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Enhancing Learning and Engagement in Computer Organization and Architecture through Hands-On Activity

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Context

The educational phenomenon being studied in this paper is the integration of hands-on activities in the teaching and learning of Computer Organization and Architecture (COA), a foundational subject in computer science and engineering. The paper aims to explore how incorporating hands-on experiences can enhance the learning process, reinforce complex concepts and develop problem-solving and critical thinking skills.

Purpose or Goal

Given the intricate nature of COA, which encompasses a multitude of theoretical concepts and models, it becomes imperative to provide students with immersive hands-on activities that serve to enhance their comprehension of these complexities. Moreover, active engagement in practical exercises not only enriches the learning trajectory but also imparts students with invaluable tangible knowledge. This effectively narrows the gap between theoretical understanding and practical application.

Methods

The study compared two student groups: one focused on individual processor modules called as control group (CG) and the other, on designing a complete processor which was the experimental group (EG). Both groups aimed to develop critical thinking, problem-solving, teamwork, communication and technical skills. The research assessed skill development using rubrics and employed statistical analysis to compare the two groups. This paper details the EG's activity and skill attainment. In this hands-on activity, approximately 250 students in EG were divided into teams and tasked with designing and simulating a processor datapath based on specific design requirements (Hamacher, V. C., Vranesic, Z. G., Zaky, S. G., Vransic, Z., & Zakay, S. (1996), Computer organization, McGraw-Hill). The activity emphasized effective instructional strategies, teamwork and scaffolded learning experiences, offering step-by-step guidance and opportunities for exploration and experimentation. Pre- and post-activity conceptual assessments were conducted to measure students' understanding of concepts. Data analysis explored the impact of teamwork and collaboration on knowledge acquisition, problem solving and critical thinking (Koppikar, Vijayalakshmi, Mohanachandran & Shettar, 2022).

Outcomes

Performance statistics revealed that a significant number of students improved their understanding of COA concepts through the hands-on activity, as evidenced by increased average scores in COA assessments.

The hands-on approach boosted student engagement, motivation and interest, as they actively applied theoretical concepts. Additionally, team activities facilitated lifelong skills, knowledge exchange, promoting peer learning and concept clarification.

Conclusion

Students demonstrated proficiency in applying COA principles and techniques through the hands-on activity. They excelled in designing and simulating computer architectures, analyzing performance metrics and optimizing system components, showcasing their practical knowledge. The interactive and experiential nature of the activity provided a holistic learning experience, equipping students with valuable skills for success in the field of COA.

Keywords— Addressing modes; critical thinking; datapath design; hands-on activity; instruction set architecture; problem solving; processor design.

I. INTRODUCTION

COMPUTER Architecture and Organization are integral subjects in the field of Computer Science & Engineering. They lay the groundwork for understanding the hardware aspects of computing systems, including processors. This course also lays a sound foundation for the learning of further courses like microcontroller & embedded systems, operating systems, system software, principles of compiler design and so on. Given COA's complexity with various theoretical concepts, practical activities are essential for enhancing understanding. Furthermore, active participation in hands-on activities not only enhances students' learning journey but also equips them with invaluable practical knowledge (Erdil, Bowlyn & Randall, 2021). This reduces the gap between theory and practice. However, engaging students and encouraging their interest in these hardware courses remains a critical concern. This scenario prompted the course instructors to consider the following research questions for their study:

1. What are the most effective instructional strategies or techniques within a hands-on activity framework that facilitate learning and understanding of COA concepts?

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2. How does collaboration and teamwork in a hands-on activity contribute to students' learning outcomes in COA?

The objectives of the activity, includes

- Reinforcing COA concepts
- Applying theoretical knowledge to practical implementation (Chen, Huang, Lin, Chang, Lin, Lin, Hsiao, 2020),
- Honing problem-solving, and critical-thinking skills (Clausen & Andersson, 2019)
- Improving team building,
- Refining tool usage
- Allowing students to gain valuable insights into the inner workings of computer systems.

The activity begins with an introduction to the importance of COA in computer science and engineering (Nayak, Hiremath, Umadevi & Garagad, 2021). Students are familiarized with the key components of a processor, its role in executing instructions, and its significance in overall system performance. The hands-on activity (Erdil et al, 2021) on building a simple processor in the context of COA was conducted for approximately 250 students of second-year undergraduate Computer Science and Engineering (CSE) at a Technological University in Karnataka, India.

II. LITERATURE SURVEY

An exhaustive exercise was done to survey the existing literature where similar ideas were proposed. This gave the course teachers an in-depth understanding of the gaps existing where similar activities were conducted. An attempt has been made to address these gaps which led to the formulation of research questions mentioned in the previous section. In the work (Alqadi & Malhis, 2007) authors propose a structured methodology for imparting practical knowledge of processor design to students. The authors recognize the challenges faced by universities in developing countries when it comes to teaching advanced computer engineering topics due to limited resources, outdated equipment and lack of access to cutting-edge technologies. Therefore, the paper aims to address these challenges by presenting an approach that can be implemented with relatively modest resources. The authors in this paper (Nayak & Vijayalakshmi, 2013) share their experiences in teaching the COA course, highlighting the teaching methodologies and strategies used to effectively convey complex concepts to students. This may include lectures, hands-on labs, assignments, and assessments. The authors of the paper (Hiremath, Umadevi, Meena, 2018) provide insights into the realm of COA tutorials. The paper delves into the benefits of COA tutorials for students while also addressing the potential hurdles that educators might encounter in this context. The paper (Blackburn, Villa-Marcos, Williams, 2018) underscores the significance of using simulation software as a preparatory tool to enhance student readiness and competence in laboratory-based practical sessions, ultimately contributing to a more effective and enriching learning experience. The paper (Clausen & Andersson, 2019) adopts PBL method and discusses how to develop crucial employability skills such as critical thinking, problem-solving, teamwork and communication. These skills were seen as valuable assets for their future careers. Students felt better prepared to tackle challenges they might encounter in their future professions. The approach discussed in (Erdil, 2019) allows students to engage in practical implementation and experimentation, which enhances their understanding, engagement and real-world application of COA principles. The study in paper (Chen et al, 2020) emphasizes the significance of experiential learning in augmenting traditional classroom instruction. It states that by integrating virtual reality based hands-on activities, educators can bridge the gap between theoretical understanding and practical application. The study in (Rini, Adisyahputra, Sigit, 2020) involves a research design that includes pre-tests and post-tests to measure changes in students' critical thinking abilities after undergoing the proposed instructional intervention. The paper (Kamerikar, Patil & Watharkar, 2020) discusses on higher-order skills that include critical thinking, problem-solving, creativity and other abilities that are valuable for students' academic and professional development. The paper (Nayak et al, 2021) discusses the implementation of project-based learning (PBL) to enhance the teaching of COA. This approach emphasizes practical, hands-on experiences to deepen students' comprehension of COA concepts. The paper underscores the effectiveness of PBL in COA education, highlighting its potential to engage students and improve learning outcomes. The study conducted by authors in (Erdil et al, 2021) on the other hand, emphasizes the value of hands-on learning in Computer Organization & Architecture (COA) education. The authors designed interactive workshops where students were introduced to fundamental COA topics through hands-on activities. The authors (Siddamal & Despande, 2021) advocate that through collaborative initiatives, students engage in practical projects that mirror real-world scenarios, enabling them to develop problem-solving, teamwork, and critical thinking skills. The paper (Patil & Karikatti, 2022) discusses various assessment techniques and strategies tailored for PBL contexts. It involves strategies for evaluating project work, teamwork, problem-solving abilities and other skills that are cultivated through PBL approaches. The paper (Koppikar et al, 2022) mainly focuses on conducting the post-test effectively and carrying out an extensive analysis of the student's performance. In alignment with the various studies cited, our paper explores the implementation of a practical oriented activity in the COA course, emphasizing hands-on experiences to enhance students' understanding in addition to imparting lifelong skills.

III. METHODOLOGY

This study aims to foster a profound understanding of computer organization and architecture, encompassing both theory and practical applications, by engaging students in the hands-on task of designing and constructing a basic processor It was conducted for approximately 250 students of second-year undergraduate Computer Science and Engineering (CSE) at a Technological University in Karnataka, India. Prior to conducting the hands-on activity for knowledge acquisition and other significant skills (Erdil et al, 2021), several preparations were made to ensure a successful and effective learning experience for students. The course instructors indulged in rigorous brain storming sessions to meticulously plan, implement and assess the outcome of the activity.

A. Control Group(CG) vs. Experimental Group(EG):

The activity involved the assessment of skill attainment among two sets of students: CG and EG with 67 and 68 teams respectively. The CG participated in course projects that centered on the creation of individual processor modules such as Booth's multiplier, array multiplier, barrel shifter, carry lookahead adder among others, while the EG tackled the more holistic task of designing an entire processor. As Fig 1. depicts, the CG involved design of individual modules within the processor, which were not holistically integrated. This shortcoming was overcome in the EG. Both groups used Logisim as simulation tool. The CG and EG of students were from consecutive cohorts, with a one-year interval between them. The CG approach offered in-depth knowledge of a specific module enabling skill specialization, whereas the EG approach nurtured skills in module integration and system-level thinking. The EG were assessed for both individual modules and the overall processor design (Alqadi & Malhis, 2007). The CG had limited collaboration due to individual module focus, while the EG necessitated extensive collaboration for seamless integration. The core focus of the study was to assess the attainment of skills among students in both groups and assessment questions to both groups were set at the same difficulty levels. Skills included critical thinking, (Cáceres, Nussbaum & Ortiz, 2020) problem-solving (Clausen & Andersson, 2019), teamwork, communication, and technical competence in processor design. Rubrics based assessment was employed to consistently evaluate and measure students' skill development in both groups. This structured approach ensured fairness and accuracy in skill assessment (Patil & Karikatti, 2022). The study utilized statistical analysis methods to objectively compare the level of skill development between the control and EG. This paper focuses on the detailed description of the activity carried out for the EG.

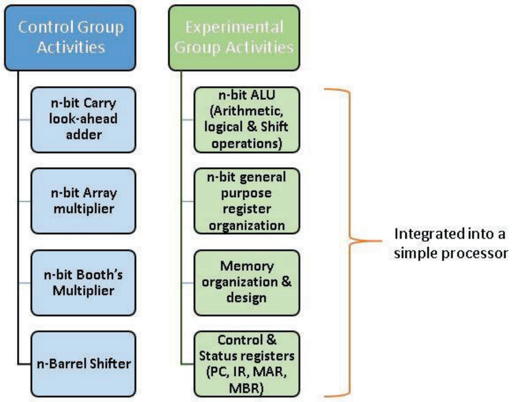

Fig 1. Activity List

B. Activity Planning:

Relevant concepts pertaining to the theoretical aspects of COA was imparted to students both in theory and laboratory sessions. Accordingly the entire activity was rolled out at the beginning of the semester as detailed below.

1) Learning Objectives: Clear and specific learning objectives for the activity were defined.

- ➢ Students should be able to demonstrate comprehensive knowledge acquisition by applying theoretical concepts such as Instruction Set Architecture (ISA), data path elements, control unit signals to design and develop the processor architecture.
- ➢ Students should be able to enhance their problem-solving, critical thinking (Clausen & Andersson, 2019), team building and communication skills by identifying design challenges, troubleshooting, optimizing performance and collaborative problem-solving (Siddamal & Despande, 2021).

These objectives were then aligned with the overall course goals to ensure that they are measurable. The activity alignment with the broader curriculum and learning outcomes of the course was ensured so that it complemented and reinforced the theoretical concepts covered in COA lectures (Nayak et al, 2021). The structure and sequence of the activity was meticulously planned. The scope of the processor design project, the level of complexity, and the required resources (such as software tools and materials) was identified and defined. The activity was finally integrated into the course timeline guided by following step-by-step process:

- *Pre-Activity Review:* A pre-activity review session was conducted to refresh students' understanding of relevant COA concepts and foundational knowledge (Clausen & Andersson, 2019). This review ensured that all participants are adequately prepared for the activity (Rini et al, 2020).
- *Resource Preparation:* Students were familiarized with the necessary resources, materials and digital logic simulator software tool (LogiSim). Necessary guidelines for tool usage and access to relevant resource materials were provided.
- *Group Formation:* Students were organized into small groups to foster collaboration and teamwork. The diversity of skills and backgrounds within each group to promote knowledge sharing and equitable contributions was considered referring to humanmetrics.com personality test with each team comprising of 4 students. Teams were

presented with the project scope and objectives, which involved building a simple processor capable of executing basic instructions. The processor's architecture, instruction set and supported operations were defined.

- *Communication with students:* The learning objectives, expectations and guidelines for the activity were communicated to the students well in advance. An overview of the project scope and the resources available for their design process was provided.
- *Documentation:* Throughout the activity, teams maintained detailed documentation of their design choices, implementation steps, challenges encountered and solutions (Hiremath et al, 2018). The documentation served as a record of their learning journey and a crucial part of the assessment.
- *Assessment Plan:* A clear assessment plan was charted out to evaluate students' knowledge acquisition, problem-solving and critical thinking skills (Clausen & Andersson, 2019) & (Cáceres et al, 2020) team collaboration and communication skills during the activity.

C. Activity Implementation:

During the lab sessions, students were actively engaged in the design and implementation of simple computer building blocks. Some of the specific tasks included:

- *Address Decoders:* Students were tasked with designing and implementing address decoders that enabled the selection of specific memory locations or peripheral devices based on address inputs.
- *Memory Design:* Memory design is a crucial component in computer architecture, and this lab activity provided students with practical experience (Erdil, 2019) in selecting specific memory location for read/write operation.
- *Multiplexers & ALU:* Multiplexers are essential in data selection and routing within digital circuits for data selection and manipulation of arithmetic & logical operations in ALU within processors.
- *Instruction life cycle:* An instruction goes through following phases during its life cycle in the processor.

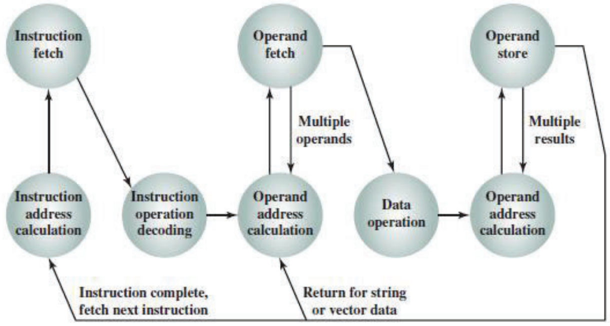

Fig.2. Instruction life cycle state diagram

The instruction life cycle state diagram as depicted in Fig.2, refers to the series of steps performed by a computer's central processing unit (CPU) to process and execute a single instruction (Stallings, W. (Ed.) (2010). Computer organization and architecture: designing for performance. Pearson Education India). It is a continuous process that occurs repeatedly as the CPU executes a sequence of instructions from a program. Each instruction goes through these stages in a sequential manner. By following the instruction life cycle, the CPU can efficiently process instructions and carry out the tasks specified by the computer program, enabling the computer to perform complex computations and operations.

Guided by instructors, teams embarked on the design and implementation of their processors. This involved taking critical design decisions, carefully considering factors like instruction set design, data path, control unit, and memory organization. The following were the guidelines floated to students to carry out the activity:

- ➢ Design and simulate a processor, which can perform load/store, arithmetic & logical operations on a set of data.
- ➢ Design for a Harward architecture, separate code memory & separate data memory to store program instructions and operands respectively.
- ➢ Include all the control & status registers like program counter (PC) (to hold address of instruction), memory address register, memory buffer register, and processor status word and instruction register (IR). Include a register file of 16 registers (R0—R15).
- ➢ Include a data memory and code memory of suitable size.
- ➢ Fetch the instruction using the contents of PC and update PC.
- ➢ Decode the instruction from IR.
- ➢ Fetch the operands (wherever applicable).
- ➢ Execute the operation.
- ➢ Write the result back in the destination (wherever applicable).
- ➢ Each team needs to implement the problem statement using 8-bit/16-bit/32-bit for 1-address/2-address/3-address format for given addressing mode. The addressing modes to be implemented are:
    - ✓ Direct addressing
    - ✓ Indirect addressing
    - ✓ Register addressing
    - ✓ Immediate addressing

- *Troubleshooting and Optimization*: As teams progressed, they encountered challenges typical in real-world processor design (Alqadi & Malhis, 2007). They involved in troubleshooting the issues, optimizing their design for performance, and ensuring proper functionality. Once the implementation was completed, teams conducted rigorous testing and validation to ensure that their simple processors functioned correctly and executed instructions accurately.

D. Assessment Strategy:

The COA activity was assessed based on several criteria as shown in Fig 3.

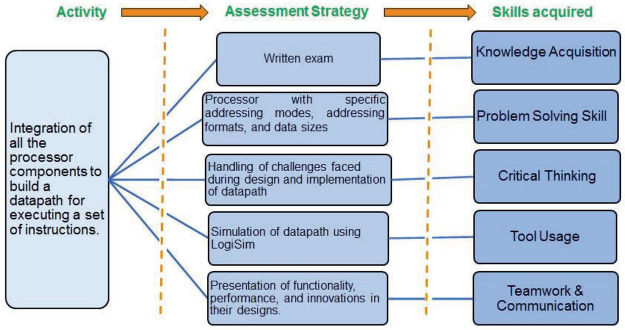

Fig.3. Activity at a glance

Knowledge acquisition: This criterion focused on measuring how well students grasped and absorbed the theoretical concepts and practical knowledge (Alqadi & Malhis, 2007) related to COA (Erdil, 2019). Students were evaluated before and after the activity to gauge their comprehension of theoretical concepts. For the pre-activity assessment a survey questionnaire was set covering all the theoretical concepts (Erdil et al, 2021) required for the conduct of the activity. Likewise the post-activity assessment (Erdil et al, 2021) was conducted using similar survey instrument (Rini et al, 2020). The functionality of the simple processor and its ability to execute instructions correctly were primary evaluation criteria. Additionally, teams were assessed on the performance metrics achieved through optimization efforts (Patil & Karikatti, 2022).

Team work and communication skills: A qualitative assessment was conducted by the course instructors where each team presented their final processor design to the class. They showcased the functionality, performance and innovations in their designs. Additionally, teams submitted a comprehensive report detailing their entire design process, including challenges faced and lessons learned (Hiremath et al, 2018). Teams were evaluated on their ability to work collaboratively, communicate effectively and contribute to the collective learning experience (Siddamal & Despande, 2021).

Problem solving, practical application and tool usage: Each individual in a team was assessed for problem solving (Kamerikar, Patil & Watharkar, 2020) practical application and tool usage skill through a single question as follows:

You have designed a processor with specific addressing modes, addressing formats and data sizes. The processor specifications dictate that you need to perform the following sequence of operations:

i. *Read two operands based on the processor's addressing mode, addressing format and number of bits.*
ii. *Perform addition on these operands and complement the result.*
iii. *Logically AND the result obtained in step ii. with another operand (read in the same way as mentioned in i. above).*
iv. *Store the final result in the specified memory location.*

Each team member was expected to write an assembly language code snippet for the above given problem statement. Convert it to machine level language and store it in the code memory of their designed processor. Walk through the steps taken to implement this sequence of operations in the processor's microarchitecture and ensure efficient execution as per the process of instruction life cycle mentioned in Fig. 1.

Critical Thinking skills: A set of questions as mentioned below was administered to each individual student in the team to assess their critical thinking.

i. *Why is it important to carefully select the addressing mode and format for each operand?*
ii. *Explain how the processor handles data size mismatches during complex arithmetic & logical operations.*
iii. *How do you ensure that the operands and the result are read from and stored in the correct memory locations?*
iv. *Are there any trade-offs or compromises you had to make in designing the processor to execute this sequence of operations efficiently?*
v. *How do you maximize the number of instructions executed per clock cycle?*

These questions were designed to challenge students to delve into the intricacies of the processor's design, consider the implications of various decisions and apply their knowledge to practical scenarios. Their responses provided insights into their ability to analyze complex situations evaluate options and synthesize solutions related to COA concepts and hence enabling measurement of critical thinking skills (Cáceres et al, 2020).

E. Assessment Rubrics:

Rubrics for assessment were used to provide a structured and transparent way to evaluate students' performance based on specific criteria. It ensured consistency in evaluation and helped both students and instructors to understand the expectations for each aspect of the activity. Rubrics as shown in TABLE I were effectively used to measure various skills and competencies, including knowledge acquisition, critical thinking & problem-solving to mention a few among others. Similarly other acquired skills such as practical application, tool usage, team work & communication were also assessed through suitable rubrics.

TABLE I
ASSESSMENT RUBRICS

	Excellent	Good	Average
Knowledge Acquisition	• Demonstrates a deep understanding of COA concepts related to the simple processor design. • Accurately explains the principles and components involved in building a basic processor. (8-10M)	• Shows a solid understanding of most of the COA concepts relevant to the simple processor design. • Explains the principles and components with few inaccuracies. (4-7M)	• Displays some understanding of COA concepts, but with significant gaps in knowledge. (0-3 M)
Problem-Solving Skills	• Demonstrates exceptional problem-solving skills, effectively analyzing and resolving complex issues related to processor design. • (8-10M)	• Displays strong problem-solving skills, effectively resolving most issues encountered during the design process. • (4-7M)	• Shows some problem-solving ability, but struggles to address certain challenges. (0-3 M)
Critical Thinking	• Demonstrates exceptional ability to identify underlying issues and challenges in the COA scenario. • Skillfully evaluates strengths and weaknesses of processor design options • Applies COA concepts to a real-world scenario and justifies their application. (8-10M)	• Identifies key aspects of the problem but lacks depth and thoroughness. • Demonstrates basic ability to evaluate evidence but lacks depth in evaluation. • Demonstrates basic application of COA concepts to a scenario but may lack clear relevance. (4-7M)	• Attempts to analyze problems, but lacks clear understanding of problem analysis. • Attempts to evaluate evidence but struggles to present clear insights. • Attempts to apply COA concepts to a real-world scenario but lacks clear justification. (0-3 M)

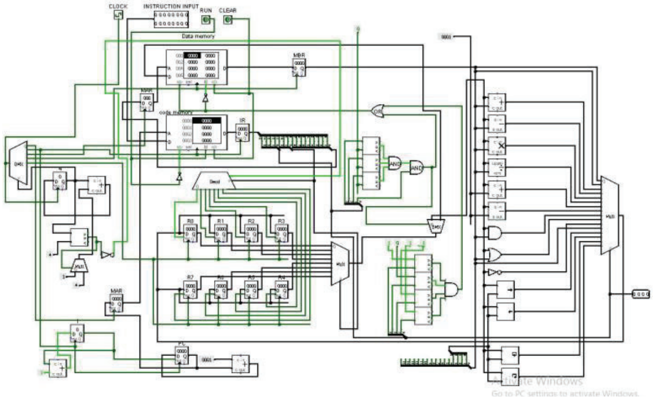

Fig.4. Sample Processor design done by a student team

Fig.4 depicts the processor designed by a one of the student teams as part of their course activity using LogiSim simulation (Blackburn, et al, 2018) tool.

IV. RESULTS & ANALYSIS

Statistical analysis was performed to assess skill acquisition and the influence of the study on both the control and experimental groups. A comprehensive breakdown of the analysis pertaining to the initial research question is presented below.

To address the first research question on effective methods to find best instructional strategies to facilitate learning, a quantitative research analysis was conducted. Initially, a descriptive statistical analysis was carried out to gain insights into the central tendency and variability of the data. Measures such as mean and standard deviation were calculated. Additionally, Shapiro wilk, skewness, and kurtosis were examined to assess the normality of the data distribution. As the data did not follow a normal distribution, non-parametric tests were deemed appropriate. Descriptive statistical analysis was performed to understand the distribution of data and non-parametric tests, specifically the Mann-Whitney U test and Wilcoxon signed-rank test, were conducted to assess the differences and identify the most effective instructional strategies or techniques within a hands-on activity framework that facilitates learning and understanding of COA concepts (Nayak & Vijayalakshmi, 2013). The dataset used in this analysis comprises student performance metrics from a CG and and EG. Performance data includes scores from assignments and activities. The Mann-Whitney U test as shown in Fig. 4 was employed to assess whether there were any statistically significant differences in performance between the CG and EG. This test is suitable for comparing two independent groups when the assumption of normal distribution is not met. Wilcoxon signed-rank test was performed within each group to assess any significant differences in performance before and after the intervention within each group.

As per the descriptive statistical analysis data presented in TABLE II, The CG had a sample size of N = 269 and the EG had a sample size of N = 273. There were three variables that were studied and they are Knowledge acquisition (KA), Problem-solving skills (PSS), and Critical Thinking Skills (CTS).

TABLE II
DESCRIPTIVE STATISTICS

	N	Mean	Std. Deviation	Skewness		Kurtosis	
	Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic	Std. Error
EG_2KA	269	7.00	1.946	-1.104	0.149	0.759	0.296
EG_2PA	269	7.36	1.806	-0.599	0.149	-0.354	0.296
EG_2PSS	269	6.25	2.090	-0.792	0.149	0.114	0.296
EG_2CTS	269	5.90	2.365	-0.456	0.149	-0.622	0.296
EG_SCORE	269	62.56	17.080	-0.871	0.149	0.202	0.296
CG_2KA	273	6.14	1.284	-0.220	0.147	0.005	0.294
CG_2PA	273	6.26	1.637	-0.592	0.147	-0.134	0.294
CG_2PSS	273	5.46	1.723	-0.664	0.147	0.102	0.294
CG_2CTS	273	4.91	1.950	-0.301	0.147	-0.871	0.294
CG_SCORE	273	56.24	12.646	-0.799	0.147	0.129	0.294
Valid N (listwise)	269						

As per the data analysis report the mean (M) and standard deviation (SD) for KA before intervention for the CG was (M =6.14, SD = 1.28) lower when compared to (M =7.00, SD = 1.94) after intervention for the EG. Additionally, the (M =5.46, SD = 1.723) for PSS for CG was lower than (M =6.25, SD = 2.09) PSS in EG. Similarly, the M and SD for CTS for CG was (M =4.91, SD = 1.95) lower when compared to the (M =5.90, SD = 2.36) of EG. Overall it can be observed that the mean value for EG is higher than the CG indicating that the students in the EG have performed more effectively in KA, PSS, and CTS assessments when compared to the students in the CG. It is interesting to observe that the students in EG had (M =62.56, SD = 17.08) when compared to CG (M =56.24, SD = 12.646) indicating that EG students performed better than CG students in the end semester assessment for the course. The skewness and kurtosis indicated that the data for all the variables was not normally distributed. To second the data another Shapiro-Wilk normality test was done and the report is in TABLE. III. The data indicated that the $p<0.05$ was statistically significant rejecting the hypothesis that the data is normally distributed violating the assumption of normality. Homogeneity of variance was conducted and the $p<0.05$ violating the homogeneity of variance.

TABLE III
SHAPIRO-WILK

	Statistic	df	Sig.
EG_KA	0.926	269	0.000
EG_PSS	0.920	269	0.000
EG_CTS	0.939	269	0.000
EG_2KA	0.879	269	0.000
EG_2PA	0.926	269	0.000
EG_2PSS	0.925	269	0.000
EG_2CTS	0.947	269	0.000
CG_KA	0.944	269	0.000
CG_PSS	0.934	269	0.000
CG_CTS	0.960	269	0.000
CG_2KA	0.945	269	0.000
CG_2PA	0.933	269	0.000
CG_2PSS	0.933	269	0.000
CG_2CTS	0.939	269	0.000

Since the data was not normally distributed a nonparametric analysis was conducted to see which are the most effective instructional strategies or techniques within a hands-on activity framework that facilitates learning and understanding of COA concepts (Nayak & Vijayalakshmi, 2013). Initially, the Wilcoxon Signed-Ranks Test was performed to assess the impact of hands-on activity in improving students' understanding of the concept. When studying EG for the KA variable, the test indicated that student's scores on the post-test with (Mdn = 8.0) were statistically significantly higher than pre-test scores (Mdn = 6.0) Z = 13.87, p = 0.00. The PSS variable also had a statistically significantly higher value on post-test (Mdn = 6.0) compared to pre-test (Mdn = 7.0) Z = 12.731, p = 0.00. Similarly, CTS improved in students from pre-test (Mdn = 5.0) to post-test (Mdn = 6.0) Z = 11.398, p = 0.00. The CG indicated increase in students performance and the score was higher in pre-test compared to post-test. TABLE IV represents the data. Overall the results indicated that regardless of pre-test or post-test performance students performed significantly better in the EG compared to the CG.

TABLE.IV
WILCOXON SIGNED RANKS TEST

	Statistic (Z)	M*dn*	Sig.
EG_KA	13.875	6.00	0.000
EG_PSS	12.731	6.00	0.000
EG_CTS	11.398	5.00	0.000
EG_2KA	13.875	8.00	0.000
EG_2PSS	12.731	7.00	0.000
EG_2CTS	11.398	6.00	0.000
CG_KA	11.450	5.00	0.000
CG_PSS	9.199	5.00	0.000
CG_CTS	6.479	4.00	0.000
CG_2KA	11.450	6.00	0.000
CG_2PSS	9.199	6.00	0.000
CG_2CTS	6.479	5.00	0.000

A second analysis was conducted to observe a comparison between EG and CG to observe whether the student's performance improved between the two. A Mann-Whitney U test as shown in Fig. 5, was conducted to examine the differences in students' performance on the final test between the EG (Mdn = 66.0) and the CG (Mdn = 58.0). TABLE V shows the report. The Mann-Whitney U statistic was U = 2.586, p <0.000, indicating a statistically significant difference between the groups. Thus we can suggest that the performance of the EG and CG differs significantly. The students in the EG performed well on the test compared to the CG.

TABLE. V
TEST STATISTICS [a]

	Score
Mann-Whitney U	2.586E4
Wilcoxon W	6.326E4
Z	-5.959
Asymp. Sig. (2-tailed)	0.000

a. Grouping Variable: Group

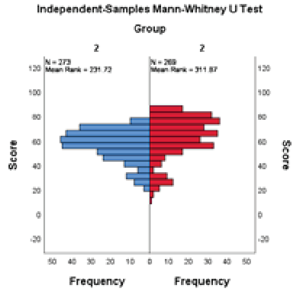

FIG.5.Mann-Whitney U test

The second research question, on how collaboration and teamwork in a hands-on activity contribute to students' learning outcomes in COA, was tackled through a comprehensive and qualitative approach that involved aggregating the average scores obtained from both peer-review assessments and evaluations conducted by course instructors. Each team member participated in the assessment process by evaluating their fellow team members using a meticulously designed form. This form encompassed a range of criteria including reliability and responsiveness, quality of work, contribution to ideas, team communication, time management, collaboration, and the overall contribution to the project. In tandem with this, the course instructors also undertook the evaluation process, employing identical parameters to assess the students' performances. The responses thus received were quantified mapping it to range of marks. This multi-faceted evaluation strategy ensured a comprehensive and well-rounded assessment of each team member's contributions and performance..

V.CONCLUSION

In conclusion, the COA activity demonstrated its effectiveness in fostering a comprehensive understanding of computer organization and architecture principles. By engaging students in hands-on processor design and implementation, the activity successfully bridged the gap between theoretical concepts and practical applications. The collaborative nature of the activity not only enhanced teamwork skills but also facilitated knowledge exchange among peers. Furthermore, the assessment outcomes showcased improved problem-solving abilities and critical thinking skills among participants. The activity's holistic approach encompassed various facets of COA, including processor design, memory hierarchy, and instruction execution. As evidenced by the statistical analysis, the activity positively impacted both the CG and EG, affirming its value in promoting skill attainment and overall learning outcomes. This COA activity serves as a model for integrating practical experiences into theory-based subjects, paving the way for a more enriching and effective educational journey.

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GLOSSARY

Abbreviation	Meaning
CG	Control Group
EG	Experimental Group
KA	Knowledge Acquisition
PSS	Problem-solving skills
CTS	Critical Thinking Skills
M	Mean
SD	Standard Deviation

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