Applying the problem-based learning approach in teaching digital integrated circuit design

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The problem-based learning (PBL) method has been applied to curriculum development in some areas of electrical engineering. The overall result has been a positive learning experience for students. However, PBL has not, as yet, been used in the area of digital integrated circuit (IC) design.

IC design is in a revolutionary phase at present. It could even be said that IC design is at the beginning of a new epoch. Design is moving toward nano-size. Thus, design techniques are advancing so rapidly that existing design knowledge quickly becomes obsolete. The IC design industry needs engineers with an integrated design perspective, real hands-on experience and well developed skills in problem solving, communications and continuous self-learning.

In this paper, we discuss the application of the PBL approach to digital IC design teaching. The course objective is to teach students about the principles and methods for designing large-scale nano-size digital IC. Through the process of searching, analysing, synthesizing, and evaluating, students finally develop their own solutions with supported arguments. They can design basic circuits manually and design complex circuits in a computer-aided design environment. Based on these learning objectives, a PBL course is designed. After the description of the traditional teaching approach, the PBL approach implementation is discussed. The course contains scenario modules, some supplementary lectures and some assessment settings. Four system-perspective scenarios have been designed appropriately to attract and facilitate student's learning, and they cover most of the course syllabus. Furthermore, the scenarios are related to the industrial design practice and provide learning flexibility for students to think and innovate. Corresponding scenarios module kits and assessment methods have been designed for each scenario. To make use of the peer-learning property and alleviate potential problems of high learning (and teaching) demand and content fragmentation in the PBL approach, some measures (e.g., peer-marking) have been proposed in this paper.

Compared to the traditional teaching method, the PBL approach should help students to build a more solid digital IC design foundation. Students should also develop confidence and transferable skills to handle new design challenges at present and in the future.

Keywords: Problem-based learning (PBL), engineering education, electrical engineering

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Introduction

The knowledge-oriented and fast-changing economy requires intellectual workers with skills of problem solving, team working and self learning. The traditional curriculum cannot meet the requirements. Problem-based Learning (PBL) is one of the proposed learning ways to tackle this problem (Boud, 1997). PBL was firstly applied in the medical study and has been applied to other subjects (LaPlaca, 2001) (Cline, 1997). Different studies show that PBL assists students to have an in-depth knowledge understanding and develop transferable skills (e.g., communication skill and independent problem solving skill). Furthermore, it helps students to build up confidence to apply the acquired knowledge to new situations.

The PBL method has been applied to curriculum development in some areas of electrical engineering, such as elementary circuit analysis (Costa, 1997), communication system (Mitchell, 2010), analogue circuit design (Mantri, 2008) and system-level electronic system design. The overall result has been a positive learning experience for students. However, PBL has not, as yet, been used in the area of digital integrated circuit (IC) design.

IC design is in a revolutionary phase at present. It could even be said that IC design is at the beginning of a new epoch. Design is moving toward nano-size. Thus, design techniques are advancing so rapidly that existing design knowledge quickly becomes obsolete. The IC design industry needs engineers with an integrated design perspective, real hands-on experience and well developed skills in problem solving, communications and continuous self-learning.

In this paper, we discuss the application of the PBL approach to the digital IC design teaching. The course implementation, scenarios design, assessment and limitations will be discussed.

Traditional digital IC design teaching

The objective of the digital IC design course is to teach students about the principles and methods for designing large-scale nano-size digital ICs. It is an advanced (Level 3) and workload intensive (6 credit, about 40 lecture hours) course. Students are expected to have basic fundamental analog circuit knowledge. In the traditional teaching method, the course consists of weekly 3-hour lectures, and students are assessed through assignments, a digital control system design project and a closed-book examination. According to feedbacks from students and industries alumni, the course content is fragmented and the project content is irrelevant to the lecture content. As a result, students do not have an integrated insight, experience and confidence to handle the industrial digital IC design after taking the course.

Course implementation using PBL approach

The reformulated course has the same objective as in the traditional course, with more emphasis on hands-on design practice. The course contains four scenario modules and a few hour supplementary lectures. Each scenario module is a repeated seven-step learning procedure (Maastricht model) and lasts for 3 to 4 weeks. Scenarios are designed carefully and appropriately to facilitate the students' studying.

The role of the student is to search, analyse, synthesize, and evaluate the obtained materials, and finally develop their own solutions with support arguments. Students will learn to design basic circuits manually and design complex circuits in a computer-aided design environment. Peer-learning is an important part in PBL. Four to six students are formed as one learning group. Continuous formative peer-assessment, assignment peer-marking and group performance grading are used to encourage students to learn and discuss with peers.

The role of the teacher is to facilitate students' learning process, and help student to summarize their learning experiences. Teachers also provide introductory lectures and scenario module kits for each scenario module to assist students' learning. Furthermore, design experience can be transferred in group meetings. Reference materials and sample demonstrations can be provided to stimulate students' thinking when inquiry.

Scenarios design

Scenario significantly affects the learning process. The selection of scenarios depends on:

- Coverage and appropriateness to the course syllabus
- Flexibility of learning (which encourages students to think and innovate)
- Relevancy to the industrial design practice
- Attraction and accessibility to students
- Time and workload demand
- Practicability to perform both manual design and computer-aided design

According to these criteria, four system perspective scenarios are designed for this course. In a system perspective, a digital processor (an assembly of digital ICs) contains modules of memory, datapath, control and input-output circuitry (Rabaey, 2003). Modules are connected through interconnect. A composition of a simplified digital processor is shown in Figure 1.

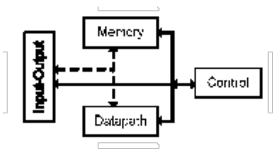

Figure 1: Composition of a generic digital processor. The arrows represent the possible interconnections.

These scenarios can be generally related to a digital radio receiver (a communication system) circuit design. The four scenarios are:

- Clock divider design: Design of a CMOS inverter chain (the fundamental component in modules) and interconnect (including the study of timing issues in a digital processor)
- Viterbi decoder design: Design of a datapath module (combinational logic, sequential logic and arithmetic operations)
- Radio controller design: Design of a control module (a finite state machine with time-triggered events and decision-triggered events)
- Digital IC design consultation report: Study of a practical digital processor design (including common design methodologies and requirements)

A module kit is designed for each scenario. The kit lists the design situation, learning objectives, the key theory introduction, design implementation and constraints, report requirements and key references. Learning objectives are specified clearly such that students will not miss any key ideas.

Assessment

An appropriate assessment strategy helps students to learn. A mixture of assessment methods are used to reflect students' respective strengths and weakness. Outcome-based assessment is used here. Some assessment details are as follows.

Formative assessment:

- Groups are required to submit an one page point-form report weekly. The report will discuss about their learning progress and difficulties, learned contents and the learning plan.
- Although transferable skills are not assessed for grading, they are evaluated through questionnaires and feedback.

Summative assessment:

- Assignments are given to help students familiar with the manual circuit analysis step. Peer marking is used to encourage peer learning and reduce workload of tutors.
- Students are required to submit group written reports and have individual viva (oral Q&A session only) for each scenario module. The grading depends on the design philosophy, the implemented result (with simulation and layout design), the reasoning for the differences between the implemented result and the expected result, possible extensions, and the readability of documents.

Limitations and solutions

It is typical that PBL requires more learning effort and teaching effort. This distracts students and teachers to use PBL in a tight teaching schedule. A few things are adopted here. Sample demonstrations, weekly tutor meeting and formative feedback reporting facilitate students to learn without disturbing their self-learning process. Assignment peer marking helps to reduce tutors' workload, and let tutors do more valuable coaching activities.

PBL may lead to the content fragmentation. This can be avoided by designing scenarios carefully. The first three scenarios are designed appropriately to cover as much content as possible. The fourth scenario (consultation report) is used to help students to identify the missed content. Furthermore, supplementary lectures are given to cover the missed content if necessary.

Conclusion

In this paper, problem-based learning (PBL) approach has been applied to the digital IC design teaching. Course structures, scenarios design and assessment have been discussed. Compared to the traditional teaching method, PBL approach could help students to build a more solid digital IC design foundation. Students should also develop confidence and transferable skills to handle new design challenges at present and in the future.

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