International Conference on Engineering Education and Research "Progress Through Partnership"
© 2004 VSB-TUO, Ostrava, ISSN 1562-3580

Project-based Active Learning in an Industry Relevant Course

S. M. AZIZ
School of Electrical & Information Engineering, University of South Australia, Mawson Lakes Campus, SA 5095, Australia, e-mail: mahfuz.aziz@unisa.edu.au, URL: http://www.unisa.edu.au/eie/

KEYWORDS: *project-based learning, active learning, self-motivated learning, VLSI Design*

ABSTRACT: *This paper presents a project-based approach to learning in a course on VLSI Design. Rapid developments in VLSI technology and the continuing evolution in design practices require adopting a teaching approach that would not only assist students in developing a core set of industry relevant skills but also enable them to adapt to changes in their professional career. There appears to be consensus among professionals that such an industry-focused course could be best conducted using project-based active learning approach. However, it is indeed a challenge to develop among students a core body of technical knowledge, practical design skills using relevant CAD tools and lifelong problem solving ability in a thirteen week long semester. The author adopted a project-based learning approach in order to assist students in developing the above qualities. This paper presents some of the challenges involved, the processes adopted and the results obtained.*

1 INTORDUCTION

Project-based learning has been recognised to be very useful in science and engineering disciplines (Aziz 2003). In this approach learning occurs by way of engagement with practical problems the students are required to solve. The key ingredients of this approach are that the students are required to *apply their knowledge* to solve practical problems and *learn more (new things) by doing* (Kerns et. al. 2002). It enables students to become independent learners, to develop important graduate qualities such as *problem solving* and *lifelong learning*, and above all it prepares them for a professional career where they would be frequently required to work autonomously. The above two qualities are among the seven qualities a University of South Australia (UniSA) graduate is expected to acquire (UniSA 2004a). In addition the University advocates the *application of knowledge* as one of its key commitments (UniSA 2003).

The rapid developments in Very Large Scale Integrated Circuit (VLSI) technology and the corresponding evolution of design practices and tools warrant a teaching approach where students develop the quality of independent learning. Industry stakeholders look for graduates who are able to adapt to rapid changes in technology and design practices. This is very important since most technical skills appear to become obsolete within five years (Lloyd 2000). Therefore, a project-based learning approach whereby students not only acquire a core body of knowledge, but also acquire practical design skills and problem solving/lifelong learning abilities would be most appropriate. The question is how to incorporate all the necessary learning activities in a thirteen week long semester, given the fact that the students need to learn to use some CAD tools before they can really start working on assigned projects. State of the art commercial CAD tools for VLSI design are known to have long learning curves. This drastically reduces the amount of time available for the actual learning, i.e., developing a core body of knowledge and problem solving skills. This paper presents a project-based approach including project examples whereby the author has attempted to address some these challenges. The student achievements and satisfaction with the course are also presented in this paper.

2 CHALLENGES

As stated in the introduction, there are a number of challenges for an academic while teaching in an industry-relevant course like VLSI Design. The students would soon be entering their professions upon graduation and would be expected to work on real world problems and deliver up to the expectation of their employers. In explaining the *teaching philosophy* of a course on Digital System Design to the students, Professor Bob Reese of Mississippi State University (Reese 2003) states the following:

> ***“Upper level courses have a different style of instruction than lower level courses!***
> This is an upper-level course (Jr/Sr/1st yr graduate). This means that you will soon graduate and enter industry.
>
> Q1. Is it important to learn new things *after graduation*?
>
> > Yes, the electronics world is constantly changing. Much of your digital electronics knowledge is obsolete in 5 years, and much more knowledge has been generated.
>
> Q2. How do you learn new things *in industry*?
>
> > Not via courses, not via weekly quizzes -- Through *self-motivated learning*!!! Nobody is going to tell you to learn topics A, B, C -- you have to figure this out for yourself or become **obsolete**!
>
> Q3. Therefore one of the most important things that we can teach you is *self-motivated learning*!
>
> > In lower level classes (i.e., Digital Devices) we will tell students to understand/memorize N things in a detailed list. We will go over those N things in excruciating detail, leaving nothing to chance.
> >
> > In upper level courses (i.e., this course!), we will discuss N topics but will not cover all of those topics in the same amount of detail as in a lower level course. We expect the students to show some self-motivation, look up information, ask questions, etc. on all of these topics. You will be expected to be able to discuss these N topics at the same level of detail as if we had spent equal amounts of time on them in class. If you do not understand a topic, ask questions of the professor, your peers, and seek outside knowledge sources. This is what will be expected of **YOU** in industry.”

Most practitioners would generally agree with the above philosophy. One thing that needs to be added though is that engineers (as well as other professionals) go through some professional development and training programs throughout their career. However, it is impossible to address the regular learning needs of a practitioner through institutionalised trainings and development programs as they would have to continually adapt to the rapidly changing contexts within which they would operate. In addition, the training programs would achieve very little to enhance the ability of a practitioner unless he/she is motivated enough to learn new things everyday to maintain his/her professional relevance. Therefore, in order to prepare students for their professional careers university courses should be designed to assist students to acquire *problem solving* and *lifelong learning* abilities, rather than simply spoon feeding them to memorise prescribed content and design methods. This is especially important for industry-relevant upper level undergraduate and postgraduate courses. As stated previously these are in tune with University of South Australia’s emphasis on development of *graduate qualities* (UniSA 2004a). The course VLSI Design being a course offered to final year undergraduate as well as to postgraduate students, it must incorporate suitable teaching and learning activities for professional development.

However, the challenge lies in the fact that a lot of ground needs to be covered in a thirteen week long semester. For example, it is essential for students to develop the following:

- A core body of up to date knowledge.
- Apply that knowledge to solve practical design problems.
- Develop adequate practical skills for integrated circuit design.
  - It is very important that students develop a fair understanding of the entire design flow (from the design of a single cell to a complete chip including all steps required for digital/analog simulation, testing and timing analysis).

As stated previously, it is indeed very hard to incorporate all the above in a one semester course given that the commercial CAD tools used by industries for VLSI Design has a long learning curve. These tools are very costly as well. Therefore due care must be taken in the selection of CAD tools, and appropriate learning activities must be put in place. This study attempted to address the issues outlined so far. One of the tasks undertaken as part of this study was to consult relevant industries (being the major stakeholders) on how the above issues could be addressed in the VLSI Design course.

3 CONSULTAION WITH PROFESSIONALS

A number of professional engineers working in the Australian microelectronics sector were consulted in order to ascertain what skills and qualities the industries would look for in a graduate. A couple of senior engineers working in two renowned US design houses were also consulted in order to gain an international perspective and current technological trends worldwide. The following points emerged from these consultations:

- Graduates must develop a thorough understanding of the full-custom design methodology
- Graduates must develop the skills required to effectively apply their knowledge in practical circuit design and must acquire adequate practical skills for circuit design
- They must develop self-motivated learning abilities in order to adapt to the rapidly changing technologies and design methodologies throughout their professional career.

The above are in tune with UniSA's codes of *good practice in university teaching* (UniSA 2001) and *graduate qualities* (UniSA 2004a). There was consensus among the professionals consulted that such an industry-focused course could be best facilitated using *project based active learning approach* in order to ensure that the students develop the qualities listed above. Three separate mini projects were designed as the main learning activities in the course covering both the design methodologies and the underpinning theoretical knowledge. *Assessment* in the course was 100% by design projects. Commercial industry standard CAD tools were not used due to their long learning curves and high cost. The industry professionals consulted expressed the view that any collection of CAD tools which would facilitate the development of the required circuit design skills and incorporate the essential components of the up to date chip design flow could be used. For a custom VLSI Design course, they recommended that the CAD tools used should ideally have the following features (Pucknell and Eshraghian 1994; Rabaey, Chandrakasan and Nikolic 2003; Weste and Eshraghian 1993)

- Facility for mask layout design including support for structured/hierarchical design methodology.
- Choice of a number of appropriate foundries (design rules) within the design environment.
- Quick functional simulation.
- Netlist extraction including parasitics for SPICE (for precise simulation).
- Design Rule Checking (DRC).
- Generation of text file in industry standard formats such as CIF and/or GDSII for fabrication of the designs.

A review of the available CAD tools was done. In addition to considering the above items in this review, features such as ease of installation and maintenance, user friendliness, support for Windows based PC platforms etc. were considered. These are all issues that can have a negative impact on the smooth running of the course unless they are adequately addressed. In the end a CAD tool named Microwind2 (Sicard 2003a, 2003b, 1998) was selected. This tool includes most of the desired features for the VLSI Design course as outlined above. The most important feature of this tool is its user friendliness and consequent fast learning curve. In addition it has a number of easy-to-use features and tools which make learning enjoyable. These include a tutorial on MOS devices to easily understand the MOS characteristics, with a friendly user interface. Changing the model parameters immediately displays the effects on MOS characteristics on the screen. 2D and 3D views of the circuit designed are available immediately at the press of an icon. These are very helpful for easily visualizing some of the details of the fabrication process. A built-in device and interconnect extractor is invoked at the press of a single key. There is a built-in analog simulator, which eliminates the need for external simulator for most educational purposes. It uses MOS model 1, 3, 9 or BSIM4 to perform static or time-domain verification of the circuit. Simulation can be performed on a wide range of technologies: 1.2 micron down to 35 nm. On-screen power estimation is also available. On top of all these the tool is available for free (Sicard 2003a).

4 DESIGN PROJECTS

4.1 First project: a self-learning guide

The projects were designed carefully so that students could enhance their understanding of the theory and develop circuit design skills right from the beginning. With this in mind the first project presented a very simple circuit design exercise to the students, that of designing the mask layout of a CMOS (Complementary Metal Oxide Semiconductor) inverter. A step by step guide (project handout) to building the inverter layout was given to the students. Following the steps the students could comfortably navigate through the various features of the software and gradually build the inverter layout without much difficulty. In other words the project handout was designed as a *self-learning guide*. The first project achieved two things, first the students learnt how to use the software, and second they got the satisfaction of building a circuit that did something useful. This did a lot of good for student satisfaction and motivation.

Figure 1 shows a monochrome view of the inverter layout and Figure 2 shows the simulation results (voltage vs. time) for checking the functionality of the inverter. Figure 3 shows the transfer characteristics of the inverter and enables students to determine important parameters such as noise margin. The students are able to extract a SPICE netlist from the layout and simulate the inverter with SPICE for various aspect ratios of the MOS transistors. This is done simply by editing the SPICE text file rather than having to painfully redraw the inverter layout for various aspect ratios. Doing repeated simulations with SPICE students are able to optimise the design for output rise and fall times (propagation delay) and noise margin (Weste and Eshraghian 1993). Students also begin to gain some idea about structured design methodology right from the first project as they are given instructions to build the inverter layout in such a way that facilitates automatic abutment (Pucknell and Eshraghian 1994) with other cells.

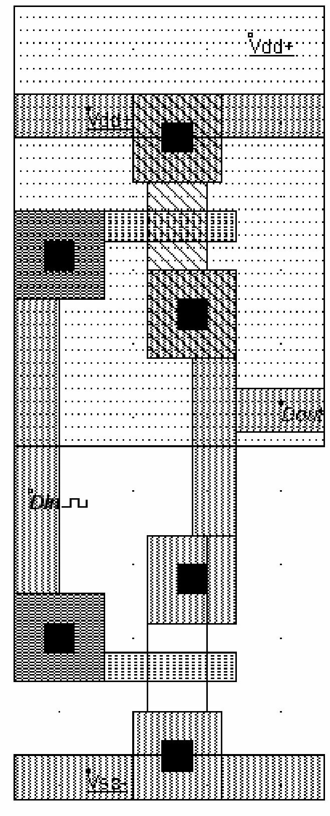

Figure 1 - Mask layout of the CMOS inverter

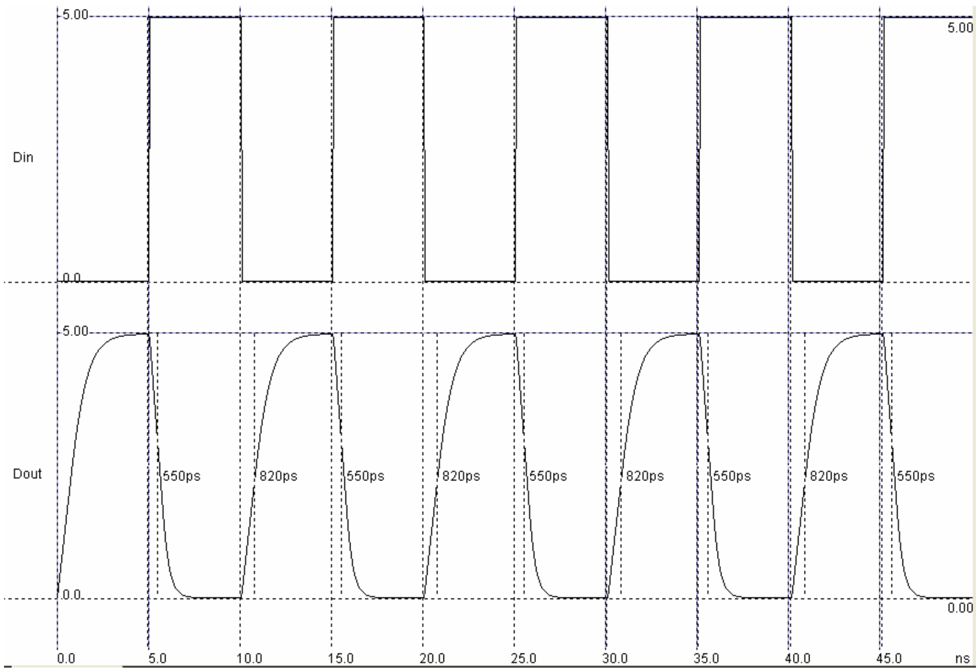

Figure 2 - Simulation results for the CMOS inverter: input and output voltage waveforms as a function of time

4.2 Subsequent projects

The projects gradually increased in complexity to provide students with opportunities to develop skills for designing larger and more complex circuits. The second project is on designing the layout of a 4-bit shift register. A structured design methodology is followed. The students build the layout of a CMOS transmission gate and join it with the inverter layout created in the first project to build a 1-bit *inverting* shift register cell (Pucknell and Eshraghian 1994). The layout of the inverting shift register cell is shown in Figure 4. Two of these cells are placed side by side to make a 1-bit *non-inverting* shift register cell. Two non-overlapping clock signals (Clk1 and Clk2) are added to the two transmission gates. Finally four non-inverting shift register cells are placed side by side to make a 4-bit shift register as shown in Figure 5 (Pucknell and Eshraghian 1994). Students simulate the 4-bit shift register to verify the shifting operation. In this project students develop structured circuit design skills and also develop understanding of the effect of changes in the two-phase clocking scheme on the operation of the shift register. This is important for designing synchronous circuits whose operations depend on active clocks (Rabaey, Chandrakasan and Nikolic 2003).

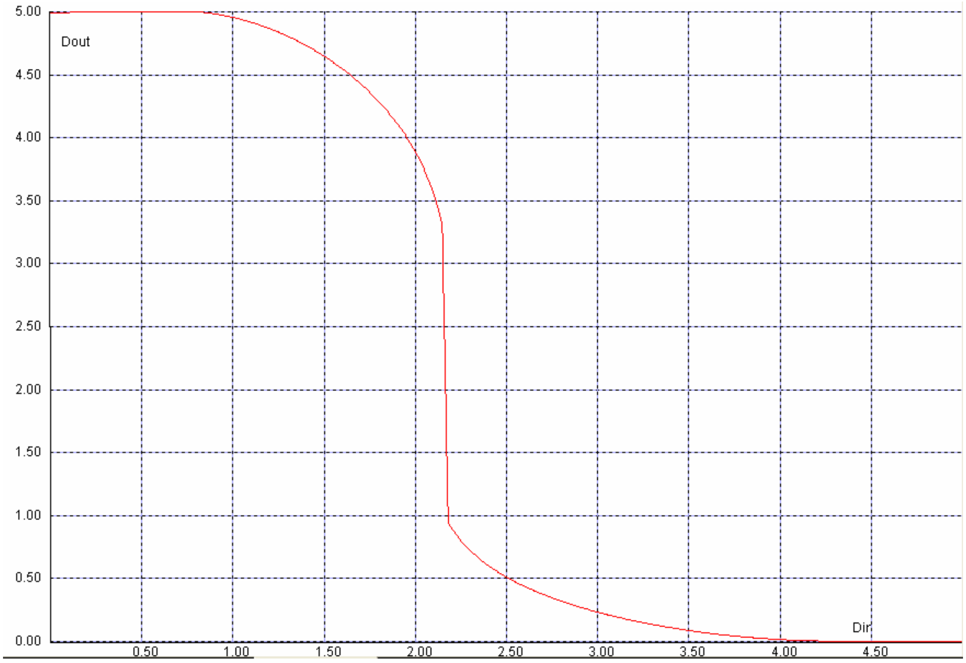

Figure 3 – Transfer characteristics of the CMOS inverter

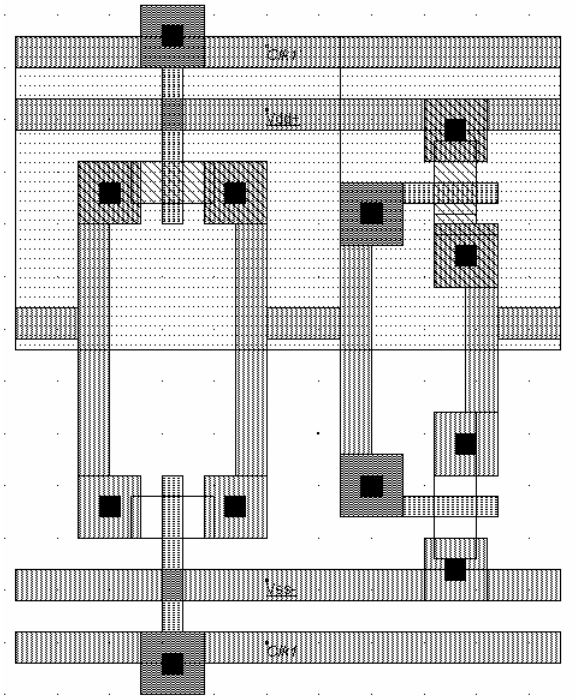

Figure 4 – Layout of the 1-bit inverting shift register cell

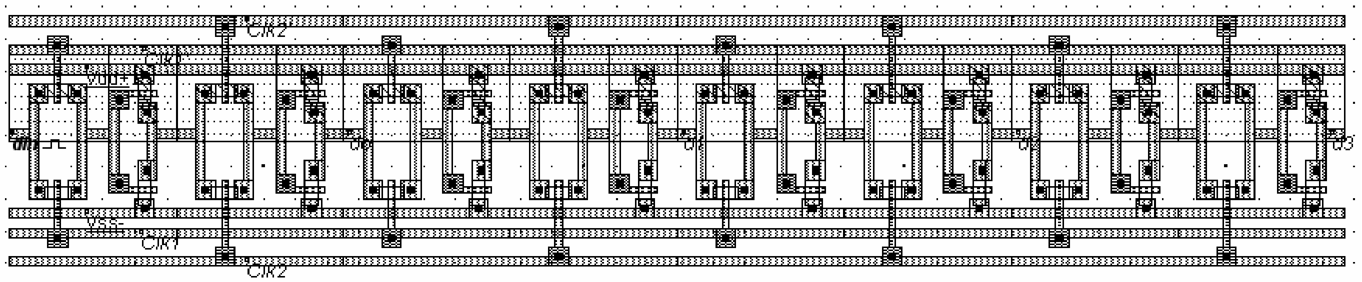

Figure 5 – Layout of the 4-bit shift register

The third project is on the design of a complete 4x4-bit static CMOS Random Access Memory (RAM) chip (Pucknell and Eshraghian 1994) including I/O pads. This was aimed at giving students some idea about the overall chip design flow. RAM being a fairly modular structure, the structured design methodology is easily adapted to designing the RAM. Students face a number of design challenges in relation to column and row selection (decoding), sense amplifiers, power supply rails and I/O pad ring (Pucknell and Eshraghian 1994). Students are required to work through the problems associated with each of the above modules in order arrive at a design that works and at the same time yields expected performance. Students who successfully completed this project developed very good understanding of the issues and processes of efficient chip design, developed good design skills, and gained a level of confidence not possible by any means other than the project-based approach.

4.3 Thoughts on further projects

Further projects could involve the design of a datapath, for example, a 4x4-bit parallel multiplier (Weste and Eshraghian 1993), an analogue voltage reference circuit etc. The number of projects and their complexity should be determined by the time available and the student groups for whom the course is being offered, i.e., undergraduate or postgraduate. Nevertheless the students should be encouraged to think about and undertake designs of useful circuits on their own. It would be of enormous benefit to support the students in this respect by pointing them to relevant resources and design examples. It has been the author’s experience that there are always some students who would want to do and learn more than what is necessary to simply complete the requirements of the course. It is always good to support their inquisitive minds as some of them might progress to become pioneers in their fields of expertise.

5 RESOURCES FOR SUPPORTING STUDENT LEARNING

As stated above the author experienced the need for good course resources to support students in the project-based learning approach. A good textbook with lots of practical design examples can be a very good resource for students. Students not only get design ideas/tips from a good text, but also get a lot of their questions answered. However, a textbook alone is not sufficient for the students’ learning. It is important to have good practical (project) handouts to assist the students through their projects. It is also important to provide references to other useful resources and links to useful web sites. The Internet has a huge collection of information in the area of VLSI Design including notes, tutorials, technical papers, design examples and freeware tools from across the world. Familiarity with these resources would be very useful for the students’ learning, and for them to develop an understanding of the potential of the technology, the most recent developments, prospective future developments, and above all to develop an international perspective. The author developed *web-based study resources* for the VLSI Design course including lecture notes and project guides. However, these resources need to be developed further. These resources were accessible by the students via the University of South Australia’s online learning environment called *UniSAnet* (UniSA 2004b). These resources would be useful for *flexible delivery* of the course through the on-line medium. This is in line with UniSA's emphasis on developing web-based resources to support student learning and *internationalisation* of programmes (King 2002).

6 STUDENT MOTIVATION AND LEARNING OUTCOMES

The students started with a simple project and the complexity increased progressively as they moved to subsequent projects. This was to ensure *progressive development* of the graduate qualities, i.e., problem solving and practical circuit design skills. The project-based approach allowed students to *effectively engage* in the *active learning process* and enabled them to *learn by doing*. Student *motivation* was extremely high as seen in their desire to successfully complete the projects. The author's role was more of a facilitator then a teacher. This was to *perform critical analysis* of the students' designs, give them *feedback* on a regular basis and encourage them to think critically about alternate design ideas. It is important though to guide the students when they are either stuck, or unsure as to how to tackle a particular design issue. Many students worked beyond the scheduled laboratory hours in order to evaluate alternate design ideas as they progressed with their projects. Out of a total of 19 students enrolled in the course, 18 successfully completed all the three projects and obtained an average grade of above 'Distinction' in the course. Students evaluated the course using University of South Australia's standard course evaluation questionnaire. They ranked the course at 4.2 on a scale of 5.

7 CONCLUSIONS

The key aspects of the teaching and learning approach adopted in the VLSI Design course were consultation with professionals working in relevant industries, selection of appropriate CAD tools to minimise learning time and the use of *learn by doing* approach. The projects undertaken by the students gradually increased in complexity allowing them to make a smooth transition from early learning stages to deeper problem solving stage. The project based active learning approach turned out to be very successful in terms of *students' learning outcomes*, *achievements* and *satisfaction*. The motivation and interest created among the students coupled with the *problem solving skills* they developed would assist them in *lifelong learning* in the rapidly advancing area of integrated circuit design. The active learning strategies employed in the course were in tune with the priorities of the University of South Australia, namely (i) improving student satisfaction with teaching and learning and (ii) focussing on teaching, learning and assessment in developing graduate qualities.

REFERENCES

AZIZ, S. M. 2003. Action research into project based learning in a computer design course. In *Proceedings of the 14th Annual Conference for Australasian Association for Engineering Education (AaeE) and 9th Australasian Women in Engineering Forum*. Melbourne: Australasian Association for Engineering Education, 2003. ISBN

BALLARD, B. and CLANCY, J. Teaching international students: A brief guide for lecturers and supervisors, Deakin, ACT: IDP Education Australia, 1997.

BIGGS, J. 1999. *Teaching for quality learning in University*. Buckingham: Society for Research in Higher Education and Open University Press, pp. 33-53 and pp. 141-164.

CARBONE, E. 1998. Active learning in a large class. In *Teaching Large Classes: Tools and Strategies*. Thousand Oaks: Sage Publications, 47-56.

KERNS, D., KERNS, S., PRATT G., SOMERVILLE M. & CRISMAN, J. The search for design in Electrical Engineering Education. In *Proceedings of the International Workshop on Electronic Design, Test and Applications*. Christchurch: IEEE Computer Society, 2002, 517 s. ISBN 0-7695-1453-7.

KING, B. 2002. *Introducing the teaching and learning strategy 2010 – 2015: Presentation at the Contextual Awareness Seminar* [online]. Adelaide: UniSA (University of South Australia), 2002-05-22. Available from web: <URL: http://www-i.unisa.edu.au/cha/CorpPrio/T&L/T&L2010.htm>

LLOYD, P. 2000. Crisis on campus. *The Advertiser Insight*, 1 April 2000.

PUCKNELL, D. A. & ESHRAGHIAN, K. *Basic VLSI Design*, Prentice Hall, 1994. ISBN 81-203-0986-3.

RABAEY, J. M., CHANDRAKASAN, A. & NIKOLIC, B. 2003. *Digital Integrated Circuits: A Design Perspective*, New Jersey: Prentice Hall, 2003. ISBN 0-13-120764-4.

REESE, R. 2003. *EE 4743/6743: Digital System Design (Spring 2003)*, Department of Electrical and Computer Engineering, Mississippi State University, 2003. Available from web: <URL: http://www.ece.msstate.edu/ ~reese/EE4743/>

SICARD, E. 2003a. *Microwind2: layout editor and simulator* (freeware) [online]. Toulouse (France): National Institute of Applied Sciences (INSA), 2003. Available from web: <URL: http://www.microwind.org/>

SICARD, E. 2003b. *Microwind and Dsch User's Manuals*. Toulouse (France): National Institute of Applied Sciences (INSA), 2003. 200 s. ISBN 2-87649-046-3. Available from web: <URL: http://www.microwind.org/>

SICARD, E. 1998. *Microwind, an introduction to microelectronics design on PC*, Toulouse (France): National Institute of Applied Sciences (INSA), 1998. 120 s. ISBN 2-87649-017-X.

SICARD, E. & BENDHIA, S. 2002. *An illustration of 0.1µm CMOS layout on PC*. In EWME, 2002.

UNISA 2004a. *Graduate Qualities for Students* [online]. Adelaide: UniSA (University of South Australia), 2004, last update 2004-03-10. Available from web: <URL: http://www.unisanet.unisa.edu.au/gradquals/studs/default.asp>

UNISA 2003. *Introduction to UniSA* [online]. Adelaide: UniSA (University of South Australia), 2003, last update 2003-07-11. Available from web: <URL: http://www.unisa.edu.au/about/intro/default.asp#Creating>

UNISA 2001. *Code of Good Practice: University Teaching* [online]. Adelaide: UniSA (University of South Australia), 2001, last update 2001-03. Available from web: <URL: http://www.unisa.edu.au/adminfo/codes/teaching.htm>.

UNISA 2004b. *UniSAnet: The online learning environment of the University of South Australia* [online]. Adelaide: UniSA (University of South Australia), 2004, last update 2004-02. Available from web: <URL: http://www.unisanet.unisa.edu.au/unisanet/>

WESTE, N. & ESHRAGHIAN, K. *Principles of CMOS VLSI Design: A Systems Perspective*. CA: Addison Wesley, 1993. ISBN 0-201-53376-6.