Critical Thinking Pedagogy in Teaching Computer Hardware Design Course

Jing Pang,

Department of Electrical and Electronic Engineering and Computer Engineering Program California State University, Sacramento, CA.

Abstract

The critical thinking skills are highly required in the engineering field nowadays due to the competitive world demanding complex problem solving skills from engineers. This paper presents the critical thinking pedagogy the author applied in teaching computer hardware design undergraduate course. In this work, undergraduate computer engineering students were divided into small groups of 3 to 4 students to participate in the technical paper reading, project proposing, design discussion, and design presentation. Students used schematic based CAD tools and also Verilog[1] Hardware Language based design tools to get engaged in the process of designing the computer hardware components such as the FIFO[2], and also the Mic-1[3] microprocessor. The organization of the design assignments applied in this course was to encourage students for hypothesis formulation, problem analysis, information synthesis, clear articulation of design ideas and results, and also draw logical conclusions, which are core skills for critical thinking. Students learning outcomes were clearly specified in the projects assigned which were designed according to the course learning outcomes. They were evaluated after student designs were collected and positive results were identified in this work.

1. Introduction

Critical thinking requires the ability to analyze and evaluate information[4, 5, 6]. A lot of researchers have recognized the importance of critical thinking in education. How to organize active learning environment to enhance critical thinking among students has been one challenging and also passionate topic for many educators. In the field of health science, case studies were used to promote critical thinking. Life experience case examples or simulated real patient situation cases were used by nurse educators to help students acquire critical thinking skills[7]. In the Introduction to Civil Engineering course, carefully designed reflective writing assignments were provided to students to stimulate critical thinking[8]. Moreover, business professors developed interactive thinking and discussion games to improve students' critical thinking skills[9]. In general, educators from different fields tried to use appropriate methodology to facilitate critical thinking based on different course contents.

Understanding the internal architecture of microcomputers is crucial for undergraduate students in the advancement of their study and work in the field of computer engineering. At California State University, Sacramento (CSUS), the Computer Hardware Design course is required upper division computer engineering undergraduate course. The computer hardware related textbooks typically had a lot of abstract context and described complex interaction of different digital signals inside the microcomputer. In general, undergraduate students had difficulty to visualize and analyze the behavior of the complex microcomputer system effectively by just passively memorizing information.

In this paper, critical thinking pedagogy in teaching computer hardware design course to undergraduate students in Computer Engineering at CSUS are presented. Part 2 describes using in class discussion to stimulate critical thinking among students. Part 3 discusses computer aided design to engage students on critical thinking. Part 4 presents using the group based open-ended project to improve critical thinking. Part 5 demonstrates the outcome of the presented pedagogy, and also discusses the assessment result and future improvement plan. Finally, part 6 draws conclusions of this work.

2. In Class Discussion to Help Critical Thinking

In order for students to develop critical thinking skills, in-class discussion can be used as one method to practice critical thinking.

Mic-1 processor is based on Von Neumann architecture which supports Integer Java Virtual Machine (IJVM) instruction set. To study Mic-1 processor, students were partitioned into groups and each group was given one different IVJR instruction. The instructor also selected one different IVJR instruction. Both students and instructor participated in the discussion of the functionality of the related micro-instructions stored in the control store inside classroom. The micro-instructions were used to control the microprocessor data path. In this way, students had to actively think and analyze the behavior of the Mic-1 microprocessor architecture. Different from the traditional instructor-centered teaching which required instructor to focus on transferring knowledge directly to students, students were required to join in-class discussion to stimulate critical thinking.

3. Critical Thinking though Computer Aided Design Tool

Logisim[10] is an open source free logic design tool. The author required students to design MIC-1 processor described in the textbook[3] by using Logisim. Computer aided design work allows students to visualize the behavior of computer hardware architecture in more concrete way and engage students in critical thinking. It makes learning more interesting and meaningful to students.

Mic-1 processor has two 32-bit data busses: B bus, and C bus. It also has a control store with micro instructions used for sequence controls. In addition, it has Arithmetic Logic Unit (ALU), shifter and multiple internal registers. This assignment has the following learning outcome.

- Apply logic concepts and mechanisms to design microprocessor components;
- Apply logic concepts and mechanisms to analyze microprocessor components;
- Formulate a specific hypothesis of microprocessor architecture. Thoroughly analyze the logic components required for microprocessor architecture. Carefully design and evaluate the functionality of each logic block;
- Use schematic based tool to design and conduct experiments, as well as to analyze and interpret data;

- Three or four students form a group for discussion. Acknowledge the limits of the position and synthesize others' points of view in each group and draw logic design conclusions.

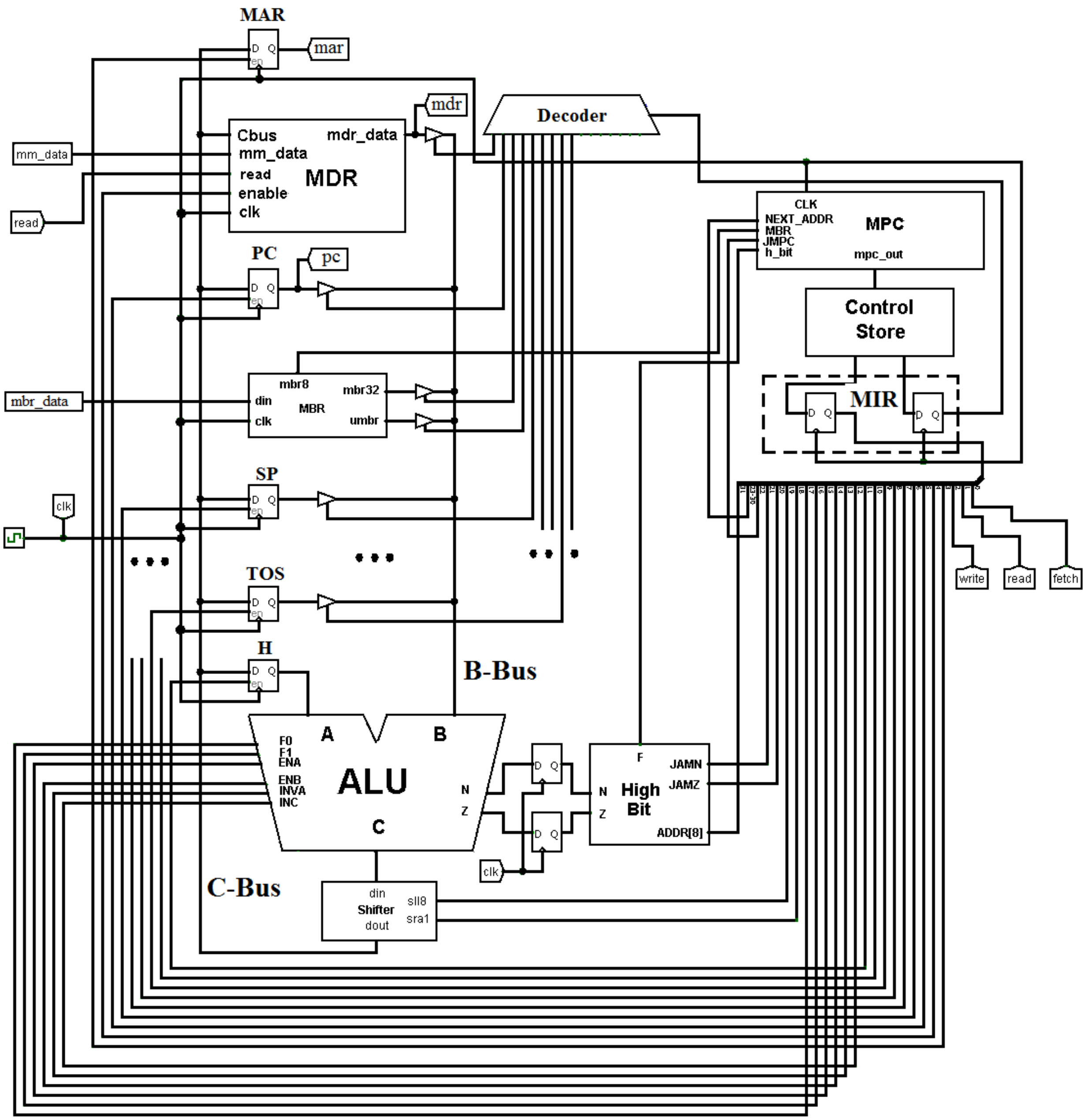

Figure 1. Logisim design of Mic-1 microprocessor

Figure 1 shows the Logisim design of Mic-1 processor. Although all registers used in Mic-1 were designed, in order to minimize the size of the circuit diagram, only part of registers are illustrated in Figure 1 which includes the memory address register MAR, the memory data register MDR, the program counter register PC, the memory buffer register MBR, the stack pointer register SP, the top of the stack register TOS, the holding register H, the micro-program counter register MPC and the micro-instruction register MIR. The size of MPC register is 9 bits. The register connected with the N-flag is 1-bit, and so does that connected with the Z-flag. The size of the MIR register is 36 bits. The MIR register in Figure 1 consists of two parts: 32-bit part and 4-bit part. All of the other registers are 32-bit long. The MDR register can input data from either the main memory or the C-Bus. The MBR register can output unsigned data “umbr” or sign-extended data “mbr32”. The shifter design supports no shift, logic left shift by 8 bits, and arithmetic right shift by 1 bit.

During Logisim simulation, the internal signals of “write”, “read”, “fetch”, “mar”, “mdr”, “pc” which are used to control the main memory can be monitored. The main memory stored data and instruction can be manually entered through ports “mm_data” and “mbr_data”. The clock signal of “clk” can also be monitored.

Logisim supports sub-circuit design strategy. 1-bit ALU logic circuit is given in textbook. By using 1-bit ALU sub-circuits, students can design 32-bit ALU circuit which has “N” (negative) flag and “Z” (zero) flag to indicate the ALU result is negative or zero.

The designed schematic of the High Bit sub-circuit used in Figure 1 is shown in Figure 2, where the signals of JAMN, JAMZ, and ADDR coming from the MIR register are used to control the highest bit of the next possible micro-instruction address location.

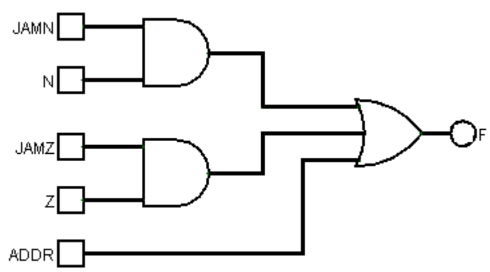

Figure 2. High Bit subcircuit

The 9th bit of the MPC register value is determined by the High Bit sub-circuit output. The lowest 8 bits of the MPC register value use “JMPC” signal from the MIR register to select the microinstruction address from either the MBR register value, or the next address field from the MIR register output.

The 4-to-16 decoder is a built-in component from Logisim. The Control Store sub-circuit uses Logisim built-in ROMs which can be loaded with micro-instruction sequence data. Figure 3 below shows the micro-instruction sequence stored inside Control Store to implement the IJVR “bipush” instruction. The equivalent hardware operations are also listed in Figure 3. In conclusion, the Mic-1 Logisim design work can stimulate students to think and analyze the logic components required by the microprocessor. Modification of this design is also possible which may stimulate students more for creative design ideas.

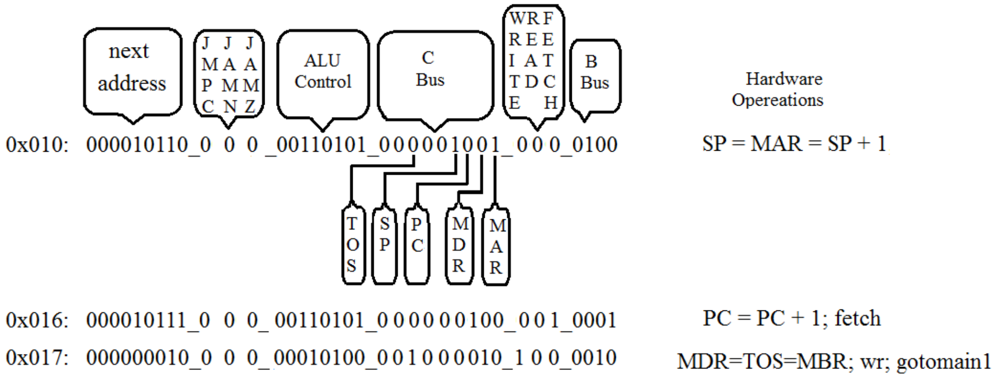

Figure 3. The Control Store micro-instruction sequence for IJVR "bipush" instruction

4. Critical Thinking through Open-Ended Project

The open-ended project is another method used by the author to stimulate student curiosity, to promote divergent thinking, and to enhance student critical thinking skill. FIFO is a memory buffer used for communication between two microprocessor components. The first data written into the FIFO will be the first data that is read out. The FIFO design was assigned by the author as one open-ended project through the following methods:

a. Instructor guidance;
b. Technical paper reading;
c. Pre-project presentation of the design proposal;
d. Design project in small groups;
e. Post-project presentation and discussion of the design result.

This assignment was to achieve the following outcome.

- Apply logic concepts and mechanisms to design microprocessor components;
- Apply logic concepts and mechanisms to analyze microprocessor components;
- Develop ability to identify interface signals and conduct a comprehensive analysis of FIFO circuit logic behavior;
- Formulate a specific hypothesis of FIFO architecture. Thoroughly analyze the FIFO design logic blocks. Carefully design and evaluate the functionality of each logic block;
- Use computer aided design tool to design and conduct experiments, as well as to analyze and interpret data;
- Three or four students form a group for discussion. Acknowledge the limits of the position and synthesize others' points of view in each group and draw logic design conclusions.

4.1 Initial Stimulation for Open-Ended Project

For complex projects, students might feel too intimated to take the first try. As a result, proper guidance provided by the instructor is necessary to start the initial stimulation. In addition, group discussion and in-class discussion allow students to stimulate each other, and evaluate other people's views. So it is beneficial to partition students into small groups to facilitate learning. The instructor provided document to give students ideas about FIFO and also required students to read a FIFO technical document with FIFO signals and functionality[2]. However, students were allowed to come up with their own ideas of necessary FIFO block partitions, functionality of each block, interface signals of each block and prepare proposals. Students were also allowed to collect different technical documents for reading and use them as references.

4.2 Pre-project Presentation of Design Proposal

Inside classroom, each group was required to give presentation of their proposed FIFO design blocks, FIFO signals and functionality. In each group, every student must present part of the proposal.

Verbal presentation helps students organize their thoughts, clarify their thinking, plan their design work, analyze and evaluate different design options. Group based presentation also motivates students to work together. The guidance from the instructor is necessary to make sure the direction of the student proposed project work will be on a reasonable route for learning. After pre-project presentation, each group of students needed to conduct deeper thought and implement the proposed design work using computer aided tools. Instructor could be consulted if students had questions.

4.3 Post-project Presentation and Discussion of the Design Result

After students completed their design work, post-project presentation was required inside the classroom for students to explain and justify their design results. Both inside classroom discussion regarding the project work and after classroom further evaluation and suggestion from instructor were used as feedback to the design work.

Students from different groups used different methods for the FIFO design project. Figure 4 shows part of the FIFO simulation result from one group of students. This group of student used Verilog Hardware Description Language to design the FIFO.

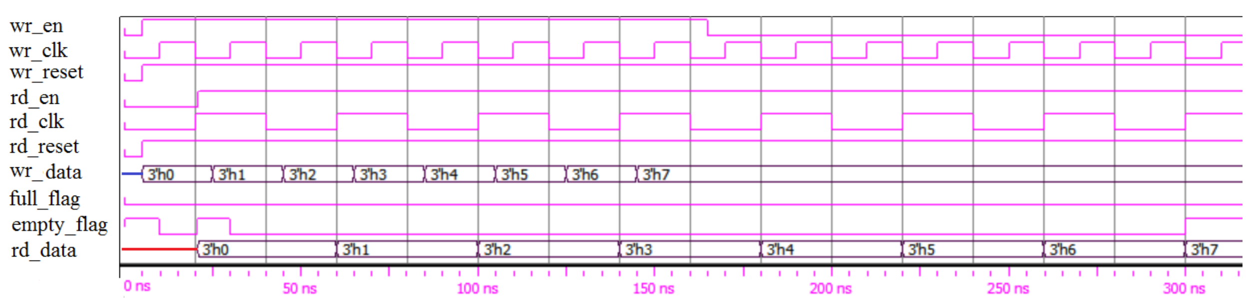

Figure 4. FIFO simulation waveform

In Figure 4, the reset, enable, and clock signals used for FIFO writing are “wr_reset”, “wr_en”, and “wr_clk”. The similar signals used for FIFO reading are “rd_reset”, “rd_en”, and “rd_clk”. The data written into and the data read from the FIFO are “wr_data” and “rd_data”. At 0 ns, the FIFO doesn’t have data and the “empty_flag” signal is logic ‘1’. At time 10 ns, the first 3-bit data 3’h0 is written into the FIFO at the rising edge of the “wr_clk” and the FIFO is not empty. At time 20 ns, the data 3’h0 is read out of the FIFO, so the FIFO is empty again. Until at time 30 ns, new data 3’h1 is written into the FIFO, and the FIFO is again not empty. The “wr_clk” and “rd_clk” have different frequency. After the last data 3’h7 is read out of the FIFO, the FIFO outputs the active “empty_flag” signal again. The successful design result indicates that this group of students could improve their critical thinking and learning through the open-ended FIFO project.

Another group of students got strong interest in Logisim circuit design tool. They designed working FIFO sub-circuits shown in Figures 5, 6, and 7 using Logisim tool. Figures 5 and 6 show the FIFO read pointer and write pointer sub-circuits.

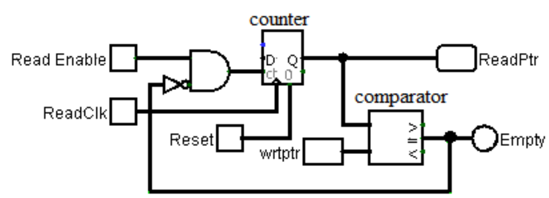

Figure 5. FIFO read pointer sub-circuit

In Figure 5, the counter circuit is a Logisim built-in component with reset, clock, and enable control signals: “Reset”, “ReadClk”, “Read Enable”. The counter output is used as FIFO read address pointer “ReadPtr”. The read pointer is synchronized with the “ReadClk”. If this read pointer value is equal to the write pointer “wrtptr” value, the “Empty” output from the comparator circuit will output logic ‘1’.

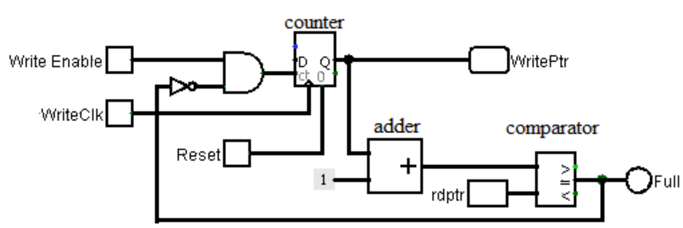

Figure 6. FIFO write pointer sub-circuit

Figure 6 uses the similar strategy as that in Figure 5. The FIFO write pointer “WritePtr” is synchronized with the “WriteClk”. If “WritePtr” value is increased by 1, and the result is equal to the read pointer “rdptr” value, the comparator output “Full” will be equal to logic ‘1’.

Figure 7 shows the 8x4 memory sub-circuit design consisting of D Flip-flops and decoder components. This memory circuit has 3-bit address inputs “addr” and 4-bit data inputs input0 ~ input3Moreover, it has reset, chip select, read/write, and output enable control signals: “Reset”, “cs”, “rd”, and “oe”. Since this design only allows either data writing or reading at a particular time, it cannot support two different writing address pointer and reading address pointer at the same time. However, the exploration of students on this logic memory circuit design is still useful to stimulate them to think the behavior of memory circuit and the limitation of this work.

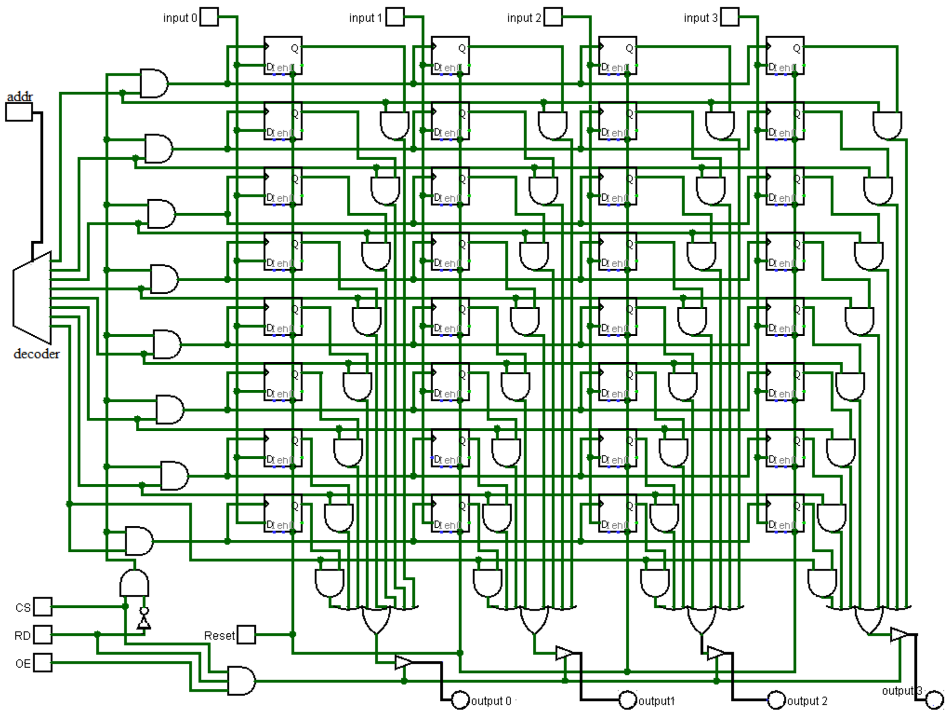

Figure 7. 8x4 memory sub-circuit

The final top level design from this group of students was not correct due to the limitation of their memory sub-circuit design mentioned above. However, multiple working sub-circuit design showed that this group of students got involved with deep thinking, analysis and synthesis of the logic level computer circuit components.

5. Outcome and Future Improvement

The author developed critical thinking method for teaching computer hardware design course according to the guideline from Association of American Colleges and Universities (AACU) [11] Critical Thinking VALUE Rubric. Students commented that they enjoyed working in small group discussion on course materials and they thought it was beneficial for learning with student-centered critical thinking and active learning approach.

The key advantages of the implemented critical thinking pedagogy in teaching computer hardware Design Course are shown below.

i. Help students gain confidence to read technical papers and to explore new information.
ii. Motivate students to use computer aided design tools to sharp their critical thinking.
iii. Assist students to develop critical thinking skills through small group based learning.
iv. Encourage students to express ideas, participate in group based learning, and improve critical thinking skills.

The rubric shown in Table 1 was adapted from the AACU VALUE Rubrics for critical thinking on a scale from 1 to 4. 10 student samples from 3 different groups in the computer hardware design course at CSUS were evaluated for critical thinking for the semester of fall 2014. Students voluntarily formed their own groups in the beginning of the semester. Only 3 or 4 students were allowed to be in one group. Group A had 3 students, group B had 3 students, and group C had 4 students. In the beginning of the semester, the instructor organized in-class discussion. However, only one student was able to participate in class discussion. All the other 9 students were quiet and seemed to be more comfortable with passive learning. The instructor organized critical thinking pedagogy in teaching for the whole semester. At the end of the semester, the students were assessed again for critical thinking. The assessment result is shown in Table 1.

Table 1. Student Assessment Data for Critical Thinking

SKILLS	4	3.5	3	2.5	2	1.5	1
Explanation of issues		30%	20%	20%	10%		20%
Evidence (Selecting and using information to investigate a point of view or conclusion)		40%	10%	30%			20%
Influence of context and assumptions		30%	20%	20%	10%	20%	
Student's position (perspective, thesis/hypothesis)		30%	10%	30%	10%		20%
Conclusions and related outcomes (implications and consequences)		40%	20%	10%	20%		10%

The instructor found out later that every group had 1 good learner. Groups A and B had good learners and ordinary learners. Those students in groups A and B learnt well in the group-based setting, and stimulated each other to improve critical thinking skills. Unfortunately, group 4 had 1 good learner, and 3 slow learners including students D, E and F. Student D was a slow learner, at the same time he was quiet and not active in participating in group discussion. Student E was a slow learner, he had conflicting schedule with other students, so he only participated in group discussion slightly. Both student D and student E enjoyed presentation in either group setting or in individual setting with their own proposed topics. Student F was slow learner, however he was willing to participate in active discussion with the good learner in his group and they could still stimulate each other. However, two slow and inactive learners negatively affected the attitudes of the other two active students somehow in this group. Such classroom observation matches the Table 1 assessment result.

In the future, the author plans to improve the critical thinking pedagogy by doing the following:

- Monitor the group forming process by the instructor to make sure group members are diverse in ability levels and also they have common meeting time outside class.
- Design small warm-up exercises to break down big task for slow learners.

Conclusion

Small group based learning has demonstrated learning benefit to enhance student critical thinking skills and engage students in active learning in computer hardware design course. Moreover, organizing diversified group study styles is beneficial to motivate critical thinking and active learning including in-class discussion, after-class discussion, presentations, project work and so on. Moreover, computer aided tools can help students visualize complex problems and stimulate critical thinking. Open-ended project can also be used to further improve critical thinking. In the future, the author plans to monitor the effective group forming process and also design smaller size warm-up exercises to help slow learners.

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