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Coalescing Mind Maps as a Learning Aid cum Formative Assessment Tool for Effective Teaching and Learning of Computer Architecture and Organization Course

Susithra N, Deepa M, Reba P and Santhanamari G
Department of Electronics and Communication Engineering,
PSG Institute of Technology and Applied Research, Tamil Nadu, India

***Abstract*—In order to keep up with the booming technological explosion and the revolution of Industry 4.0, the students of Gen Z are expected to be up to date in the digital era. This necessitates the teachers to employ multivariate pedagogical strategies to uphold the attention of students and provide them with a long-term knowledge base. One such strategy involving visualization and supporting active learning is the mind mapping tool. Mind maps can be employed as a teaching aid along with other active learning strategies in order to unleash the in-depth associations between related concepts. Through its innate visual structure, it helps the students to organize and assimilate concepts by looking into the broader picture. Mind mapping not only aids as a long-term memory technique but also promotes design thinking and lateral thinking skills. In this paper, exploiting mind maps throughout the teaching and learning process of Computer Architecture and Organization course for the undergraduate students of the third-year engineering programme is elaborately discussed. Through the case study presented, the mind map is showcased to take various facets like 'Storm a brain-map', 'Break the ice-map', 'Fill the neurons' and 'Unit wise summary map' in different sessions of the teaching learning process. It was not only used as a teaching aid, but also served as an effective formative assessment tool for evaluating the students' understanding of the subject matter. The schema for scoring the mind maps and its relevance to the anticipated summative performance of the students is discussed. Thus, mind maps help in transforming the delivery mechanism and thereby promotes a radical learning environment.**

***Keywords*— Interconnections; mind maps; neurons; formative assessment; learning aid; STEM education; Radical learning environment;**

***JEET Category*—Practice**

I. INTRODUCTION

IN recent days, the Gen Z students have a learning environment that includes abundant learning materials through various sources especially from the internet in the form of e-books, infographics, documents and video sources.

Even though the content that a student seeks may appear to be at the reach of a fingertip, it is a challenge in disguise, as it is essential to identify the right content and also assimilate the large amount of data, orient them into related concepts and understand in such a way that it stays longer in the memory. Also, the present education system, competitive examinations, yearly increase in the difficulty level of the competitions, and the job hiring processes, demand the students to not only consume large chunks of information, but also correlate the concepts and answer questions that test their Higher Order Thinking Skills (HOTS). It is absurd to blame or complain about the highly demanding nature of the system and competitive scenario for the students, yet the solution is to use an effective teaching and learning pedagogical strategy that eases the process for the students as well as teachers.

The brain has the possibility of linking the left-brain abilities such as logic, science and learning with the right brain abilities such as visual arts and creativity. But a normal learning process that involves reading and writing focus on the left-brain activities and right brain is often dormant without receiving appropriate activity to kindle its operations. Visualization techniques such as mind mapping helps tap the infinite potential of the right brain also, thereby creating more crosslinks between the right and the left brain. Also, it is to be noted that human brains have the innate ability to visualize things (Buzan, 2006).

"Mind Maps help you to learn, organize, and store as much information as you want, and to classify it in natural ways that give you easy and instant access from memory to whatever you want." says Tony Buzan, who popularized the mind mapping technique, since 1970 (Buzan, 2006).

Mind map is a visual tool in contrast to the traditional note-taking, it is a more interactive and dynamic tool for a learner to recall the concepts easily. Unlike charts/graphs, it is a self-directed learning tool that helps students to integrate the information and learn the concepts with understanding and paves way to be able to assimilate new knowledge. It helps the students to sense the intra and inter relationship between the concepts, connect previously acquired knowledge, with new information (Tee et al., 2014). While integrating the information, the framework each student formulates to hook up the inter related data, might be different and makes the student enrich the core subject matter. This practice helps students to easily get the concepts to their minds and make sense of the information (Selvi & Chandramohan, 2018). Through mind maps, each new piece of information one tries to put into the

TABLE I
DIFFERENCES BETWEEN CONCEPT MAP AND MIND MAP

Concept Map	Mind Map
It is a top-down approach, with main concepts as the top nodes and sub concepts as the bottom nodes.	Main topic is in the center (like the nucleus of the neuron) with categories and subcategories all around like the radiating neural dendrites and axons, indicating relationship between all the concepts (branches)
Sub concepts are written as leaves at the tip of branches	Sub concepts in picture form or words are written over the branches
It is a linear note taking method.	It is a nonlinear, flexible drawing with many cross links forming a structure similar to a neural network
Predefined structures/labels like rectangles, rhombus, etc., are used to form a structure similar to flowchart.	Mind maps are open to include clip arts/doodles with multiple colors to facilitate long term memory
Used in introducing the course by the faculty and also for revising the concepts learned by the students	It is like a note-taking exercise and helps in understanding all the interrelated concepts for both faculty and students, throughout the process.
It is hard to introduce new branches and extend the map	It is open for extension of new branches
It does not facilitate long term inter-related memory.	Good aid for linking the concepts in mind for long time

memory, 'hooks on to' all the information that is already in there. With more of these hooks of memory attached to any piece of information in one's brain, the easier it is to 'hook out' whatever information that is needed (Buzan, 2006).

Mind map is a two-dimensional drawing which shows the central theme and the radiating main concepts, the sub concepts and their interrelationships, resembling the human neuron structure or a radiating tree. Each concept or sub concept is a node in the drawing and related concepts are interconnected through edges. Small doodles and colors may be added in order to help the learner to register it in their minds easily (Parikh, 2016). It effectively helps in long term memory of assimilated information. Mind mapping promotes student engagement, as a type of active learning strategy and being didactic, it continuously motivates them to learn (Deepa et al., 2021). Further, mind mapping is considered as a fundamental step towards critical thinking. It helps in planning strategies by sketching new ideas and striving to find their relationship with existing information in a creative manner. Table I lists the differences between concept map and mind map.

Mind mapping has versatile uses such as making large voluminous information into concise artworks that is a compressed version of the content without much loss of information but with enhanced linkages. Mind maps are useful aids for all educational levels including Electronics and Communication Engineering courses like Digital System Design, Antenna and Wave Propagation, Introduction to Operating Systems, Computer Architecture and Organization, etc., especially those courses involving remembering points, formulae and step wise processes. Mind mapping can be blended with collaborative and active teaching learning practices like Jigsaw (Reba P et al., 2022), peer learning and project-based learning. Mind map also acts as an effective tool in evaluating the understanding of students in the subject matter taught in the class (Rambabu et al., 2018). Very importantly while evaluating the mind maps prepared by the students, care must be taken to frame rubrics so as to decide on the extent of quality of the mind maps prepared by the students, because they will be using it for their future reference too. Also, it is an effective pedagogical tool to teach/discuss Universal Human Values (UHV) and ethics, especially to brainstorm the introspection in the beginning of a session and to summarize the takeaway points. The other multivariate uses of mind maps include event planning and portfolio creation (Santhanamari et al., 2022).

II. Literature Review

Mind mapping technique assimilates information and establishes visual linkages between the technical content via lucid illustrations. Many literatures have quoted the importance of mind map, difference between mind map and concept map. Mind maps have also been used in different courses like visual art education (Aykac, 2015), Chemical engineering course (Enszer, 2018), Environmental engineering course (Lath et al., 2016), Electronics engineering (Shakhnov et al., 2013), Electronic Devices (Vasanth et al., 1970), robotic course (Ismara et al., 2019), Signals and Systems (Shraddha et al., 2015), online teaching (Motade & Deshpande, 2022), and as assignments for distance education (Pribadi, & Susilana, 2021).

Eppler (2006) compares the concept maps with the mind maps, conceptual diagrams and visual metaphors. The authors have also elucidated its benefits and disadvantages, applications, levels of difficulty, extensibility, understandability etc., of each learning aid.

Tavares et al. (2021) highlights the advantages of using mind maps as a pedagogical tool and has introduced a new feature to mind maps called interactive mind map. Mind maps are made more dynamic by integrating it with digital technology. In Kalizhanova et al. (2020), the authors have explained about the use of software tools to explore the potential of mind maps, thereby making it much more interactive. The authors added that incorporating multimedia tools make it more dynamic.

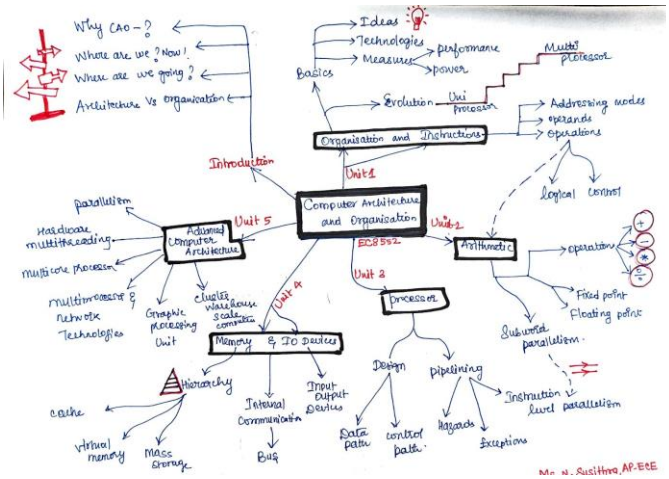

Fig. 1. Break the ice-map for introductory sessions

TABLE II
SAMPLE SESSION PLAN WITH MIND MAP PLAYING DIFFERENT ROLES

Session Topic	Objective	Mode of Teaching	Innovative Feature	Outcome
Introduction to the course and motivation	To introduce the syllabus, and recall the digital system design concepts	Brainstorming - Interaction and listing down	***'Storm a brain-map'***	The students will be able to relate how the prerequisite concepts play a vital role in understanding the new information to be grasped from the upcoming course
Introduction to Unit 1: Computer Organization and Instructions	To introduce the topics like computer organization and architecture, performance measures for a computer	Interpret and describe the given image of a mind map, faculty facilitates, clarifies and adds points to students' perspective	***'Break the ice-map'***	The students will be able to realize the objectives of Unit 1.
MIPS Instruction Set Architecture (ISA)	To familiarize the MIPS Instruction formats and Addressing modes with examples	Chalk and talk along with a scaffolding material	***'Handout - Fill the neurons'***	Students will be able to explain the features of MIPS ISA, understand formats and addressing modes thereby applying the same for encoding and decoding the instructions.
Memory Hierarchy	To elaborate the levels in the memory hierarchy, their characteristics and examples	Flipped classroom	***'Flip a mind map'***	The students will be able to understand and be able to explain the memory organization and hierarchy with examples
Unit 1 Revision	To review and revisit all the topics in Unit 1	• Summarizing through interrogation • Formative Evaluation and Feedback	***'Unit-wise mind map'***	To get a big picture of Unit 1 and be able to explain the finer details.

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In D'Antoni et al. (2010), the authors pointed out that a separate session on mind map is necessary for students before application of the same to any technical content or subject matter. They have also pointed out that learning to draw a mind map does not require any prerequisite. The authors have also highlighted that the critical thinking abilities cannot be acquired all of a sudden and mind mapping shall enhance their lateral thinking in the long run. In Swestyani et al. (2018), the authors presented how mind maps promote logical thinking and help in understanding the underlying concepts in a more meaningful way. They have quoted that incorporating mind maps in the teaching learning process will not make it complex rather make it an interactive process. Also, they suggested that the mind map tool shall be used as a measurable tool to analyze the outcomes. In Alok et al. (2021), the authors presented a case study on utilizing mind maps in project-based learning activity for an open elective course, Design Thinking and Innovation for undergraduate students. The authors quoted that, apart from assimilating the information and presenting it through visual representations, it helps align the thoughts and visions of the students and thereby facilitating critical thinking.

Mind maps have also evolved as an evaluation tool to assess the understanding of the students. In Ham et al. (2021), the understanding of 'Ecological nature' has been evaluated using mind maps. The mind maps are evaluated based on two aspects: how the students frame the chain relationship between the interrelated components and how they have illustrated the basic knowledge using the mind map tool. In Rambabu (2018), authors analyzed whether the mind maps act as an effective tool for direct assessment of learning outcomes of the course. Also, it provides a summary of different mind map evaluation techniques: mind map evaluation as a whole, evaluation of mind map based on number of topics, number of interconnections, etc.,

Enszer (2018), have formulated rubrics to evaluate mind maps. comprehensiveness, organization, and correctness were the rubric categories suggested in the paper, also considering the number of concepts quoted in the mind maps, the number of correct interconnects and the number of appropriate crosslinks. The rubrics were framed such that one point is allotted for each of the above said features added. Pribadi et al. (2021) awarded the rubrics based on two major subcategories: correctness of concepts mentioned, clarity in representing the concepts and based on visual appearance of the structure/ layout and its physical quality. Swestyani et al. (2018), evaluated the mind maps under the following four aspects: knowledge, communication, thinking, and application. In Awati et al. (2020), the authors presented the statistical tools for analyzing the mind maps

Thus, mind maps have evolved as a much effective and assistive tool for teachers in various means. However, the actual effects of integrating the mind maps into the learning environment needs to be investigated. The effectiveness of mind maps and the strategic use of the same for different active learning practices is not discussed much in literature, with specific emphasis on the course, Computer Architecture and Organization.

III. PURPOSE OF THE STUDY

To investigate the potential of mind maps and to discover

- In what ways can mind maps be used as a teaching learning and assessment aid.
- Whether the mind map can act as a suitable tool to evaluate the students' understanding at the end of different types of active learning sessions.
- How to derive rubrics to evaluate the mind maps and how to award scores to mind maps.
- How to relate the quality of mind map with the outcomes of the teaching learning process.

In this paper, we have proposed an implementation model which serves as a proof of concept, in deploying the potential forms of mind maps in teaching and learning process.

IV. METHODOLOGY

Computer Architecture and Organization is a fundamental course essential for all the undergraduate students of the circuit branches, i.e., Electronics and Communication, Computer Science, and Electrical and Electronics Engineering programmes. It acts as a bridge course between the basic digital system design and microprocessors and the specializations like Embedded Systems and VLSI Design, in alignment with the operating systems course. The course introduces the concepts like performance evaluation of a computer, organization of memory, architecture of the arithmetic blocks, data path and control path design, architectural enhancements through pipelining and parallel processing, and an introduction to the various other concepts in the advanced computer architecture domain. Thus, this course and its allied courses are the foundations to hardware and software development engineers who build efficient processors, System-on-Chip (SoC) designs and hardware accelerators. As the world is unleashing a wave of disruptive innovation in the fields of data science, Artificial Intelligence (AI) and other technologies, there is dire need for improved hardware systems and hence there is huge scope for industries that create SoC and Intellectual Properties (IPs).

The proliferation of allied technologies has made inter-related courses more voluminous in nature and so, the students have to remember, understand and link interrelated concepts from various courses and apply them in order to attain better outcomes. In the traditional education system, the students are evaluated only based on their conceptual understanding. However, the students' understanding of the interrelationship between the various elements can be better evaluated using mind maps. Mind maps trigger the cognitive part of the brain through a visual perspective. Hence the mind map is proposed to not only act as a summative assessment tool but also as a learning aid cum formative assessment tool. Moreover, mind maps can be integrated as a part of the sessions in various forms as an active learning pedagogy. In this case-study, a typical computer architecture and organization course plan is modified with fine integration of mind maps in various aspects. It is proposed that the mind maps can take different forms in various phases. Table II shows a sample session plan that incorporates the proposed mind mapping schemes as an effective tool in delivering various topics blended with different active learning methods.

The section below explains how mind maps can be used as an effective innovative feature in different pedagogical sessions. We have also suggested the other topics suitable for the proposed innovative scheme of mind map.

A. Pre-class Brainstorming Mind map

Mind maps may be used in two phases in the initial ice breaking sessions or the introductory sessions.

1) Storm a Brain-map

During the initial session of the computer architecture course, the teacher facilitated the students to recall the concepts from pre-requisite courses like digital system design. Instead of listing them all on the board, the teacher drew a mind map to not only represent as a radiating visual picture for the students but also introduced the concept of mind mapping and demonstrated how to draw a mind map even to the novice learners. For example, students recollected the number system conversions, all the binary operations (arithmetic and logical) and the function of a single bit ALU (Arithmetic Logic Unit), role of a multiplexer, encoder, decoder, clocked latches and memory cells as they are the fundamental building blocks for a computer.

2) Look and map / Break the ice-map

In the consequent session i.e., introductory session of the unit, the teacher showed a mind map like the one shown in Fig. 1, to all the students as an ice breaking activity, and prompted the students to explain or elaborate the parts of the mind map and guess how it was related to what they already knew through the prerequisites. This helped students understand their stance and gave a bird's eye view of what they can expect out of the course and the outcomes they aim to attain through the prescribed syllabus. The students attempted to frame the objectives and outcomes by looking at the mind map. Also, the mind map shown showcased the inter relatedness of the various topics in different chapters of the syllabus.

B. Handout - Fill the neurons

Few topics like MIPS Instruction set architecture (interrelation of Instruction formats and addressing modes), binary arithmetic (Conventional adders and fast adders, algorithms for multiplication and division and speed enhancement through modifications) and Memory mapping techniques (Direct, associative and set - associative cache) were provided as half drawn mind maps with missing neural parts in order to make the students assimilate the concepts that were taught in the consecutive sessions. A sample of such a handout is shown in Fig. 2. Such concepts required students to remember formats and facts also. These mind maps were also used as an alternative to the usual one-minute recall time or pre-class quiz that were conducted in the everyday sessions. Moreover, the advantage is that the mind map activity helps students to pay attention and stay active throughout the session. Such mind maps were also used as scaffolding materials in the sessions or as post session worksheets.

C. Flip a mind map

For topics that required extensive reading and understanding facts and theory, such as introduction to advanced computer

TABLE III
SCORE SHEET FOR EVALUATION OF MIND MAP FOR INDIVIDUAL STUDENT

Name: Register Number: Topic:			
Major Categories of Evaluation	**Criteria for Evaluation**	**Total Marks**	**Score**
Veracity of subject matter	Mind map clearly communicates the intended subject matter All sub concepts were identified as nodes The sub concepts were connected appropriately using interconnections or edges Sub concepts are detailed using several levels of leaf nodes Hidden inter relations between sub concepts are explored and expressed in the mind map	5 5 5 5 10	
Layout of the mind map	Does the drawing comply with the mind map presentation rules More number of interconnects are used Doodles or illustrations are used to represent sub concepts Pleasing colors and font styles are used to make the presentation attractive	5 5 5 5	
	Total Marks	**50**	

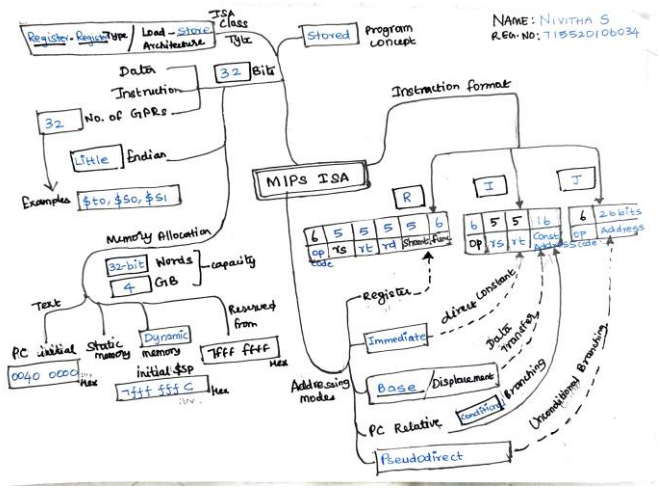

Fig. 2. Mind map scaffolding activity – Fill the neurons

architecture, memory hierarchy and input output devices, the flipped class activity was conducted. The reading material was provided to the students via MOOC (Google classroom) prior to the class and mind maps were drawn and brought by the students for initiating the discussion in the subsequent sessions. The mind map completed by the students can also be considered as a formative assessment.

D. Unit-wise mind map

After completing a unit, in order to summarize all the learnings, students were encouraged to draw a mind map by integrating all the mind maps that were used to recall the subtopics in the previous sessions. The unit-wise mind maps helped students revise the subtopics in a shorter span ahead of the summative assessment tests. It was also used by the faculty as a formative assessment tool to evaluate the student's understanding at the end of each unit.

V. RESULTS AND DISCUSSION

For this case study on mind maps, we consider a cohort of 65 students belonging to undergraduate Electronics and Communication Engineering programme. All the students were taught Computer Architecture and Organization based on the proposed course plan.

In this section, we present the analysis of the evaluation of formative assessment conducted for the course at the completion of one unit in the form of a mind map ('unit-wise mind map'). Table III shows the evaluation sheet of the unit-wise mind map assessment. The mind map is evaluated based on two major categories: Veracity of subject matter (max marks 60%) and Layout of the mind map (max marks 40%). The sub criteria under each category and the maximum marks assigned to each is also provided in Table III.

In order to define the learning outcomes of the course, we considered 4 levels of outcome.

- Level 1 Under performance
- Level 2 Moderate performance
- Level 3 Good Performance
- Level 4 Exceeding Performance

The percentage of marks considered for each level and the number of students who have attained various levels are shown in Table IV. More than 50 percent of the students met Level 3 (Good performance) showing that the mind map tool can be used to boost the effective understanding of the students. Also, the mind map evaluation marks and the internal assessment conducted by traditional written exam pattern, were subjected to t-test. It was inferred that the two sets of scores were almost similar showcasing the performance of the individuals. This was indicative that the formative scores from mind maps helps anticipate the summative score in the examination. i.e., a low score in the summative assessment was previously indicated by a low score in mindmap / formative test, similarly, students who had scored well in summative assessments had made better mindmaps in the formative phases. Thus, by anticipating the student performances via mind maps, the slow learners i.e., the low scorers in formative assessment and students finding difficulty in visualizing the concepts can be identified and provided with additional coaching sessions to help them improve their performance.

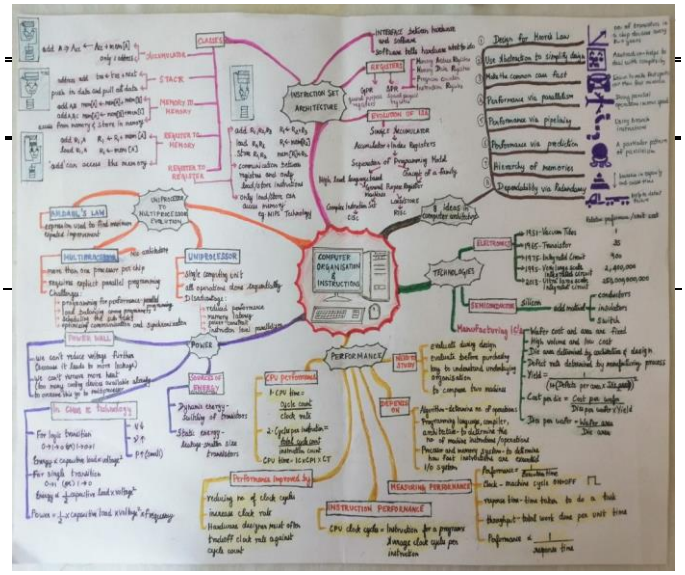

Fig. 6. Good example of mind map drawn by an undergraduate student

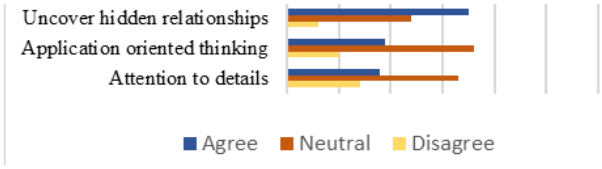

Fig. 3. Students' feedback on mind maps (showing the number of students)

The following were the survey statements used for obtaining feedback from the students.

- Mind maps provide a bird's eye view of the concept in a visual form
- Mind maps promotes lateral thinking
- Mind maps help to correlate the sub concepts clearly
- Mind maps help to assimilate the key concepts clearly
- Mind maps help to remember and recall the technical jargons in computer architecture
- Mind maps help to improve the confidence in the subject matter
- Mind maps serve as an effective guide to revise the concepts before exams
- Mind maps help to uncover the hidden relationships among the sub concepts
- Mind maps promote application-oriented thinking
- Mind maps help to enhance the attention to details

Fig. 3. shows the students' feedback appreciating the usefulness of mind maps. Fig. 4 shows the feedback provided by the students for the mind map activity. We have presented two mind maps by students in Fig. 5 and Fig. 6.

In Fig. 5, even though the central theme and all the sub topics have been identified, the layout of the mind map tends to deviate into the traditional note making style. The branches within the subtopics are not appealing and attention catching which is an essential property is missing in the shown example. Whereas the mind map in Fig.6, shows a relatively high performing student's outcome with veracity of topics as well as

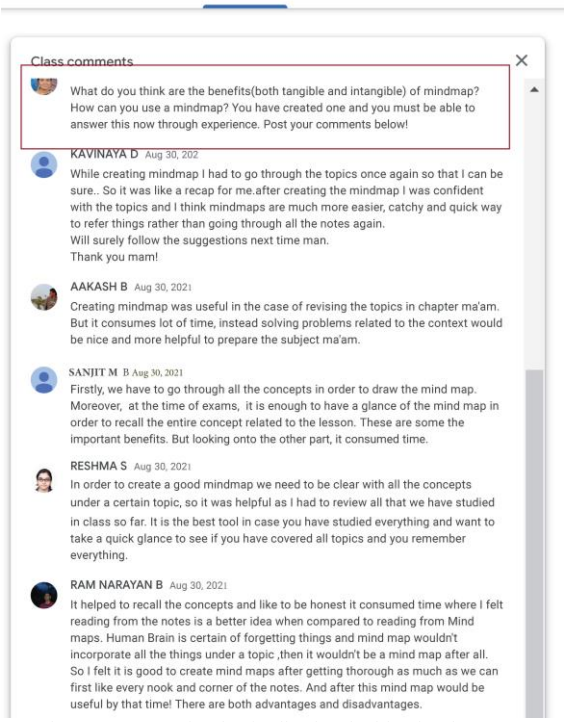

Fig. 4. Students' response for the feedback asked by faculty (as highlighted) about the mind map sessions

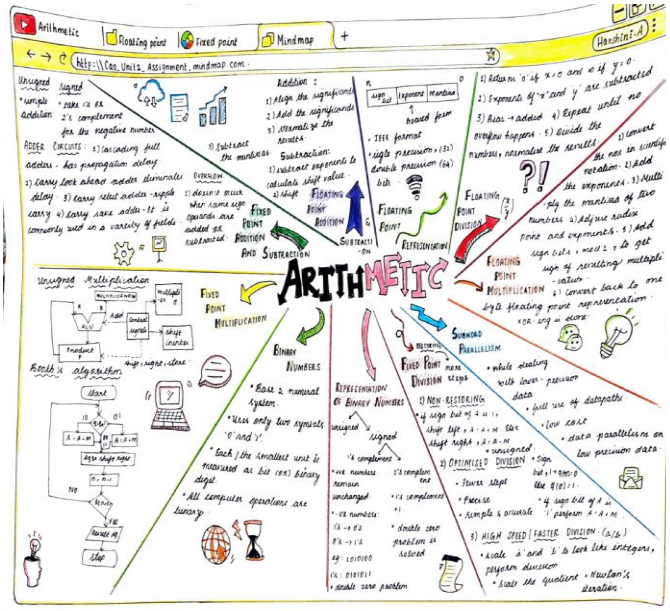

Fig. 5. Mind map by an undergraduate student with good content but not-complying to proper layout

better layout. However, the use of more words and long sentences are to be avoided. In order to help learners, create new mind maps at ease, software/online tools are also available that saves the time and effort of hand drawing. Nevertheless, hand crafted mind maps are also beneficial, helping the students connect through different senses.

VI. CONCLUSION

This paper presents an elaborate case study of deploying

mind maps in various stages of learning to assimilate the concepts in the Computer Architecture and Organization course. The students were exposed to different facets of mind maps during the introductory sessions like Storm a brain-map, Break the ice-map and Fill the neurons. Students were also encouraged to draw their own mind maps in the flip a mind map and unit wise mind map sessions. The students felt that they are able to visualize the broader picture using the interconnections and nodes present in the mind map. The mind maps were also evaluated using the rubrics formulated for the same in two categories namely veracity of the subject matter and layout of the mind map. The results showed that evaluation done with the mind maps were in consensus with the other continuous assessment methods employed. Also, it could be noted that the mind map evaluation scores help in identifying the slow learners to take necessary early action, thereby improving their performance. In addition to making the sessions lively, interactive and visually appealing with mind maps, it also stimulated the design thinking and creative ability of the students to a great extent, nurturing 21st century skills, namely critical thinking, communication, collaboration, and creativity. It was evident that the students were able to establish the inter-relatedness of the concepts in the subject matter very effectively and use them as an effective guide for examinations when compared to the other active learning strategies and traditional note taking style.

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