Tutorial on Computer Organization and Architecture- Advantages and Challenges

Namrata D. Hiremath[1], Umadevi F.M.[2],Meena S.M.[3]
School of Computer Science and Engineering
KLE Technological University
Hubballi, India
[1] namrata_hiremath@bvb.edu
[2] uma_devi_fm@bvb.edu
[3]msm@bvb.edu

Abstract— Teaching Computer Organization and Architecture to the students of Computer Science and Engineering is a responsible task, as this course lays foundation for various other courses like System Software, Principles of Compiler design and Operating System. But it's always been a challenge for the course instructor to teach the course effectively. The students of Computer Science and Engineering have been inclined towards software courses and hence teaching a course without associated laboratory, has been a drawback. To aid students with better understanding of concepts, course instructors decided to redesign the course. The tutorial was planned to address the previously mentioned challenges. The most popular RISC ARM processor was chosen as a case study. To measure the effectiveness of the tutorial, activities were conducted and evaluated as per designed rubrics. In this paper we highlight the challenges and the advantages of tutorial. As a result, we have noticed that students have shown better understanding of the courses.

Keywords—RISC processor, ARM, LPC2148, interfacing

I. Introduction

With the transformation from college to university the responsibility of an educator has increased from course design to course evaluation. Modern system engineers should know the concepts like, HPC, Quantum Computing and Parallel Computing, which falls under the system engineering vertical of the department. These courses require strong foundation of the hardware related courses like Digital System Design and Computer Organization and Architecture.

Emergence of Internet-of-Things brings a whole new class of applications and higher efficiency for existing services. Application-specific requirements, as well as connectivity and communication ability of devices have introduced new challenges for IoT applications [1].Currently industry requires engineering graduates having multidisciplinary skills. In order to cater to these requirements, courses and course contents are revised and redesigned. As observed there is an increased demand for IoT and embedded system based products.

In order to well equip computer science students with current industry requirements, the courses, Digital System Design, Computer Organization and Architecture, Advanced Computer Architecture, Applied Parallel Computing are included in the curriculum [2] .The course Digital System Design is taught at 3rd semester level which contributes prerequisites needed for the course Computer Organization and Architecture [3]. The courses Advanced Computer Architecture and Applied Parallel Computing are taught at 3rd year. The contents of Computer Organization and Architecture was planned to serve as pre-requisites for above courses which are taught at higher semesters. This course was earlier taught without hands-on approach which proved insufficient to grasp and less interactive to majority of the students.

The white paper on "Learning in the 21st Century: Teaching Today's Students on Their Terms", by International Educational Advisory Board (IEAB) discusses about nature of current generation students and role of educators. Today, information and communications technologies (ICTs) infiltrate classrooms around the world at an exceedingly rapid pace. In the wake of this influx, educators face growing challenges as they teach a very "wired"—and more and more "wireless"—generation of students using technology that is evolving every day. Millennial students do not want to be bound by traditional schedules, and they do not necessarily want to sit in a classroom to learn or in an office to work. Instead, they prefer to use technology to study at any time of the day or night, telecommute from anywhere in the world and define "balance" in their own individual ways [4]. Hence it's a great challenge for the course teachers to be well equipped and be updated with evolving technology.

As the mentioned in Computer Science (CS) curricula recommendation report of IEEE/ACM2001, the course needs to be updated in timely manner to reflect the state of art technology and course topics and contents needs to be carefully adjusted to cover more recent technologies and core topics in greater details [5].This paper discusses how the course contents upgraded to adopt to the new technology ARM and in turn how this ARM helped to address challenges faced during traditional teaching methods to teach to millennial students. To make the course effective tutorial was planned in such a way that contents of tutorial should reinforce the contents and correlate the ARM architecture with GPU architecture. The tutorial contents were systematically organized to cover the concepts like ARM architecture, ARM assembly programming and application design using embedded C.

II. Course design

In the curriculum of KLE Technological University course contents play crucial role, so they need to be carefully chosen, updated and reorganized by rigorously modifying syllabus. As per the observation the curriculum of various universities show that more focus is given to computer organization. Simulation is used as an aid to teach the organization concepts effectively. But this approach does not give strong support to teach Computer Architecture as compared to hands on approach, where the concepts like addressing modes, Instruction Set Architecture and pipelining are involved. Hence to motivate the students and conduct the course effectively hands-on approach was adopted.

The course content was designed with the following objectives.

The Course Outcomes (CO) are as follows:

1. Explain architecture and organization of modern computing systems.
2. Analyze the effect of pipelining and the way it can speed up processing.
3. Illustrate the different ways of communicating with I/O devices and standard I/O interfaces.
4. Analyze instruction execution and data processing in terms of clock cycles.
5. Discuss architecture and operation of a dedicated processor.
6. Write assembly language and embedded C programs for the defined task.

The COs 2, 3 and 4 are attained in theory and COs 1, 5 and 6 are attained in tutorial.

The different activities are planned to assess all the COs. Course outcomes were analyzed to measure the effectiveness of the changes brought out in the course design.
The course contents for the course COA are as follows:

Table 1: Course Contents

Chapter No.	Chapter Name	Co-Related with other courses
1.	Basic GPU Structure	Operating System and Principles of Compiler Design
2.	Pipelining	
3.	Input /Output Organization	
4.	The Memory System	
5.	Arithmetic	
6.	The ARM architecture	System Software, Mini, Minor and Capstone Projects
7.	The ARM Instruction Set	
8.	ARM Assembly Programming	

As mentioned in Table 1, the chapter1 discusses GPU structure which describes the internal details of general purpose computing. Chapter2 discusses significance of pipeline design and hazards handing.Chapter3 discusses I/O organization where in procedure of accessing input and output devices to processor plays significant role. Chapter4 focuses on memory system, covering the hierarchical architecture of the memory system, types of memory like SRAM DRAM, cache, virtual memory and address mapping.chapter5 discusses how arithmetical operations inside a computer are performed. Rest of chapters cover architecture of ARM and Assembly language programming.

A. *Selecting ARM as a case study*

It is impossible to teach a course on computer architecture without introducing a computer. A specific computer architecture is required as a vehicle to teach about registers, addressing modes, instruction types, and so on for teaching the concepts effectively to Computer Science students [6].
This paper has suggested that the ARM is an ideal choice for both the professor and the student because it is easy to understand initially, teaching material is widely available, and high-quality PC-based ARM simulators are can be freely downloaded from the Internet. The advantage of an architecture that allows students to get going from day one can't be over-estimated [6][7].

The ARM architecture was earlier taught in the course Embedded System for four credits with an associated laboratory, which is removed from the current KLE Tech curriculum. The Embedded system course consisted of ARM Architecture, Assembly programming and Interfacing the peripherals using embedded C programming. Students come to department with the knowledge of interfacing peripherals to AURDINO in the Engineering Exploration course in first year. Hence they do have basic foundation of interfacing and modelling. As observed it was found that the curriculum lacks an architecture of one processor which is needed to CS students. [8] To bridge the gap, architecture ARM was selected as Case Study for the course. Also care was taken to eliminate redundant topics which was covered in earlier semesters. Tutorial was planned to teach the architecture effectively.

B. *Tutorial Plan*

The tutorial was planned to teach one specific architecture with addressing modes, ISA, assembly programming and interfacing ARM with peripherals. The aim was to give the students a platform to explore the hardware details and get a proper insight with the internal functioning of a computer. The concepts taught in the tutorial targeted to teach the concept like RISC, CISC comparison, Pipelining concept, memory organization, Assembly and Embedded C programming.

Pipelining concepts incorporated as it should give exposure for students to understand concepts like concurrent execution and superscalar execution. These concepts are the basis for understanding the courses like parallel computing .

Memory organization of ARM are correlated with modern computing machine as this also serves as basis for operating system subjects.

The tutorial was planned with the following objectives as shown in Table 2.

Table 2: Tutorial Contents

Tutorial Plan		Marks: 20		
Objective: • Study the internal components of a 32 bit system. • Compare various architectures with ARM architecture. • Develop an embedded system based application using ARM processor by choosing suitable IO peripherals for a specified task.				
CO: 1,5 & 6				
Evaluation Criteria and mapping with PI				
Evaluation Criteria	Weightage in Marks (Total 20)	Blooms Level	Timeline	Indicator
Identify the internal components of computer.	5	L2	Review 1 Week 6	1.3.1
Compare a specific architecture with ARM architecture.	5	L3	Review 2 Week 8	1.3.1
Identify the problem for a given theme and write the clear definition and the objectives.	3	L3	Review 3 Week 7	2.1.1
Design and implement the prototype for the identified problem.	7	L3	Review 4 Week11	2.1.2 5.1.1 9.3.1

To meet the above mentioned objectives tutorial was organized and conducted according to Table 3

Table 3: Tutorial Term-works

Sl.No	Topics
1	Demonstration on internal components of Computer
2	ARM Architecture
3	Assembly Instructions i. Data transfer instructions ii. Data processing instructions iii. Control flow instructions
4	ARM Interfacing i. Interfacing LED and LCD display ii. DC and Stepper motor iii. Keypad
5	Develop an application using ARM processor.

III. METHODOLOGY TO CONDUCT TUTORIAL

The tutorial was 2hrs session every week where concepts ARM RISC Architecture was covered to reinforce the core concepts of COA . The activities were planned and conducted as mentioned above.

A. Demonstration on internal components of a computer

This was team activity where students were given demonstration on internal hardware details [9]. This activity helped students to identify, assemble the different components of a computer and visualize how different units like memory, buses, processor and NIC card are organized in a CPU. This activity was assessed for 5 marks to meet GA1.

B. ARM Architecture

Since power consumption is becoming a major concern for current and future projects it is of great importance to maintain adequate performance, while meeting modern power constraints. [10]. In this paper, author discuss about the discuss about the difference in CISC and RISC processors regarding ISA, performance and power consumption. This activity provides a comparison to be able to cover as many software and hardware applications used by different architectures as possible. After the activity, the students will have enough information on the RISC and CISC processors, the differences between them, and where they are most effectively used. This in turn will help in determining which ISA of the selected processor is most suitable for the required application [11].

In this session of tutorial, students were given with exposure to ARM architecture. Differences between RISC and CISC, Features inherited from RISC by ARM, ARM programming model, different working modes and ARM architecture was taught. To familiarize students with different architecture activity was conducted for 5 marks to meet GA1. It was a team activity where each team of four students were asked to present comparison of ARM architecture different architecture.

C. Assembly instructions.

ARM assembly programming gives positive impact to study the Computer Organization and Architecture [6]. It also give better exposure for students to design assembler in the System Software course taught in later semesters. This course also serves as a pre requisite for Compiler Design course.

These sessions involved teaching the following concepts to help students to write assembly programs:

- Addressing modes
- Instruction classification
  - ✓ Data transfer
  - ✓ Data processing
  - ✓ Control flow
- Usage of tool: Keil IDE

This activity helped students to get familiarized with how instructions get executed, how data is read and written to a memory and interaction of assembly code at hardware level.

To make the tutorial successful different activities were planned, conducted and assessed to meet the chosen Graduate Attributes. As this course provides fundamental knowledge to many other courses GA1 was chosen. To assess the effectiveness of tutorial simple application design was used, which meets the graduate attributes GA2, GA5 & GA9.

D. ARM interfacing.

These sessions were planned to expose students as to how ARM can interface with different peripherals like LED, LCD, motors and hex-keypad[11]. This activity helped students to build simple applications.

E. Develop an application using ARM processor.

In this activity students were asked to form team which consisted of four members. Different themes were planned and given to all eight batches

i. Smart city
ii. Agriculture
iii. Renewable energy
iv. Aid for old age and physically handicapped

v. Transportation
vi. Aid for education
vii. Security
viii. Automobiles

This activity helped students to design a computer based system to monitor and control the peripherals. This activity addressed GA2, GA5 and GA9. It was assessed for 10 marks.

F. Rubrics for various planned activities

Rubrics for assessment of various activities were planned as shown in tables 4 and 5.

Table 4: ARM Architecture Comparison Rubrics

Criteria	Excellent(10-8M)	Good (7-5M)	Average (4-1M)
Literature survey	• Very thorough details of ARM architecture and given processor architecture were collected. • Performance parameters of ARM in comparison with other processors are clearly stated ✓ Power consumption ✓ Processor speed ✓ Pipeline stages ✓ Instruction set ✓ Memory hierarchy ✓ Word size of a processor.	• Details of ARM architecture and given processor architecture were collected. • Performance parameters of ARM in comparison with other processors are stated. ✓ Power consumption ✓ Processor speed ✓ Pipeline stages ✓ Instruction set ✓ Memory hierarchy ✓ Word size of a processor.	• Details of ARM architecture were collected but given processor architecture details were not complete • Performance parameters were not clearly stated.
Presentation	• Presented the contents with confidence and without much referring to slides. • Eye contact with audience was maintained. • All queries put forth by the audience was handled gracefully.	• Presented the contents without much referring to slides. • Eye contact with audience was maintained occasionally. • All queries put forth by the audience was handled.	• Presented the contents without confidence and oftenly referred slides. • Most of queries put forth by the audience were not answered.

Table 5: Model of ARM Application Rubrics

Criteria	Excellent(10-8M)	Good (7-5M)	Average (4-1M)
Presentation on Problem identification	• Effectively identified problem. • Identified desired solutions or options • Topic introduced clearly and in an interesting way. Purpose of talk was made clear. Outline of points was given • Presenter spoke clearly and at a good pace to ensure audience comprehension. • Delivery was fluent and expressive.	• Problem Statement identified but no clarity about solution • Topic introduced clearly, and purpose of talk was made clear. • Presenter usually spoke clearly to ensure audience comprehension. • Delivery was fluent.	• Uncertainty in problem identification. • Problems not stated clearly • Topic introduced and the purpose of talk was not very clear. •
Model Implementation and Demonstration	• Great care taken in construction model so that the structure is neat, attractive and follows plans accurately. • Significant gain in knowledge or skills. • Model works fine for all possible inputs. • States conclusion with justification based on reasonable data interpretation of data	• Model accurately followed the plans, few details could have been refined for a more attractive product • Partial gain in knowledge or skills. • Partially working model • States conclusion based on reasonable data interpretation of data	• Model appears careless or haphazard. Many details need refinement for a strong or attractive product. • Model not working • States no conclusion or with conclusion based on reasonable data interpretation of data

The weightage in marks to all the CO's are distributed as per the relevance of topics and how they map to further courses in higher semesters. The weightage in marks planned for the CO's to be addressed in our course is as shown in Fig 1.

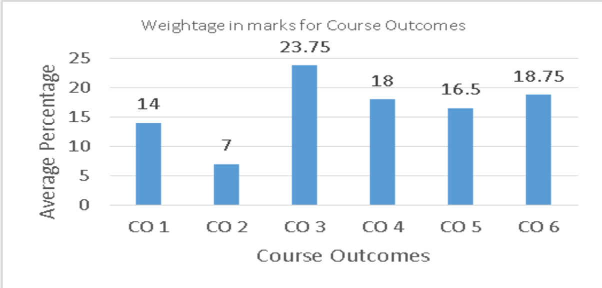

Fig. 1. Marks weighatge for Course Outcomes.

G. Samples of ARM Application developed

Some of most interesting models designed using ARM were noted and are as follows

- Automatic Seed Sowing Machine: To design a system that helps in sowing the seeds at fixed distance
  Objectives:
  ✓ The Device should be automatic.
  ✓ It should sow the seeds in the required pattern.
  ✓ Amount of seeds to be sowed can be controlled by inputs

Fig 2 shows working model for seed sowing machine. This machine developed by students was demonstrated as to show how automatically seed sowing can be done to aid the farmers.

Fig. 2. Demonstration of seed sowing machine

- Automatic Crop Cutting Machine: Automatic crop cutting system with IR sensor.
  Objectives:
  ✓ The Device should be automatic.
  ✓ Able to detect crops at specified height and cut the crops.
  ✓ Able to detect and stop the machine if object is not crop.

Fig. 3. Model of crop cutting machine

Fig 4 shows working model for crop cutting machine. The machine is designed such way that it should cut only plants and if any other obstacles found it should stop the machine.

IV. RESULTS AND ANALYSIS

This work was proposed first time in KLE University, hence results cannot be compared with previous batch. But the planned Cos attainment and POs attainment for the course is as shown in the following diagrams.

The attainment of results for all the planned activities for Internal Semester Assessment (ISA) and End Semester Assessment (ESA) is explained below. The details of the Program Outcomes are as listed in Table 6.

Table 6: Program Outcomes

S. No	Program Outcome
1.	**1. Engineering knowledge**: Apply the knowledge of mathematics, science, engineering fundamentals and an engineering specialization for the solution of complex engineering problems
2	**2. Problem analysis**: Identify, formulate, research literature, and analyze complex engineering problems reaching substantiated conclusions using first principles of mathematics, natural sciences, and engineering sciences
3	**5. Modern Tool Usage:** Create, select and apply appropriate techniques, resources, and modern engineering and IT tools, including prediction and complex engineering activities, with an understanding of the limitations.
4	**9. Individual and team work**: Function effectively as an individual, and as a member or leader in diverse teams, and in multidisciplinary settings
5	**10. Communication**: Communicate effectively on complex engineering activities with the engineering community and with t h e society at large, such as, being able to comprehend and write effective reports and design documentation, make effective presentations, and give and receive clear instructions
6	**13. Domain-specific knowledge**: An ability to apply techniques to develop computer based solutions in the domain of data, system and network engineering

Program Outcome attainment for various reviews of the course activity conducted are mentioned Fig 4.

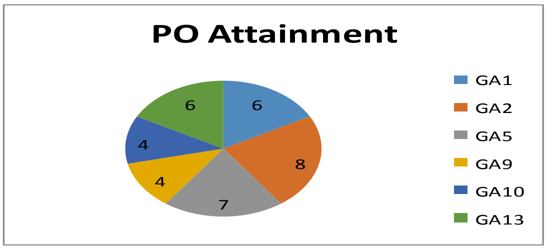

Fig 4: PO attainment on the Scale of 10

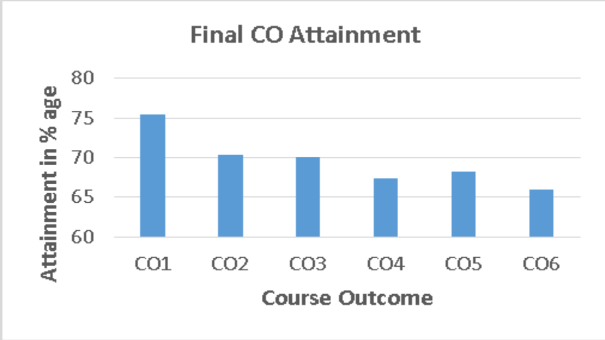

Fig 5: Final CO attainment

Fig 5 shows the final attainment of the course outcomes in ESA which was found to be satisfactory. The Co6 is addressed in the activity

V. CONCLUSION

The study of COA focuses on the interface between hardware and software, and emphasizes the behavior and structure of the system. There is a fundamental relationship between hardware, programming and software components in computer systems. In order to be an efficient programmer, it is very important to understand the computer system as a whole. Tutorial on the COA was very effective to teach the theoretical course which was otherwise considered to be a dry course. All the activities were carried out successfully in the tutorial according to the rubrics designed. Inspite of hectic schedule students enjoyed doing the activities. The concepts taught and the activities conducted serve as a prerequisite for other courses like Advanced Computer Architecture, System Software and Parallel Computing. These activities can help the students who are seeking to carry out the projects in IoT and other areas of Embedded System Applications. In order to motivate students to take up projects in IoT, the authors strongly believe that advanced ARM processor (Raspberry Pi) can be included in the tutorial.

References

[1] Samie, Farzad, Lars Bauer, and Jörg Henkel. "IoT technologies for embedded computing: A survey." In Hardware/Software Codesign and System Synthesis (CODES+ ISSS), 2016 International Conference on, pp. 1-10. IEEE, 2016.

[2] Bourque, Pierre, and Richard E. Fairley. Guide to the software engineering body of knowledge (SWEBOK (R)): Version 3.0. IEEE Computer Society Press, 2014.

[3] Calazans, Ney Laert Vilar, and Fernando Gehm Moraes. "Integrating the teaching of computer organization and architecture with digital hardware design early in undergraduate courses." IEEE Transactions on Education 44, no. 2 (2001): 109-119.

[4] “Learning in the 21st Century: Teaching Today’s Students on Their Terms”,White paper by INTERNATIONAL EDUCATION ADVISORY BOARD.

[5] The Joint Task Force on Computing Curricula IEEE Computer Society and ACM, Computing Curricula 2001 Computer Science-Final Report, 2001.

[6] Zhu, Weiying. "Teaching Assembly Programming for ARM-based Microcontrollers in a Professional Development Kit.", IEEE, 2017

[7] Clements, Alan. "ARMs for the poor: Selecting a processor for teaching computer architecture." In Frontiers in Education Conference (FIE), 2010 IEEE, pp. T3E-1. IEEE, 2010.

[8] Clements, Alan. "The undergraduate curriculum in computer architecture." IEEE Micro 20, no. 3 (2000): 13-21.

[9] Jian, Kuodi. "Meet the Challenge of Teaching Computer Organization and Architecture----Physical Computing."

[10] Hamacher, C. (n.d.). COMPUTER ORGANIZATION AND EMBEDDED SYSTEMS (6th ed.). McGraw Hill.

[11] Chevtchenko, S. F., and R. F. Vale. "A Comparison of RISC and CISC Architectures." resource 2: 4.

[12] El Kady, Sarah, Mai Khater, and Merihan Alhafnawi. "MIPS, ARM and SPARC-an architecture comparison." In Proceedings of the World Congress on Engineering, vol. 1. 2014.

[13] Furber, S. (n.d.). ARM System-on-Chip Architecture (2nd ed.). Pearson.

Namrata D. Hiremath received her M.Tech Degree in Computer Science & Engineering from Visvesvaraya Technological University, Belgaum, Karnatka, India in 2008. She has completed B.E in Electronics and Communication in Karnataka University, Dharwad, Karnataka, India in 2001. She is currently working as Assistant Professor in Computer Science and Engineering Department, KLETECH, Hubli, Karnataka, India. She has 11 years of teaching experience. She has presented 2 technical papers and 1 papers on Engineering Education in international conference.

Umadevi F. M. received her M.Tech degree in Computer Science and Engineering from VTU, Belgaum, in the year 2009. She is currently working as Assistant Professor in the Department of Computer Science and Engineering BVBCET, Hubli, Karanataka, India. She has co-authored many papers on Engineering Education.

Dr. Meena S. M. received her PhD from Visvesvaraya Technological University, Belgaum. She is currently working as Co-ordinator for School of Computer Science and Engineering, KLETech, Hubli. She had authored 18 papers in international journal and conferences.