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Hands-On Active Learning via Development of FPGA-based Intelligent Microwave Oven Controller

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1. Introduction

Design project in laboratory development course plays an important role in electrical engineering education to connect theory and hands-on skills for student learning. In this paper, a team-based design project with regard to FPGA-based intelligent microwave oven controller is presented for its development of learning modules and its pedagogy. The major methodologies, implementations, assessments and accomplishments of the hands-on project are described in this paper. ELEE4650/5650 Hardware Description Language Laboratory is an elective course in Department of Electrical and Computer Engineering, which is an advanced graduate-level course. Previous instructors employed different textbooks and experimental FPGA circuit board, Altera FPGA board. Techniques this curriculum covered are recently developing rapidly [1]. Consequently, this course was created from scratch, piecing together topics from a range of textbooks in order to keep track of state-of-the-art FPGA technology. The entire lecture slides, reading materials, various handouts, homework, quizzes, exams, and specifically, project assignments were developed in coordination with hands-on based project for active learning purpose. For the sake of creation a course that was relevant and at the appropriate level of students, the lab was entirely designed. Students taking this course must be taken concurrently ELEE4650/5650 Hardware Description Language Laboratory.

In this design project, students aim to design a composite system to control the operation of a microwave oven by IEEE Std 802.11 wireless communication module, remotely. The design mission is decomposed into two fundamental portions: 1) FPGA-based microwave oven controller design. 2) IEEE Std 802.11 wireless control implementation. The first phase is achieved based on Spartan 3 board by using VHDL programming language. The second phase structures a WLAN environment between a PC and IEEE Std 802.11 wireless module to transmit the control signal by connecting the wireless module to the Spartan 3 FPGA board. In addition, the wireless module is considered as a receiver in the whole transmission process.

2. Implementation of the Hands-on Based Project

In this project, both graduate and undergraduate students developed and implemented an intelligent microwave controller with industry standard wireless IEEE 802.11 communication based on their expertise learned in VHDL and VHDL Lab classes (ELEE5640 and ELEE5650) and other classes. The project aimed to explore wireless communication industry standard to an FPGA-based intelligent controller for daily life applications. Such project will contribute to the feasibility study of industry standard of wireless IEEE 802.11 and VHDL, FPGA for real world applications [2]. The developed system of FPGA-based microwave oven controller integrated with IEEE 802.11 wireless communication is illustrated in Figure 1.

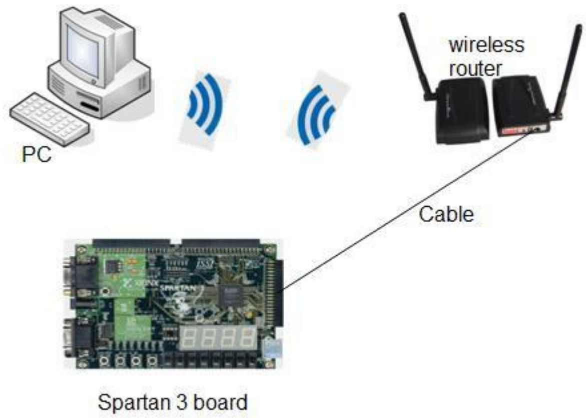


Figure 1 The system design of the wireless intelligent micrwave controller

Students implemented the intelligent controller on FPGA and also developed IEEE 802.11 communication functionality for remote control. The features of this team-based project are as follows.

- The project provides students with a great opportunity to obtain extensively hands-on experience to deal with real hardware, programming and wireless communications;
- This project allows students to implement their project on a weekly basis so as to keep track of project progress;
- This project is prepared by a sequence of lab assignments on the module-based architecture to accelerate the student learning curve in design methodology aspects necessary for the project;
- This project offers a sharing atmosphere for students to communicate effectively, practice team player skills, and work together collaboratively.
- This project functions a competitive mechanism, in which students are encouraged to compete towards a successful project.
- This project motivates students to attempt any innovative design methodology, hardware design, and software development;
- This project enhances the learning experience by performing the project both independently and collaboratively.

2.1 The Project Requirements

In this project, students are required to design an intelligent controller for remote operation of a microwave oven with wireless communication **wirelessly** connected with a computer so that one can control a microwave oven on a remote computer. In this mode, one microwave oven is able to be controlled over Internet, thus, exploring Internet of Things.

Besides an industry standard wireless IEEE 802.11 communication module is necessary, which enables the microwave oven possible to be controlled through the IEEE 802.11 wireless communication, by a remote computer, such microwave oven should have the following functional buttons implemented on the FPGA circuit board:

- Time: it has up-counter and down-counter electronically to serve as a timer.
- Power: two options - higher or lower, may automatically set the oven to have higher or lower power.
- Defrost: it will automatically set the oven to defrost at a time set by the user
- Cook includes the following options- it will automatically set the oven to cook at a time set by the user
    - Popcorn
    - Soup
    - Pizza
    - Dinner plate

Students are also strongly encouraged to develop more functionality as long as there are available buttons on of Xilinx Spartan 3 FPGA board shown in Figure 2, for example:

- Weight defrost
- Child lock: prevents unwanted oven operation by little children. The oven can be set so that the control panel button is deactivated or locked.

2.2 The System Design and Structure

In this project, hardware and application software were selected as follows. The Spartan-3 of FPGA is especially designed to meet the needs of high volume, cost-sensitive consumer electronic applications and portable instruments. Spartan-3 FPGAs are programmed by VHDL language by loading configuration data [3]. The prototype of the developed FPGA-based microwave oven controller with IEEE Std 802.11 wireless communication module is illustrated in Figure 3.

Target Device: Xilinx Spartan 3: xc3s200-4ft256
Model Name: final project. Project File: finalprojectv6.ise (for students).
Software product version: ISE 10.1 – WebPACK. Design Strategy: Xilinx Default
Design Language: VHDL

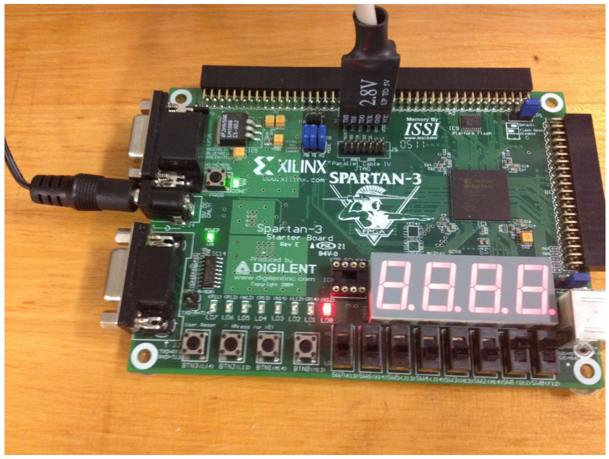


Figure2 Students fulfilled FPGA based project in VHDL Lab

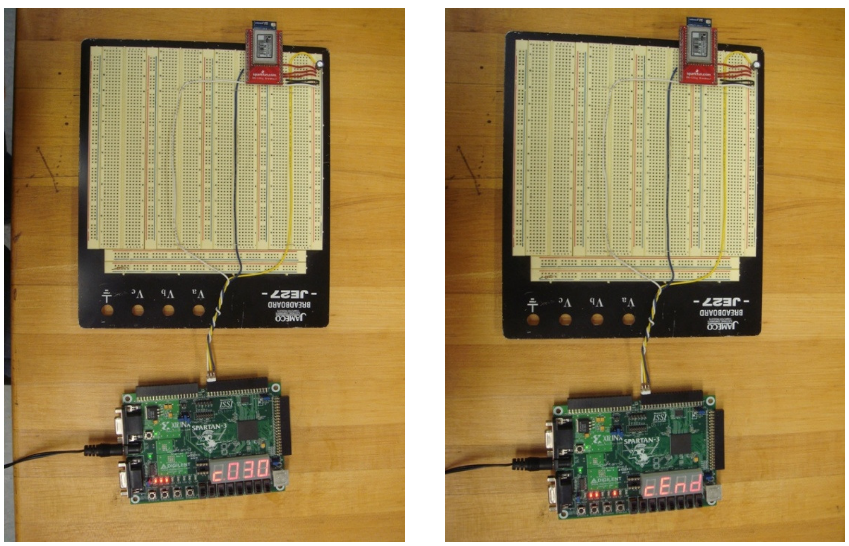


Figure 3 Prototype of the developed FPGA-based microwave oven controller with wireless module

3. Milestone Methodologies for Successful Project Implementation

A milestone methodology is adopted to keep track of project progress as a tool used in this project management to signal specific time points along this project timeline. The anchors such as a project starting point, sub-tasks, targets and end date, are marked. In this mode, the entire mission is decomposed into sub-tasks in a sequential, phase-wise manner where subsequent requirements are gathered at various stages. Students are required to submit milestone reports and have both a milestone interview with the instructors and a team meeting structures [4,5]. The milestone time is arranged on a weekly basis. If students have questions or make significant progress, they are allowed to report to the instructor before one milestone deadline. By milestone mode, the project was managed effectively. Milestone started with the availability of all the required hardware, software and tools.

Table 1 The milestone tasks, progress and performance analysis in milestone mode

Milestone Sequence	Milestone Tasks	Percentage Milestone Progress (%)	Performance Analysis	
			Motivating factors	De-motivating factors
M_1	Overall design Coding work	95	Significance of project; Assistance and encouragement	Team communication
M_2	Hardware/software co-design Coding work	85	Hands-on experience	Simulation instability
M_3	Hardware design Hardware debugging Software debugging	100	Hands-on experience	N/A
M_4	Wireless communication System debugging	75	Assistance and encouragement	Difficulty in debugging
M_5	Wireless communication Hardware/software debugging	95	Assistance and encouragement; Hardware and software integration	Team communication
M_6	System integration Hardware/software with wireless communication	90	Hardware and software integration	Hardware insufficiency
Final Presentation and Demo	Presentation, Documentation, Demonstration	100	Significance of project; Team work	N/A

Milestone outcomes and reports are completely marked and interviews are carried out, which are summarized in Table 1. In this table, milestone tasks, percentage of progress made, and performance analysis are available for us to better understand student learning activity, manage the project and assure student progress. Performance analysis indicates motivating factors for students to successfully complete the milestone tasks, and also barriers to cause postponement to complete. According to Table 1, "significance of project" and "assistance and encouragement from the instructor and TA" are two positive factors to make student significant progress. "Difficulty in debugging" is the top reason that slows down the progress of the project. Additionally, learning quality by self-assessment from students and performance analysis by interviews will be addressed in the following sections.

Some other measures to improve the quality of teaching and learning involve student lab notebook, debugging record, and highly-organized documents. For instance, in order to train students to have a professional observation for the lab and experiments, students are suggested to record images they gained in the experiments. An example is taken in this paper, in which students document not only experimental data and files, but also "signals and information" in form of images. Two images captured by students for waveforms with regard to the input signals are illustrated in Figure 4. Furthermore, students discover that controlling of states in FSM of in-use circuit systems is one of effective means to decrease the operational complexity of FPGA, based on their hands-on experimental efforts. Students are passionate about data and file organization precisely after a couple of week training [6]. Image and data of pin assignments of FPGA contributed this project are recorded appropriately, for example, illustrated in Figure 5.

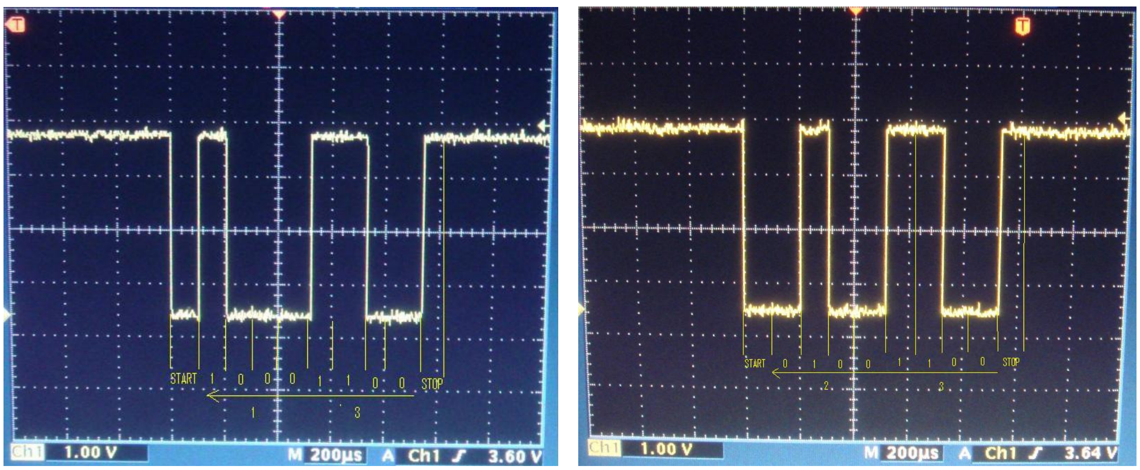
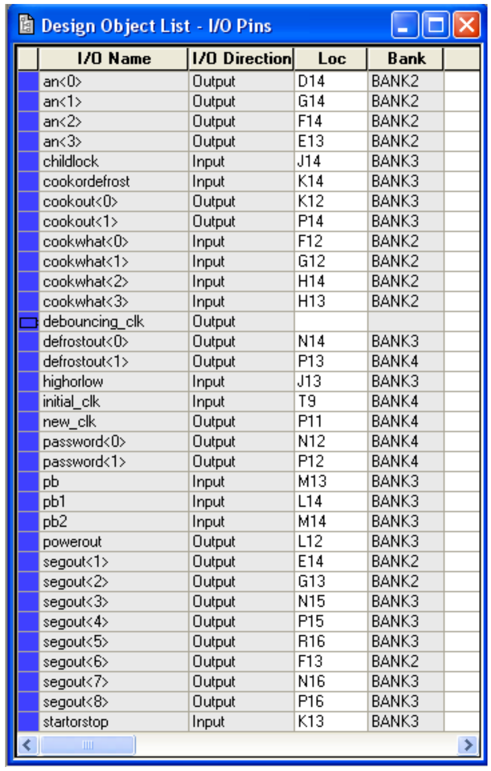


Figure 4. The waveforms for the input signals: left: input "1" and right: input "2"

4.   Assessment Methodologies and Project Evaluation

This hands-on project in the lab course is evaluated at the end of semester and during the various milestones, whereas final grades are determined by the predefined grade distribution. A significant proportion of the final grades of ELEE4650/5650 depend fundamentally on the project. At the end of the semester, the team is required to deliver a final presentation, where they describe their system design, design consideration, hardware configuration, software architecture, troubleshooting experience, and project management procedure.

The Department of Electrical and Computer Engineering collects self-assessment questionnaire from students and the instructor acquires quantitative and qualitative feedbacks from students through survey and interviews. The self-assessment questionnaire covers the questions with regard to the design project as well as the entire course that contains a variety of lab assignments prepared for the design project [7]. The benefits are revealed according to project evaluations, self-assessment and a sequence of interviews.


Design Object List - I/O Pins

	I/O Name	I/O Direction	Loc	Bank
	an<0>	Output	D14	BANK2
	an<1>	Output	G14	BANK2
	an<2>	Output	F14	BANK2
	an<3>	Output	E13	BANK2
	childlock	Input	J14	BANK3
	cookordefrost	Input	K14	BANK3
	cookout<0>	Output	K12	BANK3
	cookout<1>	Output	P14	BANK3
	cookwhat<0>	Input	F12	BANK2
	cookwhat<1>	Input	G12	BANK2
	cookwhat<2>	Input	H14	BANK2
	cookwhat<3>	Input	H13	BANK2
	debouncing_clk	Output		
	defrostout<0>	Output	N14	BANK3
	defrostout<1>	Output	P13	BANK4
	highorlow	Input	J13	BANK3
	initial_clk	Input	T9	BANK4
	new_clk	Output	P11	BANK4
	password<0>	Output	N12	BANK4
	password<1>	Output	P12	BANK4
	pb	Input	M13	BANK3
	pb1	Input	L14	BANK3
	pb2	Input	M14	BANK3
	powerout	Output	L12	BANK3
	segout<1>	Output	E14	BANK2
	segout<2>	Output	G13	BANK2
	segout<3>	Output	N15	BANK3
	segout<4>	Output	P15	BANK3
	segout<5>	Output	R16	BANK3
	segout<6>	Output	F13	BANK2
	segout<7>	Output	N16	BANK3
	segout<8>	Output	P16	BANK3
	startorstop	Input	K13	BANK3

Figure 5. The illustration of pin assignments of FPGA contributed to student training

- Students perceive that hardware and software co-design allows them to enhance their hands-on capability in a lab-based environment and improve their learning skills to resolve engineering issues.
- Students realize that this team-based project with team members provides students with more communication opportunities. There are plenty of team meetings, in which students discuss a variety of hardware, software and system aspects of this project.
- Students consider that this hands-on project with team members enables them to be better team players as coordination and consultation are very crucial to ensure successful completion of the project. They have more opportunities to discuss and share their ideas with peers, instructors and lab technician, and computer administrators.
- Students recognize that this student-centered, research-featured, team-interactive and instructor-facilitated learning atmosphere is remarkably helpful for engineering leaning experience of students.
- Students find that this team-based lab project encourages their full involvement to carry out the project from initial stage to end. The student's practical ability is exercised, learning interest is excited, and creation thought is stimulated by utilizing self-determination design and manipulation experiment mode in this project.

The interactive self-assessments are beneficial to discover the strength and weakness of teaching and learning cycles. The self-assessment was acquired from students in this ELEE4640/5640 as follows. Additionally, the self-assessment addressed in this paper is reflected from students performing this project.

1. Question 1 - “I can understand, design and analyze some typical digital circuits and systems with VHDL in experiments prepared for design project, by Xilinx Spartan 3 board such as counters, flip-flops, registers, decoders, encoders, and multiplexers, etc.”. This assessment is associated with in Outcome b in ABET. Outcome (b): An ability to design and conduct experiments, as well as to analyze and interpret data relating to electrical systems.

   Student survey shows that 66.7% students strongly agreed with the statement, “I can understand, design and analyze some typical digital circuits and systems with VHDL in experiments prepared for design project, by Xilinx Spartan 3 board such as counters, flip-flops, registers, decoders, encoders, and multiplexers, etc”. 26.7% Students agreed with the statement but 6.67% students disagreed with the statement.

2. Question 2 – “I can understand, analyze and design finite state machine (FSM) to solve some problems in homework, lab and project.” (Outcome c). Outcome (c): An ability to design electrical systems, components, or processes to meet desired needs;

   Student survey shows that 53.3% students strongly agreed with the statement, “I can understand, analyze and design finite state machine (FSM) to solve some problems in homework, lab and project”. 40% students agreed with the statement but 6.67% students disagreed with the statement.

3. Question 3 – “I have effective communication skills in the context of a collaborative, multi-disciplinary, team-based design activity”. (Outcome d). Outcome (d): An ability to function effectively on multi-disciplinary teams;

   Student survey shows that 40% students strongly agreed with the statement, “I have effective communication skills in the context of a collaborative, multi-disciplinary, team-based design activity”. 46.7% students agreed with the statement, 6.67% students were neutral with the statement but 6.67% students disagreed with the statement.

4. Question 4 – “I have effective communication skills for a collaborative, team-based design project and presentation skills to effectively present my project “. (Outcome g). Outcome (g): An ability to communicate effectively.

   Student survey shows that 46.7% students strongly agreed with the statement, “I have effective communication skills for a collaborative, team-based design project and presentation skills to effectively present my project”. 40% students agreed with the statement and 6.67% students were neutral with the statement while 6.67% students disagreed with the statement.

5. Question 5 – "I can create professional documentation in connection with the lab assignments and design projects". (Outcome g). Outcome (g): An ability to communicate effectively.

   Student survey shows that 60% students strongly agreed with the statement, "I have effective communication skills for a collaborative, team-based design project and presentation skills to effectively present my project". 26.7% students agreed with the statement, whereas 6.67% students were neutral with the statement and 6.67% students disagreed with the statement.

The assessment questionnaire is summarized in Table 2 showing percentage of assessment from the ELEE4640/5640 students and those students who participated in this FPGA project with five questions corresponding to the four ABET learning outcomes. The learning outcomes of assessment from students attending this project are more positive than the ELEE4640/5640 students. Population of students taking part in this project is one fifth of the ELEE4640/5640 students.

Table 2 The questionnaire of students for assessment of education quality

Question and Outcome	ELEE4640/5640 Students				Students attending the Project			
	Strongly agree	Agree	Neutral	Disagree	Strongly agree	Agree	Neutral	Disagree
Q1-b	66.7%	26.7%	0%	6.67%	100%	0%	0%	0%
Q2-c	53.3%	40%	0%	6.67%	100%	0%	0%	0%
Q3-d	40%	46.7%	6.67%	6.67%	75%	25%	0%	0%
Q4-g	46.7%	40%	6.67%	6.67%	50%	50%	0%	0%
Q5-g	60%	26.7%	6.67%	6.67%	75%	25%	0%	0%

In comparison with those student who were involved in the microwave project and regular (fellow) students in ELEE4640/5640 class, the average course and instructor effectiveness scores increased from 66.7% to 100%.

The FPGA project and presentation were evaluated, which cover some criteria such as communication skills, capability to design and conduct experiments, ability to design electrical systems, capability to solve the engineering issues, and multi-disciplinary team skills. In Figure 6, it illustrates that most students strongly or agree with the statement indicated in the subjects representing ABET outcomes (b), (c), (d) and (g). It is interesting that students are more comfortable with their engineering design capability, problemresolving ability and understanding hardware/software aspects than their communication skills [8,9].

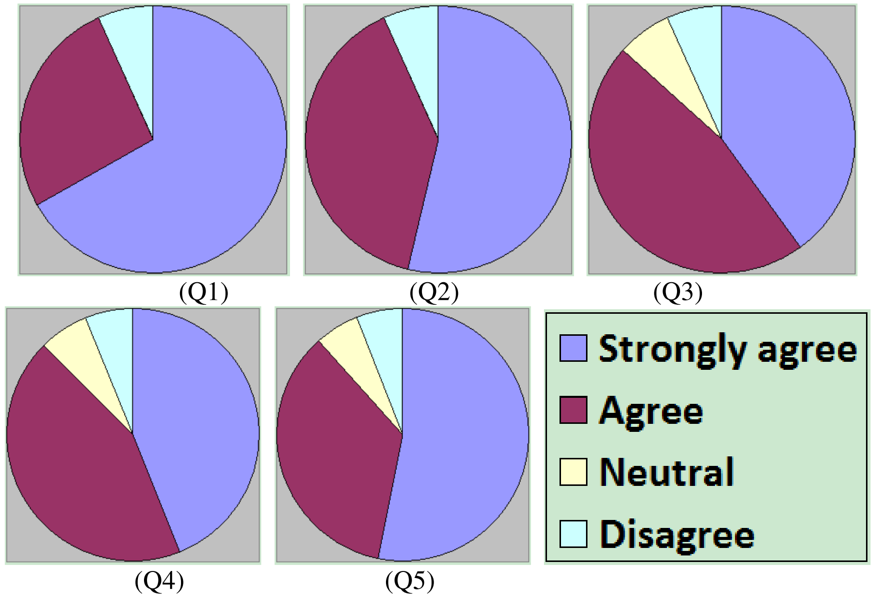


Figure 6 Student self-assessment with five subjects with regard to ABET outcomes

In Table 2, comparison of questionnaire survey from ELEE4640/5640 students and students attending the FPGA project reveals that such a hands-on FPGA experiment-based intelligent microwave project grants better learning experience on their electrical engineering education. The quantitative and qualitative questionnaires are acquired to have in-depth insight to student learning quality. Consequently, it is noted that the students attending the microwave project had better feelings on their performance than the evaluation of the other peer students in the class. The self-assessment comparison of students attending the project (Project Students) and ELEE4640/5640 students (Fellow Students) is illustrated in Figure 7. It shows that this pedagogy practiced on this hands-on project in a lab-based course was validated by this team-based design project of FPGA-based intelligent microwave oven controller.

Motivating factors for the project rated by the students are depicted in Figure 8. The motivating factors comprise hardware and software integration, assistance and encouragement from instructor and TA, project management and plan significance of project, hands-on experience, and team work, which positively contribute to project success. On the contrary, various de-motivating factors considered as barriers for the project contain the following, such as heavy workload, time management, simulation instability, team communication, hardware insufficiency, and difficulty in debugging, illustrated in Figure 9. Amongst these factors, difficulty in debugging, and team communication are two of the highest difficulty that need to be improved and overcome [10].

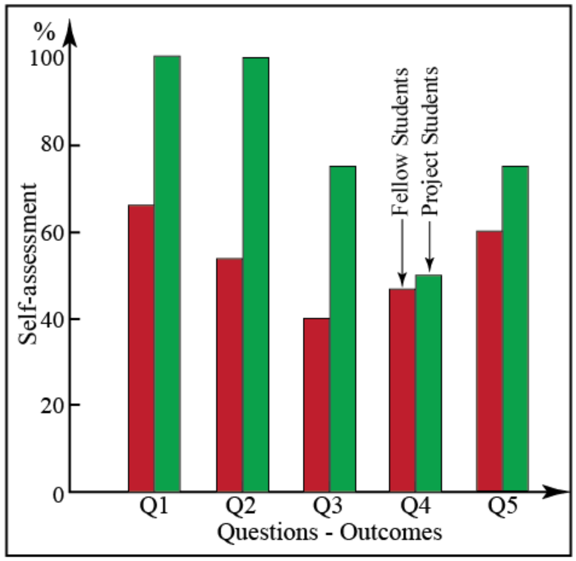


Figure 7 Self-assessment comparison of fellow students and project students

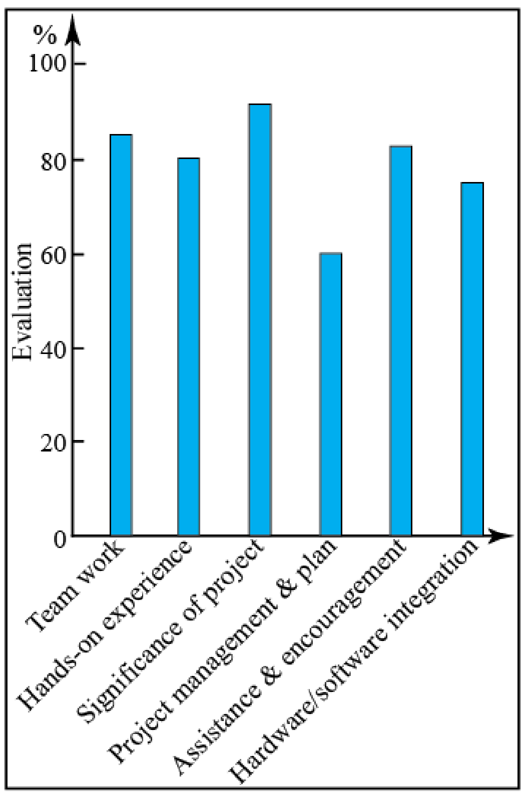


Figure 8 Students rating of positive factors for the project

It is worth noticing that "team work" and "team communication" appear in both motivating and de-motivating factors, which might be considered that team work not only contributes to the project success but collaboration and interactive skills of team members would be improved as well. The more evaluation clues are discovered by further analysis of student presentation and final report, which are indirectly interpreted to learning assessment of engineering education with regard to a hands-on based lab course.

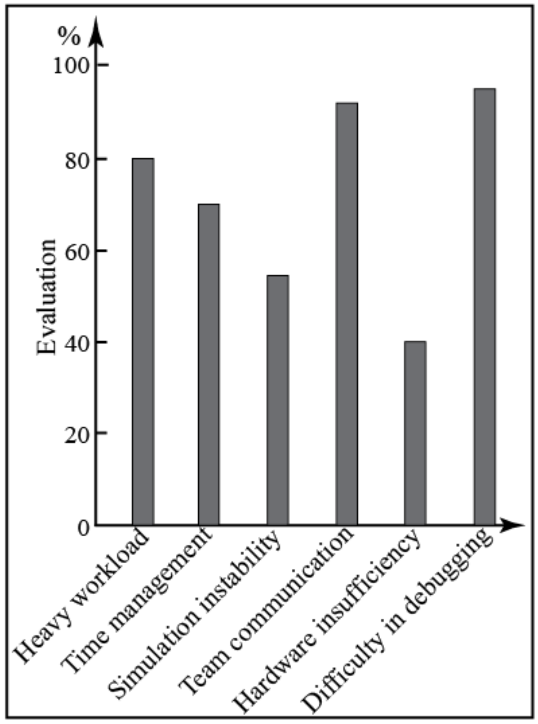


Figure 9 Students rating of barriers for the project

5. Conclusions

This paper described active learning and pedagogy taught in a lab-based course by a project development in terms of an FPGA-based intelligent microwave oven controller. The project has been successful in developing a team-based design project of FPGA-based intelligent microwave oven controller. This implementation of this project demonstrated how the novel laboratory development methodologies and pedagogy were beneficial for the hands-on skill and design efforts of students. By means of Spartan 3 FPGA board, functionalities of this intelligent controller have been designed and implemented, which effectively improved hands-on capability of students evaluated by assessments. This teaching methodology suggests a wide variety of applications of the FPGA-based project at diverse universities, which might serve as a model for other hands-on based active learning environments.

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