The First Step towards a Pre-requisite Knowledge Tracking Architecture for Engineering Programs

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***Abstract*—This work in progress paper presents the preliminary step towards developing a new educational framework titled "Tracking Evolution Architecture of Cognitive Hierarchy Maps for Engaged Classrooms" (TEACH ME). In this paper, we track the scaffolding of the pre-requisites needed in high school level physics concepts and use this information to design the higher-level scaffolding of the same concepts in a university freshmen physics course. This tracking is performed as a meta-cognitive activity inside the classrooms, using a well-established concept visualization tool called "concept maps". Further, these maps will be extended to include higher-level concepts in the engineering courses that have the physics course as a pre-requisite. This paper presents the insights from a pilot implementation of this technique in a freshman physics course. We used concept map as an additional instruction method to aid the students to visually connect the pre-requisite and the newly delivered concepts. This will allow students to understand what they know and what they need to learn. The effectiveness of this method is measured using the data collected from class quizzes and tests. The paper summarizes the initial results from this study along with a discussion on how such earlier maps developed at freshmen level can be extended to higher-level engineering classes for creating engaged classrooms using a novel teaching-learning frame work under development titled "Tracking Evolution Architecture of Cognitive Hierarchy Maps for Engaged Classrooms" (TEACH ME).**

***Keywords*—Concept map; pre-requisite knowledge; learning; engagement**

I. INTRODUCTION AND BACKGROUND

In STEM courses nation-wide, student engagement is a critical issue that affects student retention and persistence. In student engagement, "gatekeeper" courses play a key role. In engineering disciplines, courses such as introductory mathematics, physics and chemistry courses act as "gatekeepers". Typically, these courses have high enrolment and teach fundamental concepts required in higher-level courses. When a student attends these courses, his/her success in the subsequent curriculum depends on the level of understanding on various concepts gained from these foundation courses. Students with weaker foundation from their high school experience more difficulty, resulting in slower progress through the curriculum requirements. In many cases, students repeat the "gatekeeper" courses two or three times. By the time they finally "pass" the course, their academic motivation suffers an irreversible damage. This leads them to drop out or change their majors.

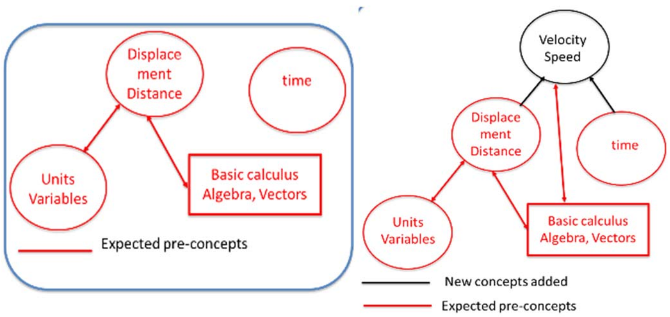
The instructors of the STEM courses assume certain level of pre-requisite knowledge in students so that they can build upon the same; however, its degree of completeness varies with students and depends on several factors. In this research project, we aim to track the scaffolding of the pre-requisites - high school level physics concepts - and use this information to design a higher-level scaffolding of the same concepts in a university freshmen physics course. The essential goal is to understand the 'real standing' of each student with respect to the normal expectation and help him/her to meet this expectation, and to establish an intellectual uniformity of knowledge among the group before teaching a new and higher level concept.

The concept maps, which are established tools in education practice [1-3] are utilized to track the existing level of knowledge in students. Further, these maps are extended to include higher-level concepts in the introductory physics course. This extension is performed as a meta-cognitive activity inside and outside the classrooms. These intellectual maps developed at freshmen level will further be leveraged while teaching connected concepts in higher/senior level engineering/science classrooms. Tracking the evolution architecture of such cognitive hierarchy concept maps from high school to freshmen and to senior level is expected to improve neural connections in students' memory to generate patterns of meaning, resulting in engaged classroom learning [3-6]. The authors are not aware of any prior work that actively engages students to create their own concept maps.

II. METHODOLOGY FOR TRACKING PRE-KNOWLEDGE

Pre-requisite knowledge tracking thorugh concept mapping

The term 'concept map' corresponds to an organized graphical representation of a concept that a student can carry along and can be easily retrieved [3, 5] These concept maps can be used to identify student's pre - knowledge that is required to develop a new concept as well as his/her depth of understanding of that concept [6-9]. Most instructors often begin a lecture by asking simple and relevant questions to the students. The purpose of this interaction is to get information on their pre-requisite knowledge. The proposed TEACH-ME model will document this knowledge level of students through concepts maps as demonstrated in fig.1.



a) *b)*

Fig. 1 Basic steps of TEACH ME approach.a) The basic pre-requisite concept map expected to introduce velocity. b) Hierarchical mapping of concept velocity

In this example, Fig.1*a* indicates the minimum pre-requisite knowledge (pre-maps) expected at the freshmen level physics before teaching a new concept 'velocity'. This requirement is represented as a concept map in Fig. 1*a*. This representation is important to students because it reminds that the new concept needs pre-requisite knowledge for effective learning and class room engagement. It will help them to identify the newer connections appeared in the concept map of 'velocity' shown in Fig. 1*b*.

In this example, the freshmen physics instructor expects that all students in his/her class know all the pre-requisite concepts represented in Fig. 1a such as distance, displacement, time, basic algebra, calculus and the basics of physical quantities and units. However, this expectation is not always accurate. The majority of the students need re-visiting and re-wiring of these elemental connections. If the instructor neglects this critical requirement, further mapping will contain gaps. We propose specially designed tests to track these maps at the beginning of the class so that instructor will know exact standing of each student. These tests are referred to as "Concept Evaluation Tests" (CET). After the first CET, the links of the concept maps are made and graded as follows: Level 0 indicates that the student does not have the basic pre-knowledge to build a new concept. Basic flaws in elementary algebra, calculus, insufficient knowledge in the pre-requisite course etc. lead to level 0. Level 1 mapping indicates that the student is capable of doing simple problems by applying this concept. However, when this concept is applied in a different situation he/she cannot solve it. Finally, level 2 is for maps generated by students who have sufficient pre-requisite knowledge and depth on this concept. Depending on the levels, students will be provided with additional materials to repair or rewire the missing connections. Fig. 2 shows an example of pre-knowledge tracking using CET for the concept 'velocity'.

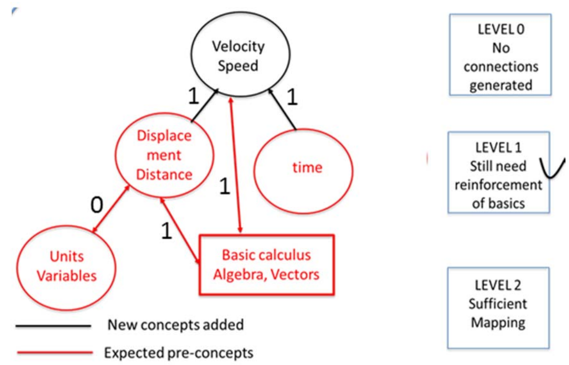


Fig. 2 An example of pre-knowledge tracking using concept evaluation test for the concept velocity

III. INTIAL REUSLTS

For the pilot study, we chose two sections of Physics 301 - the algebra based introductory physics course – one as the treatment batch and the other, control. Both the sections have 25 students each. The textbooks, lecture materials, exams and quizzes, and the exam/quiz dates were kept consistent for both the treatment and control batches. Both the sections had similar office hours and other tutoring facilities. The difference in delivering the lecture between the two sections were subtle – in the treatment batch, the basic concept mapping methodology was employed without naming it as concept mapping or making the students aware of the process as such. Concept mapping was not a rigorous part of the course and this preliminary exercise was meant to evaluate whether any significant differences arise by employing this active learning technique. The instructors established the connections between the concepts delivered on the white board. This allowed the students to establish the link between various concepts that were introduced.

During the implementation of the project, extreme care was given to make sure that the two batches were not too different to stay requirements of the accreditation agencies. Thus the additional exercise for the treatment batch was limited to drawing concept maps or establishing the links between concepts on the board by the instructor. Students also volunteered at times to draw the maps. In addition, the instructor verbally connected the concepts repeatedly in the treatment batch. Since the pre-tests and initial quizzes revealed lack of pre-requisite algebra mastery, algebraic equations that would be used were also presented before problem solving in both classes. However, for the treatment batch, direct links were made on the board connecting the algebra to the problem.

Both sections 1 and 2 had three required tests during the whole semester. At the start of the term, concept mapping was not employed. After the completion of the first two chapters exam 1 was conducted. By then, basic units system and one dimensional motion was covered in class which is a pre-requisite for the upper level concepts. The results of exam1 for both section are shown in Fig. 3. Note that for exam 1 both sections have had identical instruction method. In fact, the average score of section 1 was lower than the control batch. However, this difference was not statistically significant ($t = 1.29$; $t = 020$). With that noted, we started to employ concept mapping in section 1 batch which is the treatment batch.

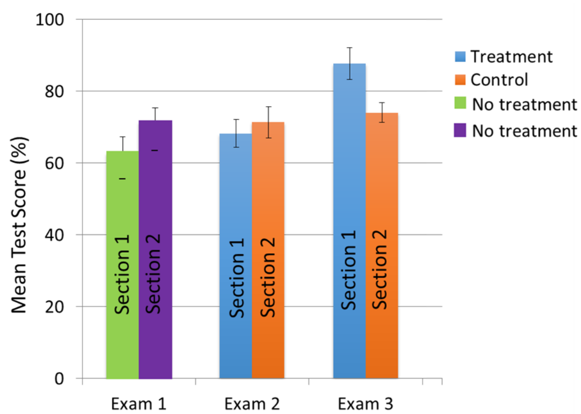


Fig 3. Mean scores in the exams for both the control and treatment batches. The error bars show (±) 1 SE.

As the semester advanced, it was observed that the weaker students in the treatment batch started to advance rapidly. The response from the treatment batch to conceptual questions during the class had much clarity as compared to the control batch. For example, after explaining the concept of elastic collisions, the students are asked to find the final velocities of two balls after an elastic collision (v_1' and v_2'). Since there are two unknowns, two equations that arise from the condition for elastic collision are used to solve the problem. The pre-test and interaction with the students has revealed that majority of students lack the pre-requisite algebra knowledge. Therefore, the instructor introduced solving two simultaneous equations with variables x and y to find two unknowns. After the introduction of pre-concept, the students were asked to find v_1' and v_2'. Majority of the students in the treatment batch were able to connect the physics problem to the algebra and solve for the variables v_1' and v_2'. However, majority of the students in the control batch were struggling with variables and had to make the substitution $x= v_1'$ and $y= v_1'$ to solve the problem. In the treatment group the students had a better understanding of the variables as compared to the control group.

Fig. 3 also shows the results of exam 2, and 3 where section 1 is treated with the concept mapping techniques for tracking and re-wiring, while section 2 is kept in the control mode. As seen in Fig. 3, with the treatment, section 1 is showing significant improvement for exam 3. Even for exam 2, the treatment had reduced average score difference between the two sections, noticed in exam 1 where no treatment has been given. Exam 3 shows significant improvement (t-test for Exam 3 – control vs. treatment: $t = 2.59$; $p = 0.01$) for section 1 with treatment.

Further, to understand how the concept mapping helped weaker students, the progress of the students who failed in exam 1 was tracked through the other two exams. Fig. 4 shows these data. These data show that the improvement in the learning of weak students (measured by their exam score) is significantly better in the treatment batch compared to the control. A pair-wise t-test shows that this difference in improvement is statistically significant ($t = 2.18$; $p = 0.02$).

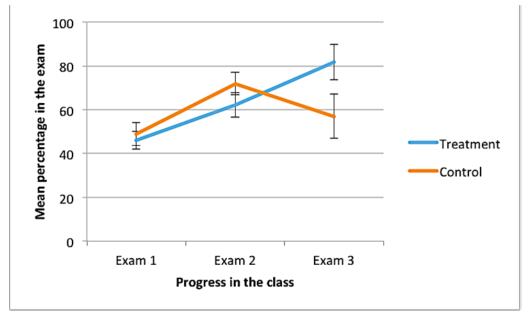


Fig 4. Improvement of exam scores in the treatment and control classes for students failing in exam 1 from Exam 1 to Exam 3. The error bars show (±) 1 SE.

IV. THE FUTURE-TRACKING EVOLUTION OF COGNITIVE HIERARCHIAL MAPS FOR ENGAGED CLASS ROOMS(TEACH ME)

In section II we introduced the novel idea of using ‘concept maps’ for tracking pre-knowledge to help student and the faculty to understand the engagement issues of individual students. Although the preliminary studies reported in this paper consider them as group, tracking of individual concept maps for each concepts and tracking of its progress through higher semesters is our ultimate goal [10]. When these students complete the freshmen physics course to advance to engineering courses, the earlier maps that they have developed will be used as a baseline to start their concept map. Such a tracking of cognitive hierarchical maps of concepts will help them to identify reasons for learning disability.

In the future, we will specifically target the following:

- Evaluation of individual existing concept maps of all incoming students using CETs.
- Giving feedback on their individual concept maps and they are made aware of any gaps in their maps.
- Any weaker or missing connections are repaired before introducing new concepts that build on the original concept map. Short video lectures and/or tutorials are provided to supplement the in-class concept delivery and concept maps. In addition, different levels of practice problems involving virtual lab simulations are also provided to develop meaningful linkage in the maps.

- Once the students are able to build on their pre-course concept map, the instructor delivers new concepts. While delivering each new concept, the instructor makes sure that a connection to any pre-requisite concept in their concept map is established.
- The students are instructed to update their own concept map after each new concept is delivered. This helps the students to understand the links between the knowledge they gained previously and the new concept they are expected to learn.
- After a certain number of new concepts are delivered, class tests similar to the CET' which involves both concept level and problem solving type of questions are employed to ensure the advance of their concept map from the previous level.
- By the end of the course, each student is ready with their finished concept maps and knowledge about what they know (meta-cognitive knowledge about their concept map). The students are also given sufficient training to continue developing the concept map in their next course.
- Development of a framework (TEACH ME) that will allow formal tracking of earlier cognitive maps and use in engineering courses.

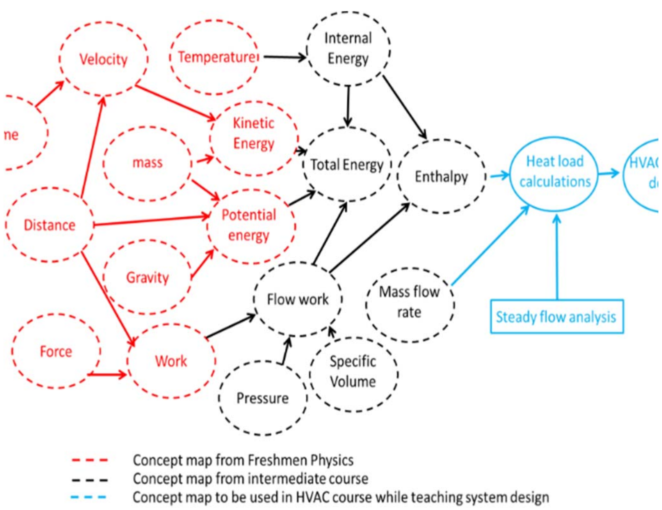


Fig 5. Evolution of concept maps envisioned in TEACH ME framework. Map from freshmen class will be used to design next level connected concepts used in sophomore/junior courses (shown partially for clarity).

In TEACH ME framework each student will carry his/her concept map over to the next participating course in junior and senior year. Tracking of individual concept maps of these selected elementary scientific concepts will help further meaningful evolution of these concepts to higher levels. Fig. 5 represents example of evolution of cognitive hierarchical map of a concept 'heat load' we expected to use in a senior mechanical engineering course HVAC (heating, ventilating and air-conditioning).

V. TEACH ME

We are developing a metthod that promotes healthy interaction between the instructors at different levels (especially freshman physics and engineering faculty) which will help to design suitable cognitive maps of concepts with varied intellectual strength. We anticipate that faculty teaching a concept at higher level can easily recall and access earlier maps that students were exposed, learned and carried along with such collaborations. Connecting a higher-level concept to its foundation level concept will certainly help engaged classrooms and systematic learning. The final concept map carried along for a pre-requisite course will be baseline for teaching advanced levels of these concepts. This will help faculty teaching higher-level courses, especially for students needing individual care and attention and repeated concept re-enforcement. Repeated activation of pre-knowledge and its connection to the current concept will take full advantage of established brain-based cognitive learning theories. Access to earlier maps will help students to learn more complicated concepts by connecting it to the pre-concepts in a systematic manner.

VI. Conclusions

This paper presents initial studies on the pilot implementation of a 'concept mapping' technique in a freshman physics course as a tracking tool to understand the strength of pre-requisite knowledge of students. The 'concept mapping' is performed as a meta-cognitive activity inside the classrooms. The instructor used concept mapping as an additional aid in classroom. Such a mapping technique has allowed the students to understand what they know and what they need to learn. The effectiveness of this method is measured using the data collected from class quizzes and tests. The analysis of the data that were obtained by just including concept maps during the delivery of lectures looks promising. The authors expect that encouraging the students to create their own concept maps and tracking those maps over different courses will deepen the level of understanding among students. The paper summarizes the initial results from this study along with a discussion on how such earlier maps developed at freshmen level can be extended to higher-level engineering classes for creating engaged classrooms using a novel teaching-learning frame work under development titled "Tracking Evolution Architecture of Cognitive Hierarchy Maps for Engaged Classrooms" (TEACH ME). Students identifying the connections between the concepts by answering concept tests will help them to identify their strengths and weakness. The concept tests will be used during the next semester to test and understand the effectiveness of the TEACH ME approach. In the future, these maps will be extended to include higher-level concepts in the engineering courses that have the physics course as a pre-requisite.

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