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Problem-Based Learning (PBL) in Microelectronics*

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The paper concentrates on the integration of the pedagogical theory and the Problem-based Learning (PBL) practice. This is illustrated on an engineering module example, Microelectronics, which follows a vocational teaching and learning strategy. Assessment methods in relation to PBL, facilitating and mentoring roles of teachers in PBL, transferable skills and learners' motivation are also aspects discussed by the paper and demonstrated on the basis of the Microelectronics module case study. Conclusions on the use of the PBL method in modern engineering education are drawn.

INTRODUCTION

NOWADAYS students are increasingly attracted to the vocationally-oriented qualifications such as those accredited by the British Business and Technical Educational Council (BTEC). They are coming with a wide variety of technical and cultural background, motivation, age and experience and this must be taken into account either by extending the courses and establishing a common foundation or by lecturers' in higher education adapting their expectations and the programmes they offer. As the first method normally requires extra resources, such as extra teaching staff hours, availability of rooms, technical support, etc., it is the last one which is normally preferred because it is cost and time effective. Therefore, the necessity arises to reconsider the teaching and learning strategies, and to adapt them to the move away from traditional academic qualifications towards more competence-based vocational approaches [1].

This paper presents the problem-based learning (PBL) strategy applied to the Microelectronics module, taught to second-year BSc students (full-time and part-time) in Electronic Engineering, at De Montfort University, Leicester, UK. The learners do not have a strong background in the field and the module is vocational oriented, aiming to transfer to the students mainly practical skills but some theoretical knowledge, too. The teaching strategy and assessing criteria are developed considering the complex combination of laboratory coursework, as the main component, and the theoretical foundation.

MICROELECTRONICS MODULE DESCRIPTION

The content of the microelectronics module to be taught includes the following topics:

- design philosophy for VLSI
- simulation
- verification
- programmable logic devices
- gate arrays
- field programmable gate arrays
- semi and full custom devices
- fabrication issues on C-MOS technologies
- test strategies
- design for test.

After completing the module, the students are expected to meet the following *learning outcomes*:

1. Understand the design methodologies, techniques and test strategies used in the manufacture of VLSI custom ICs and the role played by CAD systems in the process.
2. Develop transferable skills in the use of computer tools to capture, simulate, verify and implement (in FGPA) digital circuits/systems of different levels of complexity.
3. Demonstrate skills in teamwork, time management, collection and presentation of information, decision making, report writing and oral presentation.

The twelve weeks module is structured as one hour per week lecture plus two hours per week hands-on course work, as follows:

- Weeks 1 to 5: completion of sign-posted exercises, as described in worksheets (No. 1, 2 and 3). A logbook must be kept, containing the record of the progress in a methodical manner. This should include details of the work, problems encountered, simulation results and conclusions and it is inspected in Week 6, together with a short on-screen viva.
- Week 6: hands-on assessment on the computer: the use of CAD software to design and simulate a circuit implementing a simple algebraic equation. No books/log-books are to be used.
- Weeks 7 to 12: the group design exercise of a 4 bit × 4 bit digital multiplier. This is a team

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project to be completed by week 11. A formal design report has to be produced by week 12, in addition to the logbook.

- Week 12: all students are taking part in a group viva voce examination; the design is discussed, the logbook is collected and an on-screen demonstration of the simulated design is requested together with a practical demonstration of the design on the FPGA development board.

INTEGRATION OF PEDAGOGICAL THEORY

The development of this module is strategically taking into account Kolb's descriptive model of the adult learning process consisting of four stages [2]: Concrete Experience is followed by Reflective Observation that generates the Abstract Conceptualisation. This leads to Active Experimentation that will generate a new Concrete Experience. Abstract Conceptualisation can be stimulated by lecture sessions, whereas Active Experimentation, Concrete Experience and Reflective Observation can be better addressed in interactive laboratory sessions.

The lectures cover the main theoretical issues, addressing the first cognitive type of objectives (memory, interpretation) in accordance with Bloom's taxonomy [3], in strategic combination with the laboratory hands-on sessions and the project, which concentrate more on the other cognitive components (translation, application, analysis, evaluation) and the affective aspects of learning (responding, valuing and organisation in particular). The coursework is based on practical design examples and addresses the psychomotor component (reflex and skilled movements) in accordance with [4]. Due to the vocational aspect of the course, an appropriate teaching strategy for Microelectronics should address more the practical skills expected to be gained by the students rather than theoretical knowledge. The step-by-step structure of the design exercises included in the first part of the laboratory worksheets aims to develop transferable skills without establishing this objective as such.

In terms of the distinction introduced by Hudson (1967) between *convergent* and *divergent* knowledge, the weight of the Microelectronics module is situated somewhere between Abstract Conceptualisation and Active Experimentation, as a convergent type of knowledge. This is reflected in the high contribution of the laboratory work into the assessment and the large amount of time dedicated in the module template to this aspect. Theoretical issues addressed during lectures may have some divergent aspects in the sense that they aim at times to stimulate student's creativity and suggests possible original developments of certain topics/projects. The lecture handouts contain fully the material presented during the lectures and suggestions for creative approaches. The laboratory handouts are structured as guides for practical design examples which can be followed step by step by the learners, either under supervision (during class) or individually. The applicability of the strategy adopted for this module relies on students' having early knowledge of what is expected from them in terms of module structure, assessment, library facilities and technical support. This is giving them the opportunity to plan their own activities and therefore to improve their performance.

Three major learning theories are identified in [5]: Behaviourism, Humanistic and Cognitive. The strategy developed for the delivery of the Microelectronics module is based on elements included in all three. There are behavioural learning elements related to the vocational orientation of the BSc course and the transferable skills to be gained by the students. The humanistic aspect of the strategy relies in the role of the teacher as the facilitator and co-ordinator, which gives the student the freedom to follow their natural desire to learn and to have control over the learning process. The laboratory worksheets are structured such that they can be used independently, with or without lecturer's guidance. The students are informed from the first class contact about the detailed structure of the module assessment methodology and demands, and the module template envisages an equal number of hours with that of class contact (lecture and laboratory) to be spent by each student in individual studies. The 'team scenario' of a group project, included in the second part of the laboratory work, is also a good opportunity for the students to take control of their own learning.

The cognitive learning theory is covered by the oral aspect of the coursework examination, which checks the understanding of the designs performed in the laboratory. The learners are aware throughout the module of the need to understand their work, rather then follow a pattern.

The constructivist theory [6] is also present in the strategy developed, as the laboratory worksheets and the project exercise are ended with supplementary suggestions aiming to stimulate learner's creativity and actively involve the learner in the design and analysis of new aspects. An interactive development of the laboratory sessions and dialogue with students is encouraged. The overall dynamic of the module is taking the learners from a basic level of following given material at the beginning of the module, which realistically considers the students' background, to the creative stage of managing their own project, as a team, in order to produce an original design.

ASSESSMENT RELATED TO PROBLEM-BASED LEARNING

The assessment method of this module, laying the emphasis on PBL and split as 20% theory test and 80% course work, was considered to stimulate active learning and to be matching well the expected learning outcomes of the Microelectronics module. It consists of:

- ability to assimilate and respond to a variety of theoretical information proving a logic understanding of the matters dealt with during lectures—theory phase test (20%);
- practical development of sign-posted laboratory exercises using technological equipment and a range of modern hardware/software resources (20%);
- ability to solve an unseen problem using available technology and practical skills proof (20%);
- team work project involving innovative design and hardware implementation from brief design specification (20%);
- ability to produce a well structured formal team design report and present it orally (20%).

This method also allows the coursework (problem-based learning) to be continuously assessed on a number of occasions, eliminating the unfairness of a one off examination related to poor single performances of students who react badly to exam pressure and facilitates the marker to achieve a more realistic monitoring of the learners progress [7]. Good time management is achieved, not only in students' interest but also allowing a more even workload for the staff involved.

The assessment method for the Microelectronics module is *reliable* to a large degree as each component of the mark is generated in direct connection with the skill being assessed. It is *valid* as well, as the 'measurements' are simultaneously addressing, in close related terms, the module's learning outcomes and BTEC transferable skills such as:

i) receiving and responding to a variety of information;
ii) dealing with a combination of routine and non-routine tasks;
iii) using a range of technological equipment and systems;
iv) participating in verbal and non-verbal communication.

The first three skills are assessed by looking at the following indicators of evidence during the continuous assessment of the laboratory work: identify clear and realistic objectives, employ CAD design tools and support equipment in an efficient manner, successfully apply written and verbal instructions, show self-efficiency and confidence, seek feedback on progress.

The fourth listed skill is assessed during the interim and final on-screen presentations and as part of the laboratory logbook and project report, looking at evidence such as: use a form and style of communication appropriate to the purpose, present visual information clearly, use appropriate numerical/diagrammatic information to improve readers' understanding, exercise originality and creativity in the presentation of data, use appropriate forms of communication for the situation/audience, use appropriate language, avoid jargon.

LEARNING STRATEGIES AND MOTIVATION

In accordance with the approaches to study identified by Ramsden [8], the laboratory exercises aim to encourage deep learning, to level the differences in learning culture and to develop transferable practical skills by good practice. The learning process is defined as being 'a relatively permanent change in behaviour that results from practice' [9]. As shown by Gordon Pask [10], different people have different favourite learning strategies, which can be mainly grouped as 'serialist' or 'holist'. The mixture of sign-posted exercises and a team project addresses both approaches, with the serialist learner preferring more the step-by-step assignments and the holists feeling more comfortable with the less rigid framework of a project. There are other factors that stimulate learners and increase motivation, considered by Herzberg [11] to be part of a 'motivational hygiene', which consist of:

- the ambient of learning (new computers, updated software, warm and well-illuminated lecture theatres/laboratories);
- a friendly dialogue between the learners and the teacher;
- a clear indication of the possibility to get good marks by satisfying well established assessment criteria;
- the use of appropriate visual aids.

When 'designing' the delivery strategy for the Microelectronics module, another important issue had to be considered across the group of learners: motivation as either intrinsic (doing something for its own sake) or extrinsic (doing something for some other reason). A classification of different levels of motivation has been made by Maslow [12], linking the hierarchy of needs to motivation in his classical pyramid in which the needs are motivators and stimulators at different levels, ranging from basic level physiological needs to self-esteem. The Microelectronics students' motivation for learning can be related to their needs, ranging from finding employment for example at the basic level, to the need of proving themselves in front of their family, colleagues and friends, getting a promotion or getting 'ammunition' for their creative goals and/or vocation.

Many of the learners are part-time students and their motivation is most of the times higher than that of the full time students on the same course. This is due to a more mature approach to learning, supported by adult learning theories that agree to a more 'self-directed learning' in which 'adults take control of their own learning . . . set their own learning goals, locate appropriate resources, decide on which learning methods to use and evaluate their progress' [13]. The vocational problem-based learning in Microelectronics is, for most part-time students, directly relevant to their work. Higher motivation and more responsibility are therefore shown by part-time learners.

Finally, the role of the teacher as an instructor, model, supervisor and facilitator, who gives the students the freedom to follow their natural desire to learn and to have control over the learning process, who is also expected to genuinely identify learners' needs and to develop a strategy that addresses learners' past and present experience, motivation and technical background, must be appropriately placed in the modern context of problem-based learning.

CONCLUSIONS

The paper considers the integration of the pedagogical theory with the problem-based learning (PBL) practice. This is investigated using the Microelectronics module as a case study. The strategy is contributing to a much better understanding of particular issues related to learners—age and wide cultural/technical background, self-study and distance learning, differences in motivation—and can be adapted to the identified learners' needs, leading to better overall results in the teaching and learning process. Improved attendance and increased average mark (8% in the first year and 9% in the second year) were recorded for the BSc Electronics cohort after introducing the new method, comparing with the previous year. Therefore, it can be concluded that the PBL perspective towards the complex aspects of the teaching and learning process, in conjunction with the pedagogical theory, can generally enhance the quality of teaching technical disciplines, as illustrated by the Microelectronics module case study.

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