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Knowledge Structuring and Construction in Problem Based Learning

Manjunath Netekal, Prakash Hegade and Ashok Shettar
School of Computer Science and Engineering,
KLE Technological University, Karnataka, Hubli

***Abstract*—Problem, being a driving force in Problem Based Learning is proved to be an effective classroom strategy to develop problem solving and cognitive capabilities. A curriculum focused with knowledge structuring and construction can help students develop the required 21st century skills. In this paper we propose a model and process to re-design and deliver the syllabus to effectively integrate the problem based learning with active learning strategies. With a methodical approach of beginning from the pre-requisites to using contextual cues to structure the knowledge, the process uses the problems in knowledge construction. The model proposes the possible ways to re-structure the syllabus in support to the proposed method. The paper further presents a case study of applying the model on a computer science course, its design and deliberations. The paper presents the results and analysis along with scores and time required for revision as compared to classes where the proposed methodology was not followed. The assessment scores and feedback are presented to validate the model. The model promises to be an effective strategy to think like a problem solver and be a self-directed learner with analysis carried out using qualitative and quantitative methods.**

***Keywords*—Cognition; Knowledge Construction; Knowledge Structuring; Problem Based Learning;**

***JEET Category*—Research**

I. INTRODUCTION

ALONG with the vision and mission statements that an education institute works towards, in-evidently, it's an unsaid rule to prepare the graduates for the workplace to realize their fullest potential. The graduates need to be equipped with the skills to solve the real-world problems that their workplace has committed to elucidate. Engineered solutions are aimed to improve our social space, provide comfort and support ease of living. Engineering graduates are expected to interpret the problems and effectively solve the real-life complex problems with their acquired knowledge (Masek & Yamin, 2012). The leading constituent of modern engineering education as researched and recognized is to develop the generic problem solving skills and improve capabilities to work and contribute towards social and professional problems (Boelt et al., 2022). Professional problems are unlike the problems that students solve in classroom sessions. The problems at workplace are usually unstructured and inherently complex. They have multiple solutions with contradictory goals and constraints which need experience in solving. The unanticipated problems while solving, required cognition, distributed team works, multiple forms of representation are usually not accommodated to in classroom problems (Jonassen et al., 2006). One of efforts to bridge these gaps has been effort in designing and implementing the Problem Based Learning (PBL) pedagogy.

PBL is largely regarded as effective method of teaching which motivates developing professional and generic skills and enhance student learning (Chen et al., 2021). Originating from medical education, PBL is an approach where in students are exposed to real-world problems; they learn the principles and concepts around the problem rather than being directly presented with the facts (Barrow, 1980). Integrating PBL with engineering curriculum can help connecting the gap between theory and practical learning (Hunt et al., 2010).

Usually in a program curriculum students are saturated with vast amount of information and they are usually excited working with real time problems and scenarios (Barrows, 1996). A problem can be used as a tool for learning with proper planning (Nickles, 1981). The problems complexity, formation, abstraction, structure, etc. defines the nature of the problem and type of the problem. A problems complexity can be measured depending on two factors: complexity and structure (Jonassen & Hung, 2015). We define complexity as the known portion of the problem and structure by the unknown portion of the problem. Complexity also connects to the amount of related information in the context.

A problem solving capability is directly associated with cognitive skills. Cognitive skill is the ability to acquire the knowledge, retain it, manipulate accordingly and use it to justify. To solve a problem well-constructed knowledge is very important. The process of knowledge construction is highly dependent on cognitive ability, the cognitive load that is imposed on the learner's cognitive system (Verhoeven et al., 2009). One's performance is highly influenced by their cognitive skill and cognitive knowledge (Roshanaei, 2005). Knowledge construction plays a major role in the process. Syllabus design and delivery of a course can aid in the knowledge construction process with an objective to improve problem solving skills. This paper proposes a model for knowledge construction and structuring using PBL as pedagogy.

Section 2 presents the literature survey for the context and section 3 presents our model long with research question. Section 4 presents a case study of our model, results and data analysis. Section 5 presents discussion of the model and Section 6 concludes the paper.

II. Literature Survey

This section presents literature review on PBL, knowledge construction and efforts in improving the cognitive and critical thinking skills. Traditional learning is known to create passivity among students as compared to PBL which is proven to be an effective way of helping students to build their skill set (Gorghui et al., 2015). PBL is a cognitive endeavor whereby the learner constructs mental models relevant to problems being solved. A PBL problem toggles amidst the elements of known and unknown creating situational interest in the presented context (Schmidt et al., 2011).

Problem solving is a behavioral process that helps to select the most effective alternative among the available for a given problem (D'zurilla & Goldfried, 1971). Problem solving method helps in connecting learning with the performance (Anderson, 1993). With the PBL instruction model, structuring the knowledge and its effect on student acquisition and retention has been studied (Son & VanSickle, 1993). PBL is influenced by ones prior knowledge about the problem and steps needed to tackle the problem (Novick & Bassok, 2005). PBL is a collaborative and self-directed learning process; where learning in different phases of PBL is proven to be cumulative (Yew et al., 2011). PBL is characterized by several phases and studies indicate that to retain their knowledge for longer period, use the knowledge in application, and for effective attainment of learning outcomes it is essential to undergo all the phases of the process (Yew & Goh, 2016). Conceptualization and usage of scaffolding in PBL environment is found to have impact on structuring and problematizing the tasks (Ertmer & Glazewski, 2019).

PBL has also been explored and integrated with several other approaches. Hybrid-PBL methods have been introduced and evaluated to be an effective method of learning as compared to the traditional approach improving their understanding of knowledge and problem solving skills (Lian & He, 2013). Integrated curricula of problem based learning and team based learning have been designed to help students develop core competency skills (Huang & Wang, 2020). Combining the role-play learning model with PBL has been experimented as an effective learning strategy to facilitate student-driven learning (Chan, 2012). Dynamic-PBL method allows students working in teams solving a real time problem (Overton & Randles, 2015). Jigsaw and problem based learning model was combined to witness enhanced learning outcomes (Saputra et al., 2019). Flipped learning and digital story telling methods are combined to support the teaching and learning (Tomczyk et al., 2019).

PBL has also been experimented in several domains. PBL and SCAMPER strategies have been used to enhance cognitive learning in a project course of information engineering (Wu & Wu. 2020). PBL and design build experiences have been integrated in aeronautics and astronautics (Brodeur et al., 2002). PBL when used for programming course with real-life problems at freshmen year has enhanced programming skills (Topalli & Cagilty, 2018). Design thinking process has been understood and distinguished from novice and expert using problem solving frameworks (Grave et al., 1996).

The effect of PBL on students in understanding the concepts, principles and knowledge application have been studied (Galand et al., 2012). Investigations have been carried on knowledge construction. Storytelling, being one of them in learning and knowledge construction, has been a way to connect the past knowledge and to elaborate the future knowledge (Wiessner & Pfahl, 2007). Collaborative knowledge and conflicting ideas have been used to enhance student learning (Aarnio, 2015). The way PBL structures the delivery promotes the activation of previous knowledge and also enables the intrinsic curiosity (Schmidt, 1993). Studies have been carried out on the way students analyze the problem space and how the trigger questions guide in the knowledge construction process (Chin & Chia, 2004). PBL has been integrated with many other active learning strategies to structure curriculum and instructional knowledge base (Hallinger, 20201). This integration has implications on cognitive, behavioral and social dimensional learning and promotes incorporation of theory into practice (Silva et al., 2018). PBL is found to have positive impact on learning outcomes, enhancement of critical thinking skills and knowledge construction (Moallem, 2019).

PBL requires greater human resources and continuous training for its implementation (Trullas et al., 2022). PBL has its own challenges in global and local context. Along with generic issues like faculty training, time management, delivery and evaluation strategies, in counties like India we also have additional challenges like handling larger classrooms and sessions with shorter durations. This paper presents a model of structuring and delivering a course using PBL for the surveyed gaps and local context.

III. Model and Methodology

Knowledge construction is the one of the active processes of learning, in which the learners gain new experience by constructing new knowledge with the help of previously known knowledge (Roschelle, 1997). PBL method reassures the instigation of preceding knowledge and facilitates the conception of novel information correlated to the problem. It is also known to support the lifelong learning enhancing long-term memorability (Schmidt et al., 2011). PBL is also known to support the 21st century 4C skills, i.e. critical thinking, creative thinking, collaboration and communication (Widiawati et al., 2018). Our model uses these strengths and gaps as a motivation to structure the course in two ways and support in PBL delivery. This section presents the research question, process, and the model deliberations.

A. Research Question

We formulate our research question as: What is an effective way of organizing and delivering a syllabus using problem based learning? And following are the associated contributing parameters.

- The level of PBL integration for a course and the nature of the course
- The size of the classrooms, as usually it is around 70 in typical Indian context
- The delivery mode and assessment strategies

B. Nature of the Course

We consider the courses for this PBL model with following characteristics.

- The course has chapters that are inter-connected to each other. They could be all sub-systems or sub-modules of one larger system or module.
- The chapters have concepts that incrementally grow from theories, to operational and then to applications.
- The syllabus is structured with incremental growth of a process or components
- The course is related to other courses in same semester or they have previously studied.

If carefully studied, most courses fall under this category. If not they can be re-organized to meet the above mentioned objectives.

C. PBL Model

The knowledge construction process used to design the PBL can be seen in Figure 1 below.

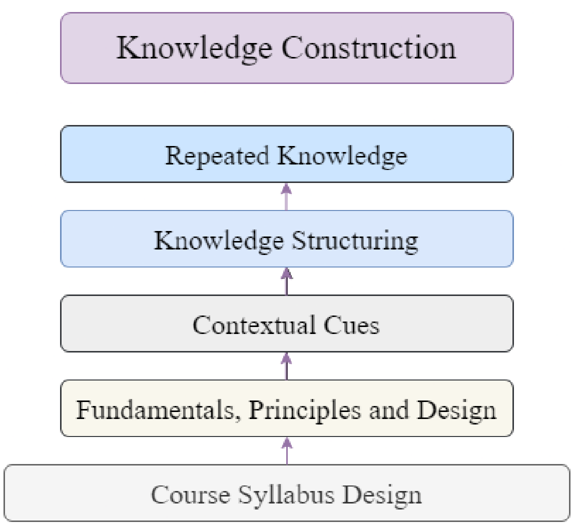

Fig. 1: Knowledge construction process

The knowledge construction for the course using PBL happens through the phases of understanding fundamentals of the course, principles and design. We then use them as contextual cures for knowledge structuring. The next step is to repeat this knowledge in numerous contexts for knowledge construction. The process is formulated using the six principles of cognitive learning (Schmidt, 1993).

Consider a set of chapters with traditional delivery as seen in Figure 2.

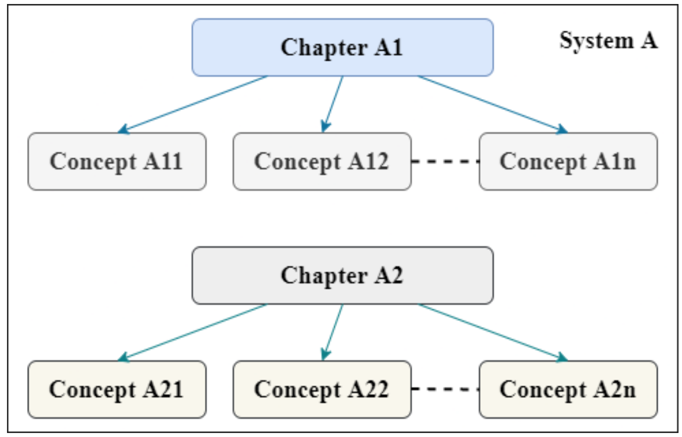

Fig. 2: Traditional delivery of related chapters

A set of chapters put together contribute to the knowledge of System A. A syllabus like above can be redesigned to structure and delivery as shown in Figure 3.

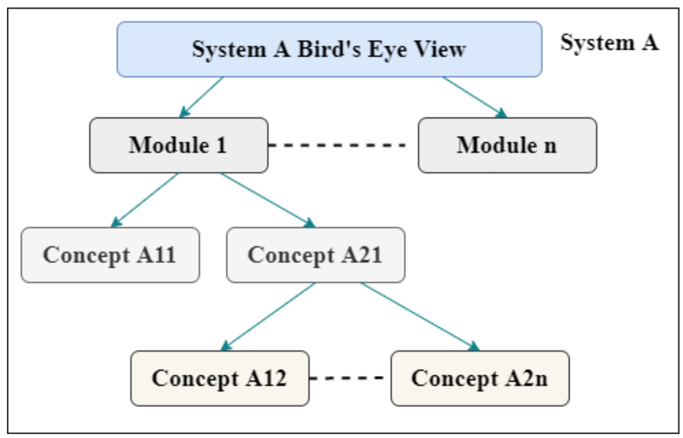

Fig. 3: Re-structuring for PBL pedagogy

Modules are explained first to give a bird's eye view and interconnection between them. Concepts are further delivered based on how they are related to the individual and set of modules. The idea is to make students create a mind-map of concepts which faculty has already developed for the course delivery in the beginning. Each of the concepts can further be delivered using a problem or a case study as appropriately needed. This method is also in support with the research that has happened with respect to the task based syllabus design (Long & Crookes, 1992). The principle and the methodology for the learner here is to re-synthesize the components and concepts that has been divided into smaller parts with the aim to learn and integrate (Wilkin, 1974). The faculty provides the information how the smaller components work giving clues on how they interact with other components.

The delivery of concepts is designed as shown in Figure 4. We formulate a concept considering the pre-requisites they know and diving between known and un-known to establish the understood theories.

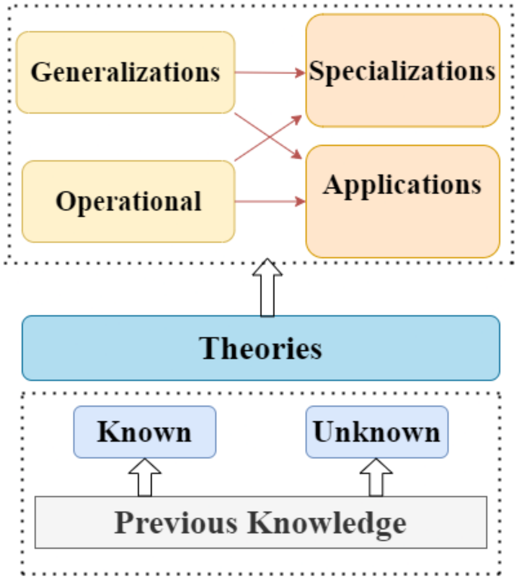

Fig. 4: A concept delivery model

We further re-organize the contents across generalizations and specializations and forming categories of operational and applications. The model intends to provide the experiences that a syllabus design must adhere to (Murphy, 2018). Previous knowledge can be used to construct generic solutions from which by applying specific conditions, new designs can be arrived at. Previous knowledge can be used to develop operational models to further synthesize the domain specific applications.

IV. Results and Data Analysis

This section presents the results and discussion of model applied on a course as a case study.

A. Course Background

The methodology was applied on the course 'Operating System Principles and Programming' offered at IV semester. There are five divisions in school of computer science and engineering and the one division followed the PBL method while the other divisions followed a variation of the flipped class room. This study only measures the effectiveness of the PBL method and does not intend to compare the PBL method with flipped method.

B. Course Structuring

As explained in section III, the course content was redesigned with Unit 1 which had all chapters related to process as per Figure 3 and one chapter in Unit 2 was entirely delivered as per the model in Figure 4. One remaining chapter from Unit 2 was delivered using traditional approach.

C. Internal Assessment Evaluation

ISA 1 which covers the syllabus of Unit 1 covered everything related to the process management. Classroom sessions were designed to draw the concept mapping of the entire unit. Students had developed a perspective of holistic picture of process management which otherwise traditional method only covered the parts in isolation. Students were provided with chart sheets to draw the concept mapped diagrams. The ISA 1 scores of all five divisions can be seen in Table I below.

TABLE I
ISA 1 Analysis

Score Range	A	B	C	D	E
13-15	4	4	3	29	4
9-12	29	50	33	30	21
6-8	12	14	16	6	19
4-5	10	5	6	4	1
0-3	2	0	2	2	2

D division, where PBL method was used has 29 students scoring within the range of 13 to 15 which was significantly more as compared to all other divisions.

The memory management chapter of seven hours was traditionally covered first with the hardware and then to design software for segmentation and paging. It was re-structured to first cover the memory design, then understand the software constraints to design the underlying the hardware. Case study handouts were provided for segmentation and paging to design and to modify the generic hardware design according to the new rules and guidelines. Method as mentioned in Figure 4 was adapted for the syllabus re-design and delivery.

A survey was conducted after the internal assessment 2 with consent from the students and was completed by 50. Likert scale of 1 to 5 was used where 1 being highly in-effective and 5 being highly ineffective. The effectiveness feedback for the question stated "We spent more than 7 hours (allotted units as per lesson plan) for memory chapter. Rather than traditional way of concept, segmentation and paging, we first understood basics and then arrived at segmentation and paging as case studies (handout and sheets). How effective was this? " can be seen in Figure 5.

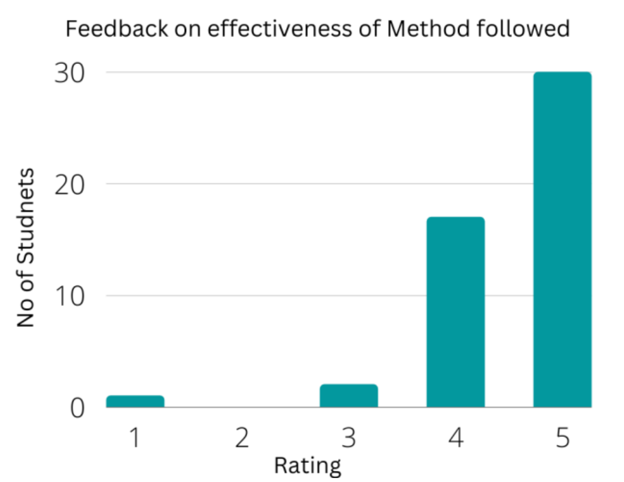

Fig 5: Student feedback on methodology

47 students of 50 rated that the method was effective. One of the feedback questions asked on how many classes they had attended and the results are shown in Figure 6.

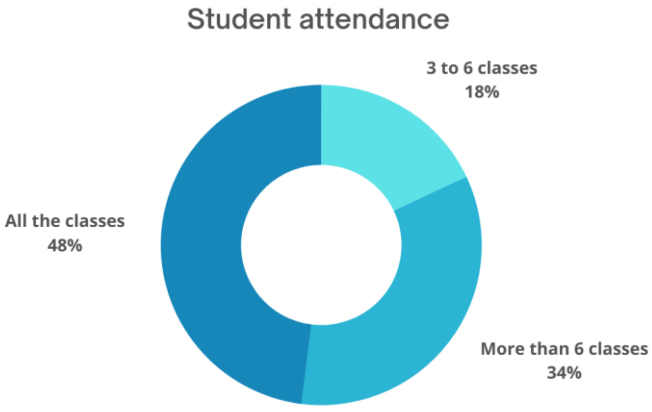

Fig 6: Number of classes attended

48% of students had attended all the classes and no student from the list had attended less than 3 classes. For the question asked on how much time they spent on preparation for the internal assessment and the results are presented in the Figure 7.

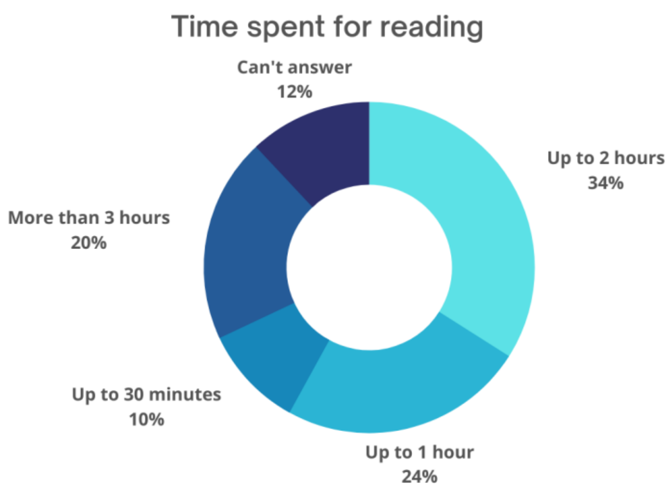

Fig 7: Time spent for exam preparation

We can see that 34% of students have spent about one hour or less (30 or 60 minutes) for the revision and preparation. And 34% of students have spent about two hours.

TABLE II
CLASSES ATTENDED AND HOURS SPENT

Category	30 minutes	60 Minutes
Attended All classes	04	09
Missed 1 or 2 classes	01	03
Total Students	05	12

We can see from Table II that of 5 students who spent 30 minutes for revision had attended almost all the classes. Of 12 total students who spent 60 minutes for revision, 9 had attended all the classes.

TABLE III
HOURS SPENT AND ISA SCORES

ISA 2 Scores (15)	30 minutes	60 Minutes
15	1	2
14	2	2
13	2	3

A feedback was collected from students to understand if the process helped them to think like a problem solver and the structuring of the memory management chapter. The results can be seen in the figures 8 and 9. The feedback for the process is positive.

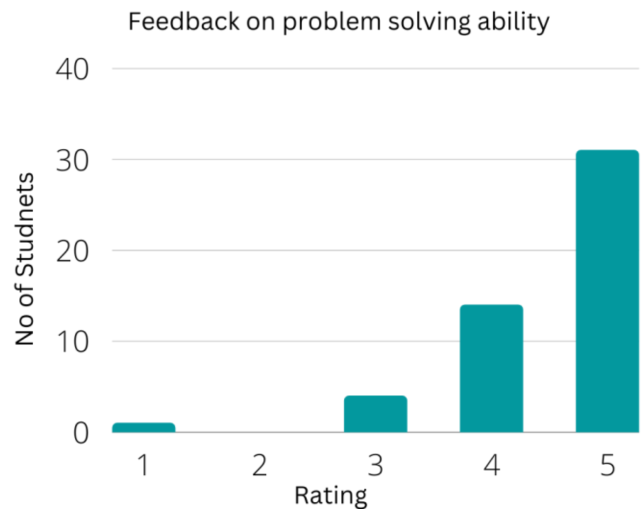

Fig 8: Feedback on ability to solve a problem

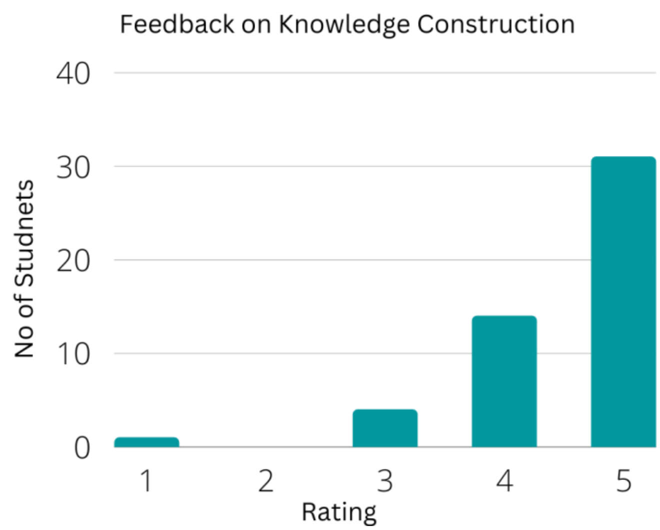

Fig 9: Feedback on knowledge structuring.

Figure 10 below presents that providing the basic knowledge of paging and segmentation helped students to understand easily and effectively. The feedback is given for the question "We first understood the constraints and then designed the hardware tables. This helped me to understand the segmentation and paging better. (In traditional, hardware is covered first)".

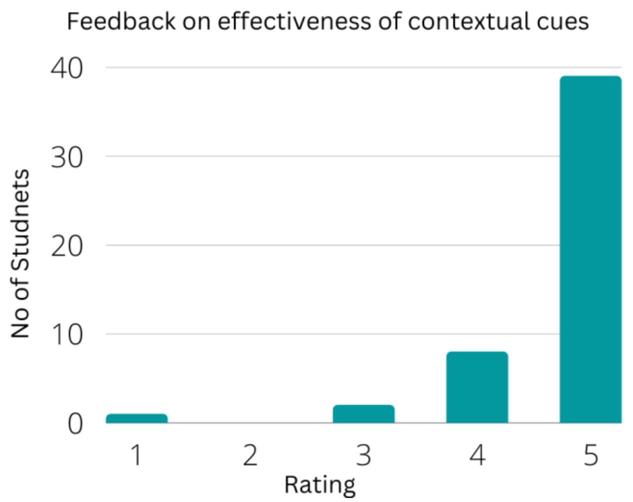

Fig 10: Feedback on the contextual cues.

The method has positively contributed in the process of teaching and learning and also to meet the desired course learning outcomes.

As the model concentrates on the knowledge construction process, most of the activities were individual. Considering the larger classroom size and employed model, the activities designed were short and for 60 to 90 minutes of class duration. The process employed was different from the traditional project based learning methods. As a concept mapped example, memory design was revised first with respect to program execution, than the hardware and software design for generic memory organization for operating systems. The concepts were further followed by segmentation and paging.

V. Discussion

Table I presents the number of students and scores split into several ranges and 29 students from D division were able to score between 13 to 15 which is significantly more than the other divisions where there are 3 to 4 students. B division had lot of active learning strategies employed and hence there is a large portion of class scoring between the ranges 9 to 12.

From Table III, we can see that 5 of the students who spent 30 minutes in preparing memory management chapter have scored 13 or more out of 15 in ISA2 and they had attended almost all the classes. Similarly 7 out of 12 students who spent up to 60 minutes for preparing were able to score more than 13 out of 15. After the end semester examination, only 9 students managed to score more than 90 for 100 and 7 of them were from D division. With the employed method, students who were regular and attentive in class spent less time in revision the concepts and also scored well in the internals and the semester end exams. The feedback received from the students collected by the university on LMS was also more than 98% for the course faculty indicating that students were happy with the approach and assessments methods.

A random sampling strategy was employed and eight students were interviewed by taking the consent seeking feedback for the process. The interview was unstructured and lasted for around 20 minutes for each student. The interview discussions and key points were noted during the process. Students were generally asked about their opinion on the teaching strategy and its effectiveness. The feedback was later coded and following is the summary:

- Syllabus covered in Unit-2, delivery part of memory chapter was appreciated
- The problem-analysis approach was appreciated
- Drawing concept map of entire syllabus helped to get a holistic perspective of the course
- Students expected more sessions to be conducted as few parts were felt rushed
- Students also wanted to know the relation of concepts with other courses
- The process led to understanding than memorization and helped to build a concept context
- The speed had to be slowed for certain concepts
- The overall process was satisfactory and appreciated

VI. Conclusion

Structuring the syllabus with contextual cues and for knowledge construction has a positive impact on problem solving and teaching-learning process. The method promises to be an effective strategy for larger classroom to build and develop cognitive skills. The process can be further generalized to other courses based on the need and outcomes and currently limits only to the courses of the described nature. Using PBL for larger classroom has always been a challenge and so has been the depth to which it can be employed. The proposed model is an effective course level integration of PBL and also a hook to integrate other active learning strategies into the process. Syllabus re-design and taking smaller steps at a time (chapter at a time) also provides space to the faculty to experiment and progress incrementally.

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