Engaging students to develop conceptual understanding in physics using ICT

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Abstract

Mauritian students' understanding of physics concepts and their general performance in examinations are not satisfactory. We have initiated a two-year project that will build on students' understanding and make the teaching and learning of O-Level physics more lively and in context. The pilot project is targeted at 10 secondary schools which have been supplied with relevant resources for integrating ICT and data logging in the teaching of physics. The physics teachers were given the opportunity to develop new skills in the use of ICT and data logging.

Initial data collected during the project, showed that the teachers were resorting to their traditional type of practice relegating the use of ICT and data logging to an emphasis on the development of ICT skills which was not the aim of this project. With a view to bringing value to the project, our research team decided to carry out some physics lessons (phase 2). The lessons were developed in such a way that at each stage of the lesson, students experienced a state of cognitive dissonance. Moreover, the Comprehensive Interactive Model of assessment (Parmessur, et al., 2003) formed the basis of the teaching. In order to sustain learning, students were given structured tasks to be performed at home which had to be endorsed by their parents (school-parental partnership).

Introduction

The paper describes the early stages of an ongoing curriculum integration initiative in the teaching and learning of physics in our Mauritian schools. The project intends to make a significant contribution in inducing learners to develop a dynamic approach to learning of physics rather than being merely passive recipient of knowledge. Mauritius, an island of area 2000 km^2 is situated geographically in the Indian Ocean and has a population of 1.2 million. Mauritius has no natural resources and has been striving hard to lead its people towards prosperity. The resources lie in its human power. Rodrigues Island forms part of the Republic of Mauritius. It is located about 600 km from Mauritius and includes a population of about 35,000 inhabitants.

The educational system of the Republic of Mauritius is based on two years of pre-primary education followed by six years of primary education leading to the Certificate of Primary Education examination. The latter is a prerequisite for entry into secondary education that extends over seven years. At the end of five years of education, students qualify for the Cambridge O-Level Certificate which is a prerequisite for entry into the ultimate secondary education of two years (Higher School Certificate) that enables learners to qualify for the Cambridge A-Level certificate. Students possessing this qualification can now proceed either to their career paths or to university for higher education.

Formal training in physics starts in the first year of secondary school education (Form I; age 12/13 years). Students study the three sciences, namely Biology, Chemistry and Physics which are taught as separate subjects along with English, French, Social Science, Art. As from Form III (age 15/16), students may opt for the science stream or the non science stream. The intake of students for the science field as from Form IV (age 16/17) is already meagre figure. Many factors have been associated to this low enrolment (Ramma, 2001), namely poor teaching (traditional method), very few activities and career opportunities.

It is a matter of fact that fresh graduates from the University embark on the teaching profession without having acquired a pedagogical qualification. It is noted with concern that the teaching of physics is done in a rather random manner without a pedagogical framework to justify the strategy adopted by the teacher.

Laboratory work and activities form an integral part of physics instruction. Though it is not formally assessed at O-Level, it is a reality at A-Level. Teachers are nonetheless expected to indulge regularly in laboratory based work as from Form I. Informal surveys tend to show that this is not the practice in our schools and teachers tend to overlook practical tasks and focus more on theoretical part which further makes our system of education examination and certification oriented. In fact, practical work is a crucial part of science instruction at all levels and should not be relegated at any cost. The first and foremost aim of physics instruction states that it should

> *"provide, through a well-designed studies of experimental and practical science, a worthwhile educational experience for all students … to become confident citizens in a technological world and able to take or develop an informed interest in matters of scientific import" (UCLES CIE 9702)*

To facilitate and coordinate the administration of educational activities throughout the republic, five educational zones have been set up by the Ministry of Education and Human Resources. Recently, the Government of Mauritius has provided all schools with round the clock high quality internet service, free of charge. Students are expected to make optimal use of all these facilities in their learning. Students may also use CD-ROMs which enhance learning of physics through visualisation of simulations of processes, virtual experimentation, problem solving with clues and immediate feedback.

Aim and Purpose of the Project

The physics ICT-data logging project aims at enabling learners to develop appropriate conceptual understanding of physics concepts using ICT as a support tool with a view to becoming independent learners.

The study was limited to the classroom interaction and processes though the approach that was adopted made provision for out-of-school factors such as parental involvement.

Physics is considered as one of the most difficult subjects in our school curriculum. Many students in the Science streams prefer to opt for the other science subjects (Chemistry and Biology) rather than Physics. Girls in particular tend to discard the subject as Physics is considered to be very abstract and remotely linked to practical application and experience. The ratio of girls to boys doing physics at O-level (UCLES Examination) is approximately 1:2 (2005 examinations). Many problems in Physics are solved by students in a mechanistic way and very often by trial and error, without going into the process of inductive and deductive reasoning (Lawson, 2004) which includes the use of scientific process skills to develop understanding of concepts. This eventually leads to an oversight of the underlying logical principles involved. In addition, students are expected to demonstrate 'understanding' of acquired knowledge. The resulting consequence is that critical thinking does not seem to take place in the learning process. An analysis of the Cambridge Examination Reports does reveal the conceptual problem that our students are facing.

Our immediate concern is to improve the quality of teaching of Physics at the secondary level and raise the enrolment rate of students in Physics and Science in general. For the past three years, our team has been able to develop an integrated approach to formative assessment (Parmessur *et al.*, 2003) in the learning process whereby the cognitive acquisition of knowledge and skills of learning can be constantly monitored and addressed. This model of assessment is well balanced and is well suited to an inquiry (or constructivist) approach. It also takes on board differential teaching and learning that caters for mixed ability teaching and learning.

Physics is one of the toughest subject that students, mostly feared by girls (Ramma, 2001), encounter in the curriculum and it is not a surprise that 22% (2005 examinations) of students (boys and girls) would opt for physics at School Certificate level (O-Level) and only 20% would opt for physics at the Higher School Certificate level (A-Level). Most of the time, students would simply memorise concepts and procedures and more so they would memorise the various steps in problem solving solely for the purpose of getting through an examination. It is unfortunate to note that the 'depositor-depository' approach as recognised by Freire in 1972 still persists in our educational system nowadays. In this model, learners are merely passive recipients of knowledge and their ability to act independently is restricted. However, in order to develop in students a sense of ownership in the construction of knowledge, we have no other choice than to bring about a paradigm shift in the teaching and learning of physics. The physics ICT data logging project was initiated with main objective to address both the teaching and learning processes taking place in the classroom by developing an appropriate pedagogy based on constructivism.

Review of related literature

The methodology used in this project is based on a constructivist approach, whereby the learning is viewed to be a process of "deconstructing misconceptions and reconstructing valid scientific conceptions in their place" (Cobern, 1993, p. 54). This process of deconstruction, construction and re-construction of cognitive structures is not an easy task (Saunders, 1992; Appleton, 1993) as it requires careful step-by-step guidance from the teacher, where the pre-conceptions of the students should form the basis of the lesson (Hadzigeorgiou, 1999). The role of the teacher is also to determine the zone of proximal development (Hodson & Hodson, 1998; MacGilchrist, Myers & Reed, 1997) of the individual learner and through proper feedback and assessment (formative), the learners' apprehensions can be addressed. The classroom activities and transactions between the teachers and learners should no more be a one-way traffic motion as is the case in a traditional classroom. Computers are powerful tools to enable learners to visualise processes that are happening at the microscopic and well as at the macroscopic levels. Moreover, "students who use ICT as an integral part of their work develop learning strategies of their own" (Cuthell, 2002, p. 137). Knowledge becomes therefore tangible and is easily assimilated. Cognitive structures which are responsible for purposeful acquisition of concepts are firmly constructed. L

The introduction of ICT in the school curriculum worldwide has brought a drastic change in the way concepts are taught. The opportunity for students to visualise a process, in particular when it concerns developing understanding of a difficult or abstract concept has made ICT a very powerful tool in the classroom transaction. For example, Martin et al. (2004) highlight the following uses of computers in the science classroom: (1) doing scientific procedures or experiments, (2) studying natural phenomena through simulation, (3) practicing skills and procedures, (4) looking up ideas and information, and (5) processing and analyzing data. Unfortunately, the curriculum framework and structure has merely changed and as it is presently, it is not entitled to accommodate ICT related curriculum framework. Yelland (2006) rightly argues that we "need to reconceptualise the curriculum for these new times so that we are able to assist in creating contexts for people to become citizens of the information age" (p. 121). The author identifies three learning areas in the new dimension of the curriculum, namely *techne, oeconomia* and *humanitas*. These three learning areas will emphasise new skills which are aliens from the mechanistic actions and memorisation of facts. The curriculum should therefore be reconceptualised with clear elements of ICT embedded into the learning experiences of the learners. In addition to that, elements of values and ethics which are not existent in the present curriculum should form an integrated component in this new process.

How far can ICT and data logging bring about a paradigm shift in the way physics is taught in our schools?

The success of any project lies in the hands of the teachers; if teachers are willing to invest their time to structure their lessons so as to embed ICT related activities supported by pedagogy, then learners will be able to develop understanding of concepts, otherwise the introduction of ICT and data logging may slow down the learning process and put away learners from the subject. ICT itself will not improve pedagogy unless teachers shift their pedagogies to be more learners centered and gender friendly approaches while taking into consideration that learners have to construct meaningful and purposeful knowledge structures. Lee (2006) confirms that teachers encounter difficulties in integrating ICT in their teaching due to their limited ICT integration experiences.

The physics ICT data logging project

Ten schools were selected according to a selection criteria based on equal representation in the five zones (four zones in Mauritius and one zone in Rodrigues) and in terms of gender. Eight schools from Mauritius and two from Rodrigues were among the selected. The project was targeted at learners of the following age groups:

(i) 13-15 (Form I-III)
(ii) 16-17 (Form IV-V)
(iii) 17-19 (Form VI)

Phase 1: Implementation by teachers

Data logging sensors and accompanying resource materials were purchased from Addestation, Singapore after a tendering process. Each school was provided with the following materials and equipment for a duration of two years: one computer and accessories, one video projector, all the data logging sensors and the aMixer to operate the sensors.
The aim of this project was not aimed at enabling students to develop hands-on experiences with the computer but to enable them to develop conceptual understanding of the process as they would be able to visualise the various processes when it concerns abstractness of a particular concept. The data collected will be analysed and the recommendations will be forwarded to the Ministry of Education and Human Resources for developing policy on the use of ICT in teaching and learning of the sciences. Due to lack of funds, only one computer was supplied per school and we had to extend the project to as many schools as possible to be able to collect substantial data. Our intention was to bring a change in the teaching process and with careful monitoring and adjustments made to the teaching process, it is hoped that learning will be influenced and learners will benefit significantly.

The physics teachers from the schools involved in the project were called for a one week training session. The first step consisted in setting up of a training programme that would equip the teachers with adequate and appropriate ICT and data logging skills and techniques to teach quality physics lessons. If teachers are to effectively support students' learning, they themselves must possess rich and flexible subject matter knowledge (Taylor & Dana, 2003). Teachers were involved in hands-on activities and were encouraged to devise lessons with the ICT-data logging integration pattern clearly spelt out. An evaluation questionnaire was circulated to the teachers at the end of the training programme to obtain feedback for consideration in another training programme.

Some of the responses from the feedback questionnaire are produced:

T2: "*I believe that the use of these devices is a must nowadays. The teaching-learning of Physics will become more interesting and will consequently attract more pupils to opt for Physics*".

T3: "*This will help us teachers to deliver certain abstract concepts in a more meaningful way to the students. They will be able to grasp those concepts very easy. More workshops should be organized (on & off) to convey new ideas like this one to improve the teaching of Physics using ICT. Use of hypermedia: very interesting tool especially the demos or simulations for a better understanding of situations*".

T4: "*Definitely, the teaching of Physics will be more interesting as we can get away with the usual blackboard stuff i.e. recalling equations and trying to figure out how different physical quantities with one another. In this case, as an experiment is being done, the students will be able to see the graph of two variables being plotted simultaneously*".

T16: "*It would be a vital tool in the classroom. However, it should not be used for demonstration only. Students should be given the opportunity to carry out the expts themselves. This should increase their interest in the subject*".

The responses were quite positive and encouraging and they provided an initial feedback of the training programme and enthusiasm of the teachers.
However, Tinker (1999) and Yelland (2002) rightly claim that so much work has been carried out in relation to the ways in which the new technologies are capable of transforming learning but due to the inflexibility of the curriculum, the situation in schools has remained unchanged. In our Mauritian context, the keenness to complete the syllabus at the expense of adopting a learner centred approach is one of the main focus of a teacher during the lesson delivery. Most of the time, teachers would blame the system, forgetting that they are one of the stakeholders in the educational system ladder.

After the training programme, regular visits were carried out by our team with the following objectives:
- (i) to assist teachers in the implementation phase,
- (ii) to obtain feedback which would be used to improve the implementation phase.

However, to our surprise, the project was not being implemented as per the established framework, which includes elements of constructivism whereby learners are able to construct knowledge. We noticed that the teaching had not changed since the same traditional approach was being used, except that the teachers were using Power Point presentations. The lessons were carried out with a linear perspective and the learners were simply passive recipient of knowledge. This approach was in complete contradiction to the aim of the project. We were quite surprise to notice this situation as the feedback obtained during the training programme was very promising.

Phase 2: Implementation by research team

In order to add value to the project, the team decided to carry out a number of physics lessons in the project schools which aimed at:
- (i) Enabling the teachers to develop confidence in their approach while using ICT and the data logging equipment,
- (ii) Enabling the project team to collect first hand data which could be fed back in the process to address any shortcomings.

In order not to disrupt the normal running of the lesson, prior arrangement was made with the teacher and the same physics concept that the teacher was going to teach was selected for the research team to teach same. The sample of students varies from class to class; on average there are 35 students in a class.

For the purpose of this paper, the study was carried out in two schools and two O-Level classes were chosen. The concept that was taught was ‘pressure’.

Results and Discussions

The lesson was conceptualised on Power Point presentation and with the following perspectives:
- (i) *Devising a conceptual lesson plan*,

Table 1: Construction of the lesson

Stage/time	**Activities**	**Learning points**	**Remarks**
Introduction (5 mins)	Testing of prior knowledge, for e.g.: *<focus learners’ attention on the current issue which is pressure>* *<allow them to reflect on everyday life experiences of pressure – show them the graphics>* *<consider putting a paper on the notice board or using a pair of blunt scissors>*	One of the effects in focus is pressure, a concept different from force. Allow class discussion to occur to enable students to challenge notion of the concept.	>Learners are led to the concept of pressure which is the basis of this lesson. >Misconception with force should be probed further. >Adopt the open type questioning.

Development of the lesson Stage 1 (20 mins) Stage 2 (20 mins) Problem solving Stage 3 (30 mins)	1. Based on responses on prior knowledge, set the definition of pressure and highlight the wording 'normal'. Allow learners to suggest a synonym of the word in that context. 2. Allow learners to write down the mathematical relationship from the definition. 3. Allow learners to state the SI units with justification. 4. Allow learners to justify the type of relationship between the two variables. 5. Divide the class into 8 groups of 5 students. - Assign a group leader for each group. Students are required to attempt the problem solving task which includes the cognitive strategies (Taconis et al., 2001) in the worksheet. (The worksheet has been structured in such a way that students will be led on their own to the most likely solutions). Activity on pressure in liquids – experiment using data logging to confirm theory. Demonstration by teacher to support theory and hands-on by groups of students. Use of worksheet to focus attention of students. Teacher will use the digital video files on manometer and pressure increases with depth to support theory.	Curriculum integration – English Curriculum integration – maths > Use Excel to confirm the dependence, supported by a graph. Encourage team work. The responses are agreed upon collegially. Through scaffolding (Puntambekar & Kolodner, 2005), justify approach whenever learners face difficulty. (The main idea in using the worksheet is to enable learners to use their cognitive structures to develop understanding of the concept). Students will perform the activity and will infer that pressure (i) increases with depth, (ii) pressure acts equally in all directions Different approaches are used to cater for mixed ability learners. Differentiation is the basis of the lesson. Students will be encouraged to interact with the teacher and their peers (van Zee, 2001)	Constructivist approach to learning Development of core-constructs (Parmessur et al., 2005) >Teacher moves around and facilitates the process of learning. The teacher has to intervene when there is hindrance to learning (Gipps, 2001). Students are to come up with this definition through prompts (scaffolding).
Conclusion/ Summary and evaluation (5 mins)	Prior knowledge is linked with findings from experiment. Students should identify other examples in everyday life. They are asked to plot a graph based on data collected from the experiment.	Students have to calculate pressure in liquids.	Brief students about what will be taken up in the next lesson.

It should be emphasised that the lesson plan described above is rather flexible and accommodates any eventual changes depending on the prior knowledge of the learners and on the different examples projected from the PC, students were led to develop conceptual understanding of ‘pressure’.

(ii) *Learning outcomes based on Bloom’s Taxonomy were prepared to guide us during the lesson*,
The four levels of the taxonomy were mainly used during the lesson development; they are: knowledge, comprehension, application and evaluation.

(iii) *Testing of prior knowledge using open type questions and adopting the Comprehensive Interactive Model of Assessment (Parmessur et al. 2003).*
The concepts were directly related to every day life experiences of the learners; the concepts were illustrated either as pictures or as interactive gif files, downloaded from the internet,
Students were led to reflect on the type of knife they would use to cut something and why. They were eventually led to infer that force and pressure are completely different concepts.
The CIModel of assessment is a dynamic model that the teachers can used to assess learning in the process of classroom interaction and lesson delivery. The model comprises conceptual, procedural, analytical, and conclusive process evaluation. Through graded open questioning, the students’ understanding of concept during lesson delivery will be probed and the shortcomings will be addressed on the spot or reported soon after the lesson, during individual coaching sessions.

(iv) *Relating physics to english and mathematics as part of a curriculum integration* (Lake, 2004) *proposal plan*,
When this lesson was carried out in the project schools (school A & school B), there was a need to probe further on the conceptual understanding of the concept when the students were introduced to the definition of pressure as some of them were still experiencing difficulties to suggest a synonym for the term ‘normal’ as used in the context of this definition. Students have the tendency to rote learn definitions and procedures of an experiment. They usually face difficulty when they are challenged at the conceptual level. However, they could rightly answer when they were told to link that term with their maths lesson on geometry. It follows that their conceptual understanding of concepts needs to be reviewed again and again during the lessons. The adoption of the constructivist approach will certainly benefit the learners.

(v) *Enabling learners to situate their problem solving skills and abilities*,
Many tasks we perform in our daily life activities require careful sequencing of events and domains, which leads to the most probable solution, followed by some stages of reflexion. It is important to take note that only those problem solving tasks that are cognitive-based will contribute to the development of an internal representation of the task (Taconis et al., 2001). For the authors, it is essential that learners possess both the knowledge base (containing domain of general knowledge) and skill base (containing a repertoire of cognitive activities).

In order to ensure that learners’ attention is focussed at the problem solving activities, worksheets have been designed which would guide them to solve conceptual problems. The problem solving tasks have been designed to either prove a specific theoretical understanding of a related concept associated with pressure or simply to solve a structured problem solving task on pressure. At times, the problem solving activities introduced the theory and at other times the activities reinforced acquisition of concepts.

(vi) *Supporting theory with digital movies illustrating the concept.*
Selley (2006) is of the opinion that a variety of models and methods used in the classroom will certainly empower students to make sense of the world around them. The use of ICT in the classroom transaction is a powerful means of addressing mixed ability learning.
A few experiments, such as pressure increases with depth or properties of atmospheric pressure have been recorded on digital camera and during the lesson development they were projected with a view to reinforcing learning and acquisition of concepts.

More open type questions were set to students and they were led to the 'correct' answer. It was important for the research team to adopt a careful use of the questioning techniques so as not to suppress students' thinking (Selley, 2000). Whenever the answers provided by the students were wrong, class discussions were initiated to maximise participation so that students could themselves provide the most probable answer.

(vii) *Demonstrating and involving students in data logging activities,*

Students were asked to carry out the activities on pressure increases with depth and pressure acts equally on the same horizontal line using the Addestation equipment. They could see how the pressure on the digital meter included in the software was changing as the data logging pressure probe was immersed and raised into the water.

The data was saved and exported to Excel. The students were then asked to draw a graph of pressure against depth and their results were compared with the graph from Excel. The students were very excited when they could see that their graphs and that from Excel looked similar.

Students were asked to perform the activity of pressure increases with depth using low cost materials (plastic bottles) at home under the supervision of their parents who should sign in the same copybook to acknowledge that this activity has been done in their presence. This approach was adopted to bridge the gap between parents and school for a better partnership programme.

Figure 1: Teaching in secondary schools

Evaluation of students' appreciation of lessons

The lessons were evaluated with a view to determining the degree of appreciation in the use of ICT with data logging as well as the methodology used.

When asked what they liked best in the lesson, the responses from both schools were as follows:

School A

S5: *The videos, the animated worm drinking juice, the drawings which will be easy to remember during exams.*

S10: *The explanation on pressure using ICT and data logging and doing experiments.*

S23: *The presentation was good, the experiments that have been carried out was mind - blowing. At school, because we don't have such equipments, we can't really learn and gain skills about how to carry out an experiment ourselves*.

S 26: *It would have been more interesting if you could come more often to work with us.*

S 36: *The class works which was a great use for me and I was able to understand the lesson better. The practical activities also enable us to understand better.*

S 39: *The experiments which were shown through the video clips.*

School B

S18: *Everything was interesting and very good. Especially when using the ICT devices. The diagrams and experiments help us to a better view.*

S 19: *The way gas pressure has been presented. The molecules in motion with the changes in quantity and temperature. It is very interesting along with the explanation of the teacher.*
S 30: *The presentation was fascinating, especially because we could see the particles in motion. It also made us understand more, it made us see the logic concerning space, area, temperature etc. in the motion of particles.*
S50: *If we could get more lessons, using ICT that would be wonderful. Also, the use of more animations will be better because we like to learn through pictures and diagrams! Thank you!*

The responses from the students clearly show that they have appreciated the teaching which was constructed on multiple methodologies to cater from mixed ability learners.

Concluding Remark

The approach adopted by the research team to engage learners to construct knowledge has been well appreciated by the students. Though it took a significant amount of time to construct the ICT-data logging lesson, the outcome was very pleasing. Teachers can do away with the element of time constraint if there is collaboration in the schools as well as across schools.

Considerable and more reliable data should be collected to enable us to confirm that performance will improve with the use of ICT and data logging. However, quite a number of researches (e.g. Hakkarainen, 2003; Gipps, 2001; Edelson, 2001) do confirm that ICT when appropriately used will foster critical thinking and this is a prerequisite for understanding and development of cognitive structures. The strategy adopted in this research study is based on a constructivist perspective whereby learners are led to develop understanding of the concepts through graded exercises supported by ICT and data logging activities. There is a need to emphasise that the inclusion of only ICT and data logging will not bring about motivation and understanding unless there is a good pedagogical package attached to them.

The teachers involved in the project have surely gained up-to-date knowledge and skills during the implementation phase by the research team and it is hoped that the teachers will apply them to make the project a success so that schools can start acquiring computers and data logging equipment to enhancing teaching and learning in schools.

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