Troubleshooting exercises using circuit simulator software: support for deep learning in the study of electronic circuits.

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Abstract - **This paper reports on a pilot research project that investigated the use of an electronic circuit simulation software, Multisim 2001 from Electronics Workbench™, and troubleshooting exercises in the study of introductory digital and analogue electronics in a tertiary institution. The ultimate aim of this pilot study was to investigate the levels of higher order learning that may have been achieved by the students while (i) using such software to observe correctly operating simulated circuits, (ii) attempting to simulate described faulty circuit behaviour by introducing defects into the virtual components in order to troubleshoot the badly behaving circuit. An active learning environment was created in a computer laboratory where the students, under academic supervision, worked alone on their desktop computers. At each stage of this process the students' results were communally discussed with their alternative solutions demonstrated to all attendees on a data projector screen. To find out the level of higher order learning that may have occurred with this learning design, students were asked, while completing the tasks, to respond to survey questions. The questions were constructed with reference to the higher level abilities in Bloom's cognitive domain taxonomy. This paper also reports on an analysis of answers to the survey questions to reveal whether students have (i) applied the higher level abilities in the cognitive domains of Bloom, (ii) gained deeper understanding of the material and (iii) took part in active learning.**

Index Terms - Active learning, Bloom's Taxonomy, Deep learning, Simulation, Troubleshooting.

INTRODUCTION

The earliest documented examples of the use of simulators for training, such as tree trunks for practicing sword strokes, are in the military and date back to the Roman Empire. Simulation for training in the military has continued over the centuries and is still used today. Furthermore, modern simulators are currently used to train individuals to control the movement of aircraft, automobiles, and ships as well as to control processes such as air traffic, atomic power generators, and even a patient under anaesthesia.

In industry the use of simulators has enabled efficient product development and debugging. In leisure and entertainment, video games can be viewed as simulations of real and/or imaginary systems. In education, software simulators of microprocessors have assisted with the detailed understanding of the behaviour of these devices. In a wider context these latter day computer-generated environments clearly support "a specific form of constructivist learning, namely, scientific discovery learning" [1], that is expected to result in deep learning. In order to rate the student experience that, in this case, resulted from the physical venue, the academic-led structured activity and the extensive use of the simulator software, responses to student-centric surveys were analysed.

The use of the simulator software was a very important element of this investigation. In general terms, some of the advantages of using simulators include:

- allowing the user to modify system parameters and observe the outcomes without any harmful side effects,
- eliminating component or equipment faults that may have an undesirable effect on outcomes,
- supporting user paced progress in discovery and understanding of issues,
- facilitating deep learning by illustrating "dry theory" in another way.

However a major disadvantage of the use of software simulators for physical artefacts, such as electronic circuits, is that the user is unable to physically handle the circuit components hence some elements of conscious and subconscious learning may not be available.

THEORETICAL BASIS OF THE APPROACH

The issue of how to achieve the desired attributes for graduate students, particularly for those who attended tertiary and post-tertiary institutions, was summarised by Krathwohl, Bloom and Masia [2] when they concluded that:

"In the cognitive domain we are concerned that the student shall be able to do a task when requested. In the affective domain we are more concerned that he *does do* it when it is appropriate after he has learned that he *can do* it. Even though the whole school system rewards students more on a *can do* rather than a *does do* basis, it is the latter which every instructor seeks." [2]

Underlying most learning style research are the major categories in the cognitive domain attributed to Bloom [3], namely: ***knowledge***, ***comprehension***, ***application***, ***analysis***, ***synthesis*** and ***evaluation***, that is commonly referred to as Bloom's Taxonomy. In practice this is achieved by providing the "opportunities for students to engage in active processing and questioning of ideas, and practice thinking skills" [4].

Bloom and his colleagues hypothesised "that learning complex cognitive skills, such as the ability to synthesise (sic) interrelated information, would be based on learning simpler cognitive skills, such as understanding concepts and principles, which would be built based (sic) on learning even much simpler cognitive skills, such as remembering specific tasks" [5]. This hierarchical approach is also the fundamental pedagogy of "deep learning", and is clearly identified by Biggs [6] in this statement:

"Teaching builds on the known, it must not reject it. In deep learning, new learning connects with old, so teaching should exploit interconnectedness: make the connections explicit ... choose familiar examples first, get students to build on their own experiences, draw and explain parallels while teaching, use cross-references, design curricula that draw out cross-connections, and so on." [6]

Myka and Raubenheimer [7] clearly conclude that a correlation exists between "deep approach" and "Bloom's Taxonomy" after reporting "that moving tasks beyond a knowledge level to application, comprehension, analysis and synthesis (being the higher levels of Bloom's Taxonomy) will encourage learners to move beyond that surface approach." [7]

Both the interaction between the student and the content, and the interaction between the student and others about the content "are necessary for efficient, effective and affective learning" [8]; that has been identified as "deep learning" by Ramsden [9] and Laurillard [10]. Hughes and Hewson [11] clearly make this connection when they state that:

"A deep approach to learning can be encouraged by fostering active engagement with content, interaction with other learners, … and clear motivation by and interaction with the teacher, and opportunities for individual reflection on the experience." [11]

Troubleshooting exercises have been commonly included in the problem sections of recently published textbooks on electronics and circuit analysis. Such problems demand a minimum level of ***knowledg****e* and ***comprehension*** that has to be ***applied*** before any conclusion(s) may be ***analysed*** then ***synthesised*** in order to facilitate the ***evaluation*** of the resulting outcome(s) by the student.

The more complex cognitive skills of Bloom's Taxonomy (such as application, analysis, synthesis and evaluation) are most appropriate for laboratory-based exercises [12]. Therefore, in order to facilitate interaction between the participants and to encourage the need for higher levels of skills, an academic supervised computer laboratory was chosen as the venue for this investigation.

Britain [13] reiterates that for successful teaching to occur a variety of pedagogical techniques should be applied. He concludes that a number of these "focus on providing activities for learners to perform either in groups or as individuals that help to create deeper, swifter and more effective learning. These may be in the form of … simulations" [13].

The use of simulator software in the study of conceptual ideas, such as circuit behaviour, directly targets the visual, kinaesthetic and tactile learner. Published research papers have confirmed that students "who used the (simulation) software tool perceived a benefit to their study of … electronics concepts" [14, 15] and that using "simulation may have a beneficial effect on the learning outcome" [14, 16]. Ronen and Eliahu caution against assuming that the technique is universal, by noting that:

"The simulation was not effective for the following three groups: … Students with a very good level of conceptual understanding ... Students with insufficient level of understanding of the domain … (and those) stating (that) they 'hate computers'." [16]

Thus using the simulator to help with the solution of troubleshooting problems as a form of revision should minimise the second group of students, who may not have had sufficient levels of understanding if these exercises were used to illustrate totally new concepts.

TEACHING AND LEARNING DETAILS

The subject *HET210 – Electronics* is timetabled for 66 contact hours per student. Approximately 50% of these contact hours are assigned to each major topic, namely analogue and digital electronics. In 2006, 15 students were enrolled in the subject with the same academic scheduled for all the lectures, tutorials and laboratory sessions.

The use of the simulation software, Multisim 2001 from Electronics Workbench™, was integrated into all the elements of the subject. Firstly, the students were introduced to the simulator when the behaviour of both analogue and digital circuit elements was often illustrated during the appropriate lecture sessions. Additionally, as part of their submission requirements, the students were asked to predict their laboratory and confirm their assignment results with an appropriate simulation. Finally, the students were also encouraged to use the simulator while revising the theory covered in the subject and/or checking their answers to textbook problems.

The students obtained their own copy of the simulation software from a CD that was bundled with their textbooks. In the venue used for this study a copy of the same software was also installed on the computer used by each student.

THE PROCEDURE

In the last two weeks of their studies the students were timetabled for a total of six one hour troubleshooting sessions, in an academic supervised computer laboratory.

Although, during each such session a different section of the syllabi was revisited, the activity format in all cases was identical. The sessions commenced with a short review of the relevant electronic theorems and concepts, after which the students were asked to simulate the circuit under consideration, thus verify its correct behaviour. Next, the students were asked to predict the cause(s) for the "fault" that could have resulted in the observed circuit behaviour, which they then had to simulate as validation.

In terms of Bloom's Taxonomy of learning levels the first activity required the demonstration of knowledge and comprehension skills; followed by application and analysis skills; while the second activity required analysis, synthesis and evaluation skills from the participating students. The academic supervisor used Microsoft® PowerPoint® slideshows on a data projector screen to pace the students' activities. The student's attendance at these sessions was voluntary.

While each student worked alone on a desktop computer, at the end of each activity the students' results were communally discussed and representative solutions, using the data projector screen, were demonstrated to the class by the academic. From his research Yuretich concluded that "when students really ponder a question, discuss it in groups, or explain their answers to others, they are more likely to use skills at the more advanced levels of Bloom's Taxonomy" [17].

Additionally, during the sessions each student was also asked to complete a survey form on which each of the nine questions were framed around the major cognitive domains of Bloom's Taxonomy. In answering **Q1** the students needed to recall a wide range of information, such as the principles of electronic circuitry. This information had to be interpreted before translating it into an answer to **Q2. Q3** is an application question that aimed to test the students' ability to use their learned methods in new and simulated situations. **Q4** is an analytical question that required students to break down information into parts and draw relationships. **Q5** and **Q6** are synthesis questions that required the students to show their ability to put parts of information together thus solve the problem of predicting what caused the fault and suggest steps to confirm this by simulation. The last three questions, **Q7**, **Q8** and **Q9**, are evaluation questions that demanded of the students the ability to make judgment on their results and the value of the learning experiences provided.

According to Vygotsky [18] learners develop differently in collaborative environments, and while working alone. Consequently, the use of pre- and post-tests are an unreliable measure of learning particularly for individuals who are participants in group-based activities [19]. The "Bloom-based" survey, detailed above, was developed as a potentially more reliable instrument that may be used to identify the levels of student engagement during the troubleshooting sessions.

STUDENT FEEDBACK AND RESULTS

A total of 28 survey forms were collected after the completion of the six troubleshooting sessions. Table 1 details the number of students who attended each session.

TABLE 1
BREAKDOWN OF SURVEY PARTICIPANT NUMBERS.

Session 1	*Session 2*	*Session 3*	*Session 4*	*Session 5*	*Session 6*
4	6	8	3	5	2

The following summarises question-by-question all the responses that were obtained:

- **Q1** (***What do you understand to be the main principles behind a typical fault?***) exposed the students to the ***knowledge*** and ***comprehension*** domains of Bloom's Taxonomy during each session. From the first session onwards, all but four answers reflected an understanding of the task ahead, although the students' answers evolved towards the more descriptive as the sessions progressed.
- **Q2** (***Simply state the process of fault detection.***) answers changed from the theoretical in Session 1 (such as "*step by step process of checking of expected output/behaviour to actual behaviour; then narrowing down where the fault originates*" and "*think of possible faults; go through them in order of probability; try to evaluate behaviour of each individual component*") to more practical approaches using the simulator software in Session 6 (such as "*systematically testing regions in the circuit, to try to identify the source of any faults*" and "*induce (sic) all possible faults in simulator and see if it matches behaviour of faulty circuit*").
- **Q3** (***How did you check that the simulated circuit is operating correctly?***) answers became more detailed as the students' experiences increased over time (such as "*compare results at certain points along the surface, to output expected at these points*" in Session 1 to "*double clicked on the multimeter, went through each area of the circuit to double check components were as they should be*" in Session 5)
- **Q4** (***From the evidence provided is the circuit faulty? Briefly explain your answer.***) exposed the students to the ***analysis*** domain of Bloom's Taxonomy during each session. The responses in Session 1 (such as "*yes, would expect some voltage*" and "*measurements are not correct*") and in later sessions (such as "*yes, the mid-frequency gain is lower than it should be*" and "*yes, 1111 should be -3.75V and 0100 should not equal 0V*") demonstrate deeper levels of understanding.
- **Q5** (***Can you suggest what the fault could be? Briefly explain our answer.***) and **Q6** (***How will you test your hypothesis?***) responses (such as "*collector is open; resistor is shorted, emitter open*" and then "*introduce faults in components*" or "*bypass capacitor is short circuited*" and "*create fault and then simulate it*")

established that the students were exposed to the **synthesis** domain of Bloom's Taxonomy during each session.

- **Q7** (**Did the simulation confirm your prediction?**) answers evolved from single word single prediction to recognising the possibility of multiple solutions (such as "*yes but possibility of resistor or wire being open-circuit which would also create that sort of behaviour*" in Session 5).
- **Q8** (**Has your understanding of component behaviour deepened?)** answers were significantly in favour of "yes" (17/28) with "no" (3/28) and abstentions (8/28) in very much a minority.
- **Q9** (***Order, from 1 to 3 (with 1 for most useful), the following activities as learning tools***) responses are summarised in Table 2 and it is apparent that venue independent collaborative problem solving with academic and student participation is the students' preferred option. Also, there appears to be a preference for using a simulator in these types of activities when compared to just mathematically solving problems from a textbook.

TABLE 2
RESPONSES TO Q9.

Options	**Most useful (1)**	**Useful (2)**	**Least useful (3)**
Doing troubleshooting exercises from the textbook alone.	**0**	**6**	**14**
Doing troubleshooting exercises in tutorials with the tutor.	**20**	**2**	**0**
Doing troubleshooting exercises using a simulator (in a laboratory).	**1**	**13**	**7**

CONCLUSION

The academic-driven computer laboratory-based sessions were an attempt to create the environment for deep learning. While the number of participants was small, particularly in some sessions, the responses to survey questions shed some light on the pedagogy experienced by the students.

Subsequent qualitative analysis of the survey responses lead to the following conclusions:

- the performed circuit simulator-based troubleshooting tasks exposed the students to all the elements of Bloom's Taxonomy;
- there was confirmation of Ramsden's [9] proposition on effective or deep learning, in which he states that "it can involve interaction with content in a way that enhances understanding (through simulations, for example)";

Therefore, it appears that the venue and the chosen exercises in conjunction with the simulator software, enabled student participation in active learning; the importance of which was articulated by Laurillard [10] when she stated that irrespective what it may be called eminent writers on learning (such as Dewey, Piaget, Vygotsky, Bruner, Pask, Schank, Marton and Lave) emphasised the importance of this type of student activity.

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