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Engineering Education Reforms Using Concept Mapping

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Abstract: - An education reform is on the cards. Today's students are increasingly expecting a personalized learning experience that is relevant, authentic and real. They require on-demand skills and knowledge that will enable success in a new world that is global, agile and entrepreneurial. But can current traditional education offering provide such learning opportunities that engage the students' cognitive mind to deliver quality learning that meets the needs of every learner? In an attempt to reshape education to provide a systematic transformation of the education sector into a dynamic, demand-driven system, responsive to the rapid economic and technological advancements, we consider in this paper how to enhance teaching and learning by utilizing concept mapping techniques to provide learning personalization. Harnessing the advancement of technology, we propose a powerful way that adds real value to transforming education.

Key-Words: - Educational Reform, E-learning, Concept Map, Personalized Learning, Research and Education

1 Introduction

One of the most intriguing challenges in education – be it for the academic educators, students, or for the corporate employers, employees and training providers – is how to impart knowledge effectively. From the students' perspective, their main concern is whether they are learning anything that adds to their repertoire of knowledge while for employees, the main concern is whether the training helps in their work. Looking from the employers' perspective, if they are funding the training, it is only fair if a certain amount of 'tangible' return of investment is evident. As for the educators and training providers, they are concerned about how much knowledge their students are acquiring in respect to the long hours that they have invested on the training materials. Hence, learning/teaching effectively is essentially the concern for all.

Acknowledging the importance of imparting knowledge effectively, the next question to ask is: How can we impart knowledge effectively? Before we can answer that, we need to take a step back and think: How can we know what to teach? With the proliferation of information, access to information is never a problem. Literally, the Internet has expanded access to information exponentially. As Chee [1] puts it, "*if access is all that matters, education would be reduced to a trivial matter of simply providing an excellent library then all the learners will get an educated citizenry*". Hence, we advocate that the crucial part to impart knowledge effectively lies not in the provision of information access but on how to provide personalized learning materials. Specifically, 3 crucial tasks are essential. They are the elicitation of (1) what the learner wants to learn, (2) how to dynamically assemble the learning course that starts off from one's prior knowledge and (3) how to personalize the learning instructions according to the learner's constraints and learning preferences.

However, it is difficult, if not impossible, to effectively provide personalized learning materials under our current conventional, teacher-centric, and one-size-fits-all transmission teaching approach. Our educational system is too rigid. We often fail to understand (or rather, we choose to ignore) that students are DIFFERENT, with different backgrounds, knowledge, interests and learning styles. Each student should be treated individually. But our current modes of learning provide little individualization. Every student tends to be provided with the same learning experiences. While this approach to learning works for a few students, many do not learn, or learn only partially. The major learning modes in schools are still lectures and textbooks which provide little individualization.

While the employment of technology to aid education has made a huge impact on both the academic and corporate learning field, it is still very much of a promise unfulfilled [2]. Technology has without a doubt brought learning to new heights. However, most online systems are only translating curriculum approach directly online (except the inclusion of sophisticated multimedia design which is prohibitively expensive). Hence, it is not too surprising to find online materials also following the curriculum approach of treating all students equal.

As this paper stresses, before we can truly impart knowledge effectively, we first need to have an education system that is able to individualize learning materials to the student's needs. However, little such material exists. But there is enough evidence to show that we can prepare such material. The advancement of the information and communication technologies (ICT) coupled with the interactive capabilities of modern computers has laid down great foundation for research to probe into how we can investigate learner's needs and provide apt individualized help.

Considering these issues, this paper investigates how we apply contemporary concept mapping techniques to aid in the individualization of learning support and in the impartation of knowledge effectively. Based on the characteristics of concept maps, three possible areas where concept maps can be employed to enhance education is explored.

This paper is organized as follows: following this introduction a literature review on the current education status, particularly in the area of personalized instructions, sets the foundation for the paper. Next, we discuss the concept mapping technique and explain how concept maps can be used to reform education delivery. The fourth section illustrates our proposed solution, using a system we have developed. Lastly, this paper concludes and presents planned future work.

2 Current Education Status

New technologies, particularly ICT, coupled with the impact of the knowledge economy have put the provision of what constitutes satisfactory education under pressure. Educators are now facing the same challenges that the business community has faced. These include the loss of market share, increased competition, global demands for productivity and quality with diminished resources [3]. In view of how technology has played a huge role in revitalizing business, many have turned their focus to technology and hope it can offer the same revitalizing effect.

Currently, technology has succeeded in revolutionising learning by transcending time and geographical limits to offer on-demand education. It has provided interactive, sophisticated training tools that permit the learners to immerse themselves in virtual worlds. It is fast becoming a way of life for the students so much so that it is now taken for granted.

The tools technology place at our disposal should not define the tasks of education nor should technology shape the students as pointed out in our previous work [2]. However, it has upped the ante for the educational sector and forms a critical pressure point for challenging the dominant assumptions and characteristics of existing traditionally organized universities in the 21st century [4].

Certainly, our current utilization of technology and contemporary pedagogical principles are not adequately addressing the shortcomings of our educational sector. Even with our exploitation of technology for education, there still exists a significant gap between what the learners need and what we can currently provide. In an era characterized by knowledge as the critical resource, constant technological change and time constraints, 21st century students need the flexibility and security of taking responsibility over their learning. Gone are the days where educators should dictate what, how, and when to learn. Students are taking pride in determining and controlling their unique learning roadmap and can no longer accept homogenous learning materials nor leave their education completely in the hands of others.

Notwithstanding the purpose of education to provide opportunities to think critically, the learners of today and tomorrow will face an information-rich environment in which new expectations are demanded. Listed below are some existing problems that future educational offerings should address.

1. Relevancy

In our information-overload situation, it is not surprising that most systems still fail the relevancy test even with the most sophisticated search engines. From the learner's point of view, every additional second spent navigating the learning space is wasted time and effort. Besides the wasted time and effort, it also distances the learner from the solution. Distance creates perplexity and perplexity means less effective learning, frustration and an impediment to learning.

2. Activation of Prior Knowledge

It has been widely advocated that students learn more effectively when they already know something about a content area and when concepts in that area mean something to them and their background/culture [5]. When the learning materials are able to link new information to the student's prior knowledge, they activate the student's interest and curiosity, and infuse instruction with a sense of purpose. However, almost all forms of education (traditional or online) starts off from a common point that is deemed suitable by the educators. The starting point of the lesson takes no learner's prior knowledge into account and assumes that all learners are able to appreciate the content from the educator's point of view. Familiarity is often confused with knowledge.

3. Attention to details

The planning of curriculum today relies on the high level analysis of the education situation. Too often, teaching materials are developed based on broad areas of deficit. For example, if the scores for physics are low, most educators will probably recommend learning physics for a year. This is admirable, but it misses the main point. Knowing that students are generally weak in physics is insufficient as a starting point for planning a course development. Specific information such as the sub-skills or learning concepts that the students lack must first be gathered. It is also useful to conduct analysis of historical data. Some examples are (1) what patterns emerge from historical data? (2) What student performance deficits are eminent? (3) In what areas are students strong and weak? (4) For which type of students are these deficits and strengths most apparent? It is only with such detailed information, then we can make the best educated guess about what are the causes of problems and what solutions we should to adopt.

4. Dictation of learning content

While e-learning proclaimed the ability to let learners dictate how, when, where and what to learn, only the 'when' and the 'where' aspect is currently addressed. The remaining 'how' and 'what' aspects rest heavily on the success of the learning objects (LO) and on the concept of reusability. However, unfortunately, both these concepts are not realized. Existing LOs while modular and portable as compared to traditional learning materials still cannot be assembled on the fly to form meaningful content. Today, there are no known learning materials that are completely reusable. Although there are bits and pieces of content that can be reused, rarely is everything reusable. Rather, most LOs are repurposed rather than reused. Hence, while we are one step closer to our vision of assembling personalized learning materials on the fly, much is still left to be done.

3 Concept Map Theories

In view of the preceding discussions, this paper proposes the usage of contemporary concept mapping techniques to aid in the individualization of learning support for effective impartation of knowledge. As theories pertaining to the concept map theories have been widely documented, this paper will not attempt to make an exhaustive analysis on the act of concept mapping. Instead, this paper looks briefly at three advantages of concept maps because they cut across varied points of view on learning that were subsequently adopted in our proposed methodology. In fact, the combination of the many desired aspects of such learning advantages while not viable in traditional learning can constitute the essential conditions for quality, personalized learning using information technologies.

3.1 Broad Conceptual Understanding

The potential of concept maps as instructional tools will bring the focus of learning to having a broad conceptual understanding of the subject domain. A broader understanding serves as a 'big picture' to present the facts and act as a platform to correlate how different concepts are related. The learning of relationships among concepts will enhance the learning effect as the learners adopt an active, deep and questioning approach to the subject matter [6]. Thus, the use of concept maps will enable the learners to think on a deeper cognitive level, something that the current systems cannot provide. Moreover, concept mapping is an excellent exercise for the promotion of creative thinking and the identification of new problem-solving methods. In theory, concept maps can induce meaningful learning by making explicit the new relationships and concepts among the learned concepts that the learners already know, thus providing a structure into which new concepts can be integrated.

3.2 Visualization

Presenting the visual image of the concepts under study in tangible form aids understanding by making difficult concepts explicit. Besides reinforcing a learner's understanding and learning, visualization of key concepts allows development of a holistic understanding that words alone cannot convey [7]. The minimum use of text in a concept map also makes searching or scanning of concept phrases easy.

3.3 Abstraction

Researchers have found that a concept map can serve "as a means of producing meaningful learning in the analysis of scientific articles as well as enhancing the integration of theory and practice" [8]. It is also an effective means of "bridging the gap between conceptual and procedural knowledge". Depending on the required details, a concept map can be used either as an overview, or a specific level of detail of a knowledge domain. The level of abstraction can also be determined according to the expertise level of the learner where the more abstract logic is presented only to higher order learning. Highly abstract concept maps may even be used as meta-maps linking to subordinate maps, which drill down to greater levels of granularity and specification.

4 System Implementation

This section starts with key terminologies that are employed. The working principles to create learning personalization are also presented. Next, a scenario will be illustrated to step through our arguments.

4.1 Terminologies Explained

[Definition 1] Learning personalization is defined as the process of developing individualized learning programs for each learner with the intent of engaging one in a learning process that is characterized by their prior knowledge, needs and learning preferences.

It transforms the content from the content developer's perspective to that of the learner's perspective. Based on the gathering of information about the learner, the system formats and delivers the right learning contents at the right time to the right learner based on the learner's learning needs. The system caters not only to the learning needs or formats of the content presentation, but also takes in account the learning pedagogy considerations that were discussed in our previous work [9].

Learning personalization is a cross-domain study that involves research issues that cross the domain of Information Retrieval, Agent Technologies and Learning Pedagogy. In our research, learning personalization is formulated based on the concept of learning dependency and is catered for in two stages: (1) Expertise Gap Identification and (2) Learning Preferences and Constraints Customization.

[Definition 2] Learning Dependency is defined as a dynamic cognitive- and pedagogy- centered approach to the mapping of a course structure. It is based on the mapping of a learner's prior knowledge to his targeted knowledge point. Through the concept mapping approach, a learning map of all the possible learning paths from the learner's current knowledge point to his targeted knowledge point is formulated. Learning Dependency thus, maps out a learning map whereby each learning route represents all the prior and essential learning concepts that must be mastered before certain targeted concepts can be learned.

The concept of learning dependency hence establishes some form of a learning sequence; certain pre-requisite concepts must first be mastered before some higher level concepts can be learned. This concept is realized by the application of expertise gap identification that effectively maps out the appropriate learning paths that a learner has to take in order to master certain desired learning concept.

[Definition 3] Expertise Gap Identification is based on the learning pedagogy that students learn more effectively when the new learning materials is based on (or built upon) (1) content area where they already know something about, and (2) when the concepts in that area mean something to them and/or to their particular background or culture. When the system links new information to the student's prior knowledge, it not only aids in the synthesis of the new information into the learner's cognitive structure, it also triggers the student's interest and curiosity, and infuses the instruction with a sense of purpose. The prior knowledge thus acts as a lens through which the learner views and absorbs the new information. The expertise gap identification process is important for three reasons: (1) enhances learning experience, (2) minimizes frustrations and (3) reduces the total searching and learning time.

Thus, in view of the importance of prior knowledge and the ability to dynamically prescribed a training program in reference to a learner's cognitive structure, the first stage in learning personalization is to generate the exact learning paths (based on his prior knowledge) that the learner has to take to master a particular learning concept. In this research, the learning paths are generated based on the elicitation, synthesis and comparison of the Cognitive Map (C-Map), Course Expertise Map (E-Map) and Personalized Map (P-Map).

[Definition 4] Cognitive Map (C-Map) is an externalization of a learner's cognitive structure and records the learner's expertise in each particular domain. An example of a learner's C-Map in a mathematics domain is depicted in Figure 1.

[Definition 5] Course Expertise Map (E-Map) is the real time mapping of the course curriculum that is tailored for the learner. It is populated dynamically based on the system's assessment of the learner's learning needs (through his query). The E-Map, in simpler terms, is the visualization of the results of the learner's query in terms of a concept map form. When a learner wishes to master some learning concept(s), he will formulate a query to search for the related concept(s) in the system repository. The query can take the form of either keywords or key phrases and must be ranked according to the learner's preferences. The query will be parsed by the system search engine to ensure that the learner receives the appropriate courses in the shortest possible time. An example of E-Map is depicted in Figure 2.

[Definition 6] Personalized Map (P-Map) A P-Map is formed dynamically through the analysis of the pre-requisite knowledge that is required to master a particular targeted knowledge that the learner desires. Utilizing the concept of learning dependency, P-Map essentially maps out the possible personalized learning routes that start off from the learner's prior knowledge region. An example of P-Map is depicted in Figure 3.

4.2 Scenario Illustration

The scenario is based on the Singapore Educational System and follows the Ministry of Education learning guidelines (see http://www.moe.gov.sg/). A Primary 6 student encounters a mathematics problem which requires him to compute the ratio between the areas of two triangles. He surfs the Net and manages to find separate course offerings that teach ratio and area. However, the discussion on ratio relies heavily on the concept of percentage and proportion which he has limited knowledge on. Frustrated, he moves on to the course on area but also encounters the same problem as that course assumes pre-requisite knowledge on the topic of geometry. This scenario depicts a typical example of what our education system is offering. While current comprehensive online systems, at best, are able to provide the exact course offering, these systems cannot tailor the course according to the learner's expertise. Take for instance, if another learner takes a course on the theory of stability but does not understand the concept of "differential equations" (a core concept underlying the theory of stability), he will not only be lost in the discussion but will also be frustrated and disillusioned with his own learning capabilities. This is one of the reasons why students participating in online courses have expressed feelings of isolation, frustrations and lack of self-direction. However, even if the learner takes on a high level of responsibility and initiative in his learning to search for the concepts that he does not comprehend, this searching process can be tedious and time consuming. Besides, the constant reviewing and searching of such 'internal' incomprehensiveable concepts will distract the learner from his learning motivation.

On the other hand, given a knowledgeable learner who is already equipped with some of the stability concepts, the static course structure does not offer the flexibility to remove such 'already-known' concepts. Thus, the learner will still have to tolerate the sequential flow of the course and follow through the entire section of the prescribed training program even though the underlying concepts to be taught are already mastered. This, while increasing the learning time, does not take the learner any further in his pursue for the knowledge desired.

Our system is, however, able to minimize, if not eliminate, such problems through our novel method of learning dependency. Using the primary 6 student as an example, when he registers in our system, the system using our expertise population language is able to effectively map out his current expertise. A section of his C-Map as depicted in figure 1.

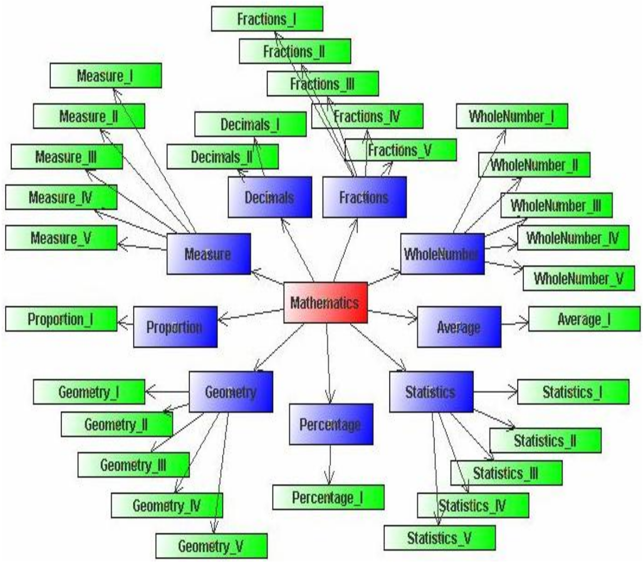

Figure 1: Cognitive Map (C-Map)

His search query on the concept of Ratio and Area will generate the E-Map as shown in Figure 2.

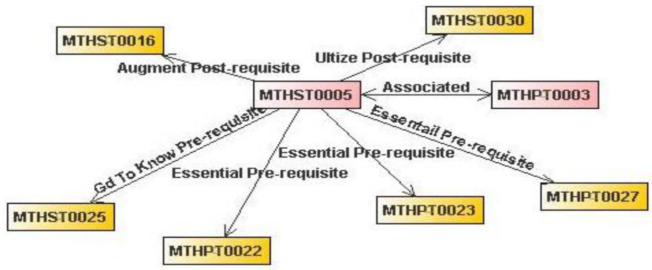

Figure 2: Course Expertise Map (E-Map)

The learning concepts that the student requests are contained in courses highlighted in red; the concept of ratio will be taught by course MTHST005 while the concept of area will be taught by course MTHPT0003. Besides showing the requested courses, the external relations are also shown (in yellow). For example, MTHST0005 requires 3 essential pre-requisites courses (concept of proportion II, percentage II and measure VI) to be covered first. It is also linked to a good-to-know pre-requites concept. While good-to-know pre-requite concept is not essential to understand MTHST0005, it can enhance the understanding of the course. Post-requites and associated courses are also depicted. These related courses while not essential to master the requested concepts, can provide the student with a broader conceptual understanding. Besides, it also gives the student the luxury of augmenting his understanding on the current learning concepts later at his own convenience.

Based on a comparison between the C-Map and E-Map, a personalized learning path that starts from the student's prior knowledge (blue) can be mapped.

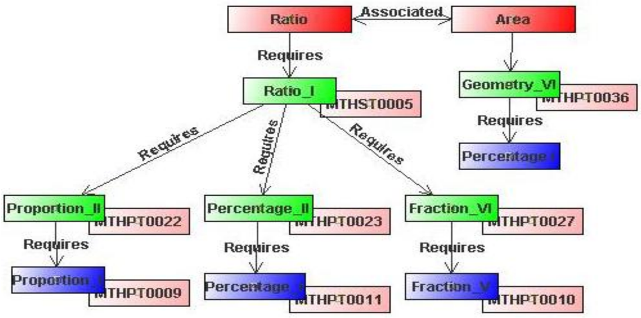

Figure 3: Personalized Map (P-Map)

In the system, instead of taking courses that contain the requested learning concept (red) as per current education practice, learning is brought 'backwards' in the sense that the starting point of the training is traced all the way back to the student's prior knowledge (blue). Hence, instead of taking course MTHST0005, the student should first take courses MTHPT0022, MTHPT0023, MTHPT0027 before attempting the higher-level courses. Alternatively, the student can also revisit the courses that they have previously taken for recap purposes; i.e. MTHPT0009, MTHPT0011, MTHPT0010.

For discussion sake, only a single learning route is presented. The actual system is able to recommend different learning routes as some concepts can be covered by more than 1 course offering. Also, each learning route is characterized by (1) number of courses, (2) expertise level, (3) total cost, (4) total time, (5) style of content presentation and (6) dominant learning preference. Hence, based on the learner's learning preferences and constraints, a variety of training routes can be recommended.

5 Conclusion

For educational purposes, we rarely treat information resources in a uniform manner or read a course in its entirety. Often, we need to reference information at sub-course granularity. Through our example, we show how important it is to dynamically assemble learning resources at a sub-course granularity level. This means that instead of linking courses-to-courses, we go a level down by linking concepts-to-concepts. While the learning path is still based on course offerings, the expressive nature of concept maps can be further enhanced through the superimposed learning concepts structures. This, we believe, is an essential step to bring personalization to the educational arena as we advocate that a learner's cognitive structure can be externalized in terms of learning concepts-concepts links. Hence, as we exploit reuse at a sub-course granularity, we can elicit a personalized learning path that starts off from one's prior knowledge.

Research effort will be ongoing to revise the system design to include new research methodology to personalize learning. We also aim to work towards benchmarking our system so that we can have a standard method to evaluate the effective of our system. The system has also been scheduled for piloting in an academic institution to fully validate our arguments.

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