed to see whether they led to optimization of interactivity and enhancement of conceptual understanding by students. Evaluation of the analysis showed that the intended purpose of students interactivity and participation in class was achieved by the design, and that students' conceptual understanding in mechanics improved, albeit that there were some activities which needed further improvement for improve student learning in the next round of data collection. These include reducing the number of conceptual reasoning questions (CRQs) and clarifying the targets of these questions, making the lecture approach more interactive and improving time management for some activities, especially in cases of prolonged arguments.

Based on the outcomes of the first round, we revised the design with the new elements intended to improve it. The design was tested again in practice, at the same institution and level and the results are reported in chapter six. Overall results of pre and post FCI, pre and post TUG-K, MBT, weekly quizzes, assignments and end of semester examination were gathered from students, analyzed and compared with the learning results of the first round. Feedback during the lecture series from the critical friend and the perceptions of the students through the use of interview are clustered into themes and analyzed to identify strengths and weaknesses of the teaching process. The learning outcomes were slightly better than in the first round of evaluation, but the difference was not significant. Questionnaire items on activities were also analyzed in comparison with the mean scores of the first data collection. Students' opinions about the course were very favourable again, as they had been in the first round of evaluation. The students were also of the view that the use of animations, everyday life experiences, MBL and the interactive engagement approach was the key to their retention of what they learnt in class or experienced. Also the critical friend and the students talked about similar issues and concluded that the approach adopted by the teacher was successful and helped students to gain a conceptual understanding of the mechanics topics treated.

A more remarkable and perhaps disappointing finding was on students' response to questionnaire items on attitudes and learning environments. Here, students were equally positive about their experiences in high school. A caution when interpreting this finding is that the students' opinions about their high school experiences were gathered only before the start of the current course, so that the students never had an opportunity to compare the two. A methodological improvement could be to ask the students about their high school experiences at the end of the course as well.

Based on the evaluation of selected episodes of transcribed recorded video and audio of classroom sessions during the second round, it was concluded that the design of the various activities in the lessons did achieve its intended purpose of students' interactivity, participation in class, and improving on their conceptual understanding in mechanics. The intervention was good enough to fit the Ghanaian university context and culture. However, there was still room for improvement, as in some cases students still exhibited conceptual difficulties, and time management was still not optimal, especially at the initial stages to allow students to get used to more participation.

Finally, possible conclusions that were drawn from the study are that the use of interactive engagement approaches in teaching mechanics in the Ghanaian educational and cultural context is feasible and did achieve its intended purpose of evoking more interactions among students, between students and teacher, and students and computer. Learning results of students on the standardized test in FCI, TUG-K and MBT improved and the quality of reasoning in answering qualitative reasoning questions improved over time.

Some limitations in the implementation of the design call for further research. Some guidelines are given for teachers who would like to set up interactive physics courses in a similar context. Suggestions for teaching universities and agencies in Ghana to explore the possibilities of implementing the use of interactive teaching in classrooms due to its possibility of adding value to teaching and learning are also given. The researcher's own view of how the study had a positive effect on his teaching career is also shared.

Samenvatting

De klassieke aanpak van het mechanicaonderwijs, met de theorie in hoorcolleges en toepassingsopgaven in de werkcolleges, resulteert bij veel studenten in desinteresse en in een oppervlakkig begrip van de stof. In diverse onderzoeken is gebleken dat "interactive engagement"-benaderingen veel effectiever kunnen zijn. Onder de noemer van "interactive engagement" valt een scala aan didactische werkvormen zoals open discussie, praktische opdrachten en groepspresentaties. De centrale vraag in dit onderzoek is of zo'n aanpak ook effectief kan zijn in de Ghanese situatie, waar faciliteiten zoals practicumapparatuur slechts beperkt voorhanden zijn, en waar beleefdheid en respect tegenover ouderen hoog in het vaandel staan.

Om de vraag te beantwoorden zijn twee onderwijsexperimenten uitgevoerd, die in de hoofdstukken vijf en zes van dit proefschrift worden beschreven. Voorafgaand daaraan beschrijft hoofdstuk twee het Ghanese onderwijssysteem. Het richt zich op de verschillende niveaus van het systeem voor wat betreft natuurkundeonderwijs, het onderwijs in wetenschap en techniek, en instanties die het Ghanese onderwijssysteem ondersteunen. Ook de problemen in het Ghanese onderwijs komen aan de orde, zoals bijvoorbeeld geldgebrek, gebrek aan carrièremogelijkheden, met als gevolg onderbemensing en verloop van docenten, gebrek aan geschikte onderwijsruimten en gebrek aan apparatuur en materiaal. Tenslotte wordt beschreven hoe de overheid stappen zet om deze problemen te verhelpen.

Hoofdstuk drie beschrijft het mechanicaonderwijs en de leerproblemen die studenten hebben op het gebied van de mechanica. De belangrijkste begripsproblemen worden geïdentificeerd. Verder wordt op basis van de literatuur geschetst welke kansen er liggen om het Ghanese natuurkundeonderwijs te verbeteren. Een belangrijke prioriteit blijkt het creëren van een onderwijsomgeving waarin studenten meer verantwoordelijkheid nemen voor hun eigen leren, en waarin ze denk- en redeneerstrategieën ontwikkelen en toepassen. Dit vraagt van docenten dat zij de nieuwsgierigheid van de studenten stimuleren, en de leermotivatie bevorderen, bijvoorbeeld met behulp van interactieve werkvormen, met opdrachten die voor de studenten betekenisvol zijn vanuit hun leefwereldcontext, en met begripsondersteunende inzet van ict.

Hoofdstuk vier beschrijft de onderzoeksmethode. Er wordt beargumenteerd dat het vormgeven van een interactieve mechanicacursus voor het Ghanese universitair onderwijs een complex ontwerpprobleem is en dat een aanpak in de vorm van ontwikkelingsonderzoek daarvoor het meest geëigend is. In zo'n ontwikkelingsonderzoek worden, gebruikmakend van leerstofanalyse en aanwijzingen uit de literatuur, veelbelovende ontwerprichtlijnen geïdentificeerd. Op basis daarvan is een reeks mechanicacolleges ontworpen voor een eerstejaarsprogramma op een lerarenopleiding.

Hoofdstuk vijf beschrijft het eerste onderwijsontwerp en de praktijkevaluatie daarvan. De interactie tussen student en docent en tussen studenten onderling wordt geanalyseerd om te zien of de beoogde procesdoelen bereikt zijn. Daarnaast wordt gebruik gemaakt van gestandaardiseerde toetsen zoals de Force Concept Inventory (FCI); de Test of Understanding Graphs in Kinematics (TUG-K), en de Mechanics Baseline Test (MBT); ook worden resultaten van periodieke toetsen, overhoringen over begrippen, en van taken en projecten gebruikt om de leeruitkomsten bij studenten vast te stellen. Ten slotte is de mening van de studenten over het gevolgde onderwijs onderzocht door middel van interviews en vragenlijsten. De resultaten wijzen uit dat het beoogde doel – een verhoogde interactieve participatie – wordt bereikt en dat er een verbetering is in het conceptuele begrip van studenten, maar dat een deel van de activiteiten nog niet functioneert zoals beoogd. Verwacht wordt dat verbetering van deze activiteiten zal leiden tot een hogere leeropbrengst. Deze voorgestelde verbeteringen omvatten het verminderen van het aantal conceptuele redeneervragen (CRQ), het duidelijker maken van het doel van deze vragen, een meer interactieve opzet van de colleges, en het beter bewaken van de beschikbare tijd voor sommige activiteiten, vooral bij de open discussies.

Hoofdstuk zes beschrijft hoe, op basis van deze bevindingen, een herzien ontwerp is gemaakt dat opnieuw in de praktijk getoetst is, in dezelfde instelling en met eenzelfde doelgroep. De onderzoeksmethode was gelijk aan die in de eerste ronde, met dit verschil dat er nu een tweede staflid als 'critical friend' bij het onderwijs aanwezig was. De feedback van de 'critical friend' is, samen met de feedback van de studenten, geanalyseerd om een objectiever beeld te krijgen van de sterktes en zwaktes van het onderwijsproces. De toetsresultaten zijn iets beter dan in de eerste evaluatieronde, maar het verschil is, na correctie voor het voorkennisniveau, niet significant. Studenten zijn opnieuw zeer positief over het vak, zoals ze dat ook in de eerste evaluatieronde waren. Een opvallende en misschien teleurstellende bevinding is echter dat de studenten in de vragenlijst bij het begin van de cursus net zo positief waren over hun voorafgaande ervaringen in het middelbaar onderwijs. Een aandachtspunt bij het interpreteren van deze uitkomst is dat de studenten alleen naar hun mening over hun ervaringen in het middelbaar onderwijs zijn gevraagd vóór de start van het huidige vak, zodat ze geen gelegenheid hadden om de twee te vergelijken. Een verbetering van de methodologie zou dus kunnen zijn om de studenten ook aan het einde van de cursus naar hun ervaringen in het middelbaar onderwijs te vragen.

Voor een nadere beoordeling van de kwaliteit van de interactie in het onderwijsleerproces is een selectie gemaakt van drie momenten in de cursus waarin bekende begripsmoeilijkheden aan de orde kwamen. Op basis van de getranscribeerde video- en audio-opnamen van deze episodes wordt de conclusie getrokken dat de gestelde doelen ten aanzien van interactie, betrokkenheid en conceptuele diepgang in het onderwijs bereikt zijn. De interventie sloot voldoende aan op de context en cultuur van een Ghanese universiteit. Er is echter nog ruimte voor verbetering, aangezien studenten in sommige gevallen nog blijk geven van conceptuele problemen, en tijdsbewaking nog niet optimaal is, vooral in de beginfase als studenten nog aan een meer actieve en gelijkwaardige rol moeten wennen.

De conclusies die getrokken worden uit dit onderzoek zijn dat een interactive engagement benadering voor het mechanicaonderwijs in de Ghanese onderwijs- en culturele context succesvol en haalbaar is gebleken en dat het niveau van argumenteren over kwalitatieve begripsvragen en het leerresultaat op gestandaardiseerde toetsen verbeterd zijn.

Het slothoofdstuk beschrijft de beperkingen van het huidige onderzoek en de noodzaak voor vervolgonderzoek. Er worden richtlijnen gegeven voor docenten die in een vergelijkbare context een interactief natuurkundecurriculum willen opzetten. Ook worden er suggesties gegeven voor universitaire lerarenopleidingen en instanties in Ghana om de mogelijkheden van het toepassen van interactief onderwijs in de klas, gezien de toegevoegde waarde die het biedt voor het onderwijs. Ten slotte wordt beschreven hoe de persoonlijke onderwijsvisie van de onderzoeker door dit onderzoek veranderd is.

Acknowledgements

Thanks to God for granting me the chance and the ability to successfully complete this study.

This dissertation would not have been possible without the guidance and help of several individuals who in one way or the other contributed and extended their valuable assistance in the preparation and completion of this study.

First and foremost, my utmost gratitude to Prof. Dr. H.M.C Eijkelhof and Dr. E.R. Savelsbergh, my supervisors, for their valuable advice and guidance of this work. I am very much impressed with their exemplary patience, humility, care and work ethics. There is no doubt to show such behaviours to my students when I resume duty in Ghana. Special gratitude also goes to the Dutch Government and NPT (NUFFIC), who provided financial support for this research and my stay in the Netherlands.

My grateful thanks to the members of the PRACTICAL Project, especially Prof. Quaye, Project supervisor, Ghana; Leo de Feiter and Lieke Stoffelsma, Project supervisors (former and current respectively), the Netherlands; Dr. Rien Kool, Senior Education Advisor, CIS, Vrije Universiteit, the Netherlands; Dia Eek, the financial controller and all the staff of CIS, who played certain roles for the successful accomplishment of this thesis. All projects that I undertook during the programme would have turned to nothing without the support, enthusiasm and imagination from you. Besides, the programme makes me realize the value of working together as a team and has given me an experience in working in a new environment.

I am also grateful to the authorities at the Freudenthal Institute for allowing me to undertake my research and use their facilities, including offices, library and equipment. I thank all the staff at this institute for accepting and giving me a special treat when the need arose. The opportunities given to me to participate in most of the activities in the institute have given me a formidable exposure in socializing well with different people. Your cordiality and warm reception will always be remembered. I also appreciate the good work done by Koos Kortland and Nathalie Kuijpers for doing the proofreading of my thesis. Not forgetting the colleagues I worked with in the same office, Dr. Jo Nelissen, Jantien Smit, Marjolijn Peltenberg, Marjoke Bakker, Hilde Boer and Nienke Gerkes. Your presence and encouragement were dear to my heart. I am also appreciative to Peter Dirkson for his assistance in the use of the Coach 6 instrument.

I am thankful to the authorities of the University of Education, Winneba (UEW), especially the Vice-Chancellor, Prof. A. Asabere-Ameyaw, the Dean of Faculty of

Science Education, Prof. M. K. Amedeker and the then Head of Science Department, when I started the programme, Dr. K. D. Taale, for their support of this research by giving me study leave with salary for four years and also to the other staff and students of the Department of Science Education, UEW, for their assistance in diverse ways to gather data for this thesis.

I am deeply indebted to my friend Dr. Paul van der Zande and his wife, Barbara Wiessing, who were more or less my parents in the Netherlands and were always inviting me to their house for dinner on Wednesdays. I still cherish the good times we had together with your friends anytime we went for camping, not forgetting the numerous museums you took me to. Also, I give my deep felt regards to Ms. Mieke Kaptein, who also acted like my auntie in the four-year duration of my project. Our outings to interesting places, watching movies and having dinner together sometimes have made an indelible imprint on my mind. You did not make me feel like a stranger here. Thanks to Dr. Kees Klaassen for his concern and advice on my study, not forgetting the discussions we held on football matches, as both of us are enthusiasts of the game. Indeed, you were a real cousin to me. Also indebted to Dr. Peter Dekkers for his initial assistance to my research work. Special thanks to Mr Gordon Yamoah, his wife Mrs. Victoria Yamoah and their kids Joycelyn and Joel for their family love and showering Ghanaian hospitality on me always. They were my siblings in the Netherlands and I cannot forget the incessant love and encouragement they gave to me. Thanks to my Ghanaian colleague, Douglas A. Darko, who also did his Ph.D research at Twente University, the Netherlands, for his encouragement and support. Also to my Ghanaian friends, Mrs. Ruby Hanson, Mr. William Z. Haruna, Mr. James Awuni Azure, Mr. Sam Arkoful, Miss Helena Embil, Dr. Ishmael K. Anderson, Dr. Frimpong Kwaku Duku and Dr. Patrique deGraft Yankson for their concern about my research work. My brothers and sisters cannot be left out. I appreciate their moral support and prayers for taking me through this research. I am also thankful to the numerous individuals who have directly or indirectly contributed to the completion of this work.

Finally, I am particularly grateful to my wife, Mrs. Theresa Antwi and my children, Kwame Antwi Boasiako and Yaa Sarfowaa Antwi, for supporting me through all the stages of this work. Without their understanding this study would never have been possible. Allowing me to leave them proves their love and support during the whole course of this work. Special thanks to my wife for her patience, all kinds of support and advice during my studies. To everyone, I say God bless you.

Curriculum vitae

Victor Antwi was born in Kumasi, the second largest city of Ghana, on the 13th of January, 1966. He went to a teacher training institution after his sixth form education in Kumasi in 1989. He then became a general science teacher at the basic level of education in 1992 and taught for two years. He furthered his teacher education at the University of Education, Winneba (UEW) from 1994 onwards. He was selected among a few students to work with the Department of Science Education, University of Education as a teaching assistant after his first degree in 1999. After working with the department for some years, he was sponsored by the university to do a Master of Philosophy in Physics at the University of Cape Coast, Ghana. He graduated in 2005 and joined the Department of Science Education, UEW, as a lecturer in physics in the same year. Until the beginning of his thesis at the Freudenthal Institute, Utrecht University in 2009, he was the coordinator of the PRACTICAL Project, UEW branch (2006-2008), which was sponsored by the Netherlands Government Programme to improve the quantity and quality of mathematics and science teaching staff at all levels of education in Ghana. It was through this project that Victor Antwi had the privilege of doing a PhD research study at Utrecht University, also under NPT (NUFFIC) sponsorship.

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