A Knowledge-Driven Model to Personalize E-Learning

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This article highlights basic issues that have hindered e-learning systems from becoming the revolutionary force it could be for education. While current systems aim to foster significant improvements in learning, this article argues that most systems are still limited to just being online repositories. This and the lack of learning personalization has become a topic for research. A knowledge-driven model to personalize e-learning is proposed in this article. A novel methodology for eliciting and personalizing tacit knowledge is presented. We focus on describing the complex information processing in terms of knowledge, rather than the details of its implementation.

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Additional Key Words and Phrases: e-learning, concept map, distance learning, instructional design, knowledge management

1. INTRODUCTION

E-learning, by virtue of its unique distributed, asynchronous nature, shows much promise for fostering significant improvements in accessibility and opportunity to learn. It couples advances in technology and the advent of the information highway to eliminate barriers of time, distance, and socioeconomic status, thereby creating a whole new dimension of learning. Because e-learning can transmit knowledge fast and effectively, many people accept it as a means of upgrading themselves and keeping up with the rapid changes that define the Internet.

However, with all of e-learning's promise and the research effort spent on it, a literature review has unveiled major concerns about its effectiveness and appropriateness [Lytras and Pouloudi 2001; Polsani 2003]. Without a universal standard for online learning and teaching, many organizations are jumping into the arena and proclaiming their systems as "e-learning-compliant." But actually these organizations are only automating their services and delivering their courses online. Except for the elimination of the time and space barrier, the online content provides no additional enhancement to the educational learning experience. Even the most important aspects of e-learning (i.e., reusability and learner personalization) are not realized, as these organizations are developing e-learning resources to suit their own contexts and using tools (restricted due to their proprietary nature) that hinder collaboration and reuse.

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More importantly, instead of designing reusable and learner-centric content, many developers are placing too much emphasis on the technology aspects of e-learning [McCalla 2004]. This has lead to an unfortunate situation where most content developers are now more concerned with showcasing their technology-enhanced products, showing little interest in enhancing the "knowledge aspect" of e-learning, which should be at the heart of it.

In fact, considering the fact that human interaction is now being minimized, the design of instructionally sound e-learning subject matter should be given even more importance (as compared to traditional classroom learning. Hence subject matter has to be more informative, and also intuitive enough, to stand on its own, without the need for further interpretation. This worrying trend, that is, the emphasis on technology, combined with the dramatic growth in access to ever burgeoning amounts of information, has made it crucial to find a more refined definition of what constitutes knowledge in the e-learning context. It is important to note that information on the web is not really knowledge. What is done with this information will make it knowledge.

A novel system that makes use of a knowledge model to facilitate continuous dialogue between knowledge and e-learning is proposed in this article. This system seeks to create as a prototype a knowledge environment that represents the semantic web version of e-learning. This view is clearly reflected in the EU-NSF Strategic Workshop Report 2001, where it is observed that e-learning, even when properly designed and meta-tagged, will not realize full reusability without the full benefits of the semantic web.

The semantic web is an extension of the current web, whereby information is given well-defined meaning, to enable computers and people to work cooperatively [Berners-Lee et al. 2001]. It is simply a web whose content can be understood and processed by computers or software agents. It can be thought of as an infrastructure for supplying the web with formalized knowledge, in addition to the current informal content. The semantic web aims to complement the web in areas where formal knowledge can be useful.

Besides exploiting the advantages of the semantic web, our system strives to close the gap between knowledge management and e-learning via the combination and integration of different knowledge components. A concept map [1] approach will be adopted to visualize knowledge representation, as well as to illustrate how the personalization of learning can be achieved. The methodology on how to convert knowledge into learning resources will be fully defined and modeled in a learning continuum.

This article is organized as follows: First, research issues on current limitations in e-learning and the role of knowledge in e-learning are discussed. This is followed by an extension of our previous work on concept maps [Teo and Gay 2004a; 2004b; 2006a; 2006b] to include knowledge management issues like knowledge representation, visualization, and the concept of learning dependency. Next, the learning continuum comprising data, information, and knowledge resources are discussed. This article concludes with an overview and a practical architecture for the knowledge system and future research.

2. RESEARCH ISSUES

The internet and the web can be credited with transitioning the world from being information deprived to being besieged by it. Its widespread adoption has spawned a

[1] The concept map is exploited as a visual representation of the subject matter; it enables the sharing, exploring, gathering, and synthesizing of knowledge.

mass of information. But the proliferation of machine-readable information, coupled with advances in technology, has created an illusion that e-learning is purely technology-enhanced learning via the internet. Currently, many readily available web items, or "shovelware" (i.e., traditional paper-based materials mounted directly on the web in digital format [Rosenberg 2001]) are often touted as learning resources. Although it is possible to find excellent content on just about any subject on the web, e-learning, unlike online training, is much more than simple assimilation of internet information. However, as a paradoxical consequence, the growth in information technology triggered an information explosion that simultaneously spread and often distorted information, making its value unpredictable.

The e- before learning has also misled many. Although the introduction of information and communication technologies into education has improved the learning process, aided in building our knowledge base, and increased our multiple intelligences [Gardner1999], the technologies should be seen only as vehicles for delivering learning content. E-learning should be more than just a collection of technological solutions. For instance: an e-learning solution however sophisticated, using stylish multimedia delivery, should focus on enhancing the learning and intellectual interaction at the cognitive, behavioral, and physiological levels. Any technology is pedagogically neutral and can therefore be applied to different aspects of pedagogy. The educational approach or philosophy is more important than the selection of the technology itself; pedagogical methods utilizing even the simplest technologies can be extremely effective. Unfortunately, this is not the case in most existing e-learning systems, as technology considerations seem to take on a more important role than pedagogy.

Another impediment to the successful adoption of e-learning is the lack of learning personalization. The learner-centric aspect of e-learning is often neglected. Current courses although online and automated, are still delivered within the boundaries established by the subject matter experts (SMEs[2]), who play the role of both the director and dictator of the learning experience. Most e-learning systems are focused on what the SMEs offer, despite the imperative that e-learning should be learner-centric. The learning paths are still rigid and restricted. A minimum or no learner's preferences are being taken into account. For example, once the learner is enrolled in an e-learning course, the learning will become passive and all the learner has to do is to simply follow the prescribed paths through the whole courseware (dictated once again by SMEs) right from pre-assessment to post-assessment. This style of learning brings us back to the days of traditional classroom learning, except that the learning now takes place online instead of being restricted by place and time. The tendency to simply replicate traditional structures of classroom teaching and to make the instructions online adheres to what Barr and Tagg [1995] refer to as the *instruction paradigm*. While the instruction paradigm (or the SME-centric approach) may be appropriate for traditional classroom learning, the "distance" component in e-learning makes this approach to instruction less effective [Chee 2004]. Effective learning must produce deep understanding, not merely knowledge reproduction. Hence, with most e-learning programs organized around the needs of the SMEs, the learners are left to tolerate the homogenized, standardized subject matter.

Another problem is that most if not all the courses are still being offered within the time frame of an academic semester, without consideration of the learners preferred pace

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[2] SME is a person who understands the skills and knowledge the learner needs to meet a learning objective. The SME will understand the best practices, strategies, and approaches to learning a concept. SMEs will be the advisors and sounding boards during the design phase and subsequent phases of a project.

and expertise. Hence, there is an obvious disconnect between the learning needs of today's learners enrolling in e-learning courses and the traditional, instructor-directed models being used to deliver them. Moreover, "online delivery" is often motivated by "economical and technological factors" rather than by the possible learning benefits associated with e-learning [Sarker and Nicholson 2005]. This, together with the limitation of current platforms in transcending the linear, sequential searching and viewing of learning resources, hinders the widespread progress of effective e-learning.

Based on the preceding discussion and vision[3] for e-learning, our research effort has been directed towards the design of a new knowledge-driven model that is intended for personalized e-learning.

3. KNOWLEDGE PERSONALIZATION AND VISUALIZATION

The essence of e-learning lies in knowledge management [Ronchetti and Saini 2004; Kostas et al, 2002]. The ever-increasing importance of knowledge in our contemporary society calls for a shift in thinking about innovation in e-learning. It is not the information that has value. Information is abundant, and even excessive, due to current advances in information and communication technologies. Instead, what is of value is in the meta-information. That is, knowledge of the type of information, when it is useful, what to do with it, and how to reuse it. Therefore, the heart of e-learning that we envisage lies in how the system defines and manages knowledge content. Most importantly, the future direction of e-learning should be shifting from a content-oriented approach to a knowledge synthesis approach [Gay and Teo, 2006]. Knowledge management is crucial, but beyond that there are two other distinct tasks of concern to the system: facilitating the creation and synthesis of new knowledge and managing the way people share and apply it. Thus, the first step towards achieving knowledge synthesis lies in the formulation of a methodology to formally define what constitutes knowledge in the e-learning context. In this article, learning continuums that define the various knowledge stages crucial to the synthesis process are addressed in Section 3.2.

Besides defining knowledge and casting its structure, it is important to address knowledge personalization and visualization in our e-learning context. In addition to providing explicit representation of knowledge, it is also crucial to tackle the problems of knowledge personalization. In this article we attempt to model and personalize the knowledge resources via concept maps. The potential of concept maps as instructional tools and learning personalization via use of concept maps has been proposed previously [Teo and Gay, 2004a; 2004b; 2006a; 2006b]. This article further details the augmentation of the approach and introduces a knowledge model to enrich the learning experience by creating a platform to provide continuous dialogue between the learners and the knowledge resources.

Concept maps will be used as the graphical representations of knowledge to depict both the learning concepts and the salient relationships between them with a human-oriented approach. Graphically, concept maps consist of nodes and labeled lines that represent some important aspect of a learner's propositional knowledge in a subject domain. While it is graphics-based, natural language sentences can be readily extracted, hence this expressive power and its closeness to natural language make a concept map-based system robust. However, the expressive power of a concept map and its flexibility comes at the expense of formality. So to address the trade-off between flexibility and

[3] Vision in e-learning is to achieve an innovative approach for delivering electronically mediated, learner-centric, and interactive learning environment to anyone, anyplace, anytime by utilizing the Internet and digital technologies in concert with instructional design principles.

expressive power, we adopt a modified concept map approach that incorporates a learning continuum as a form of knowledge modeling. The learning continuum models the type of knowledge structures and relationships within which e-learning content resources can be held and reasoned with. This involves explicitly defining the type of structures that can be used as a template to store knowledge resources. One crucial decision to be made when building the knowledge model is the characterization of what types of knowledge fragments constitute a learning product.

While the learning continuum models the type of "knowledge" in the system, the modified concept map-based knowledge model makes use of the visual aspect of concept maps to depict, visualize, and manage the structure of the knowledge rather than the knowledge itself. In terms of visualizing, the knowledge structure is not so much a map of knowledge but a roadmap of how the SMEs acquire new knowledge and synthesize it into their existing knowledge map. More accurately, the knowledge structure for each domain should be seen as an externalization of the experts' cognitive structure. Technically, these knowledge structures can be seen as a form of visualizing the SMEs' tacit knowledge, a term coined by Polanyi [1958; 1962], who encapsulated the essence of tacit knowledge in the phrase "*we know more than we can tell.*" Although subject to much controversy, we find it convenient to classify knowledge into two forms, tacit knowledge and explicit knowledge.

We see tacit knowledge as highly subjective in nature, as it is developed by an individual based on his cognitive and conceptual models of external processes. This type of knowledge is often difficult to identify, quantify, formalize, or communicate to others as it is largely unspoken and implied. Explicit knowledge on the other hand is knowledge that is objective in nature, easily expressed, and shared because it can be tested rationally through repeated use over time. While explicit knowledge takes on characteristics of theory and serves as instructional content, tacit knowledge is deeply embodied in the SMEs' cognitive structure and is, therefore, not publicly available.

Although tacit knowledge seems to be only an expression of personal interaction processes, this knowledge when transformed into organizational knowledge and expanded through the whole organization will become an extremely important aspect of learning. The elicitation of tacit knowledge takes on an even greater significance in the context of e-learning as communication between the SMEs and learners is minimized. Contrary to the assertion that tacit knowledge is manifested only in application, is not amenable to transfer [Grant 1997] and can only be represented through nonarticulated knowledge, we believe that under certain circumstances, certain parts of an individual's personal knowledge and expertise can be modeled and explicitly transformed into concept maps. In practice, the system sees the tacit and explicit dimensions of knowledge as inexorably and inextricably interwoven. Thus, although there is always more that is embedded, implied, assumed, and presupposed than can ever be externalized and made explicit, this article agrees with Davenport and Prusak [1998] that "*the more rich and tacit knowledge is, the more technology should be used to enable people to share that knowledge directly. It's not a good idea to try and contain or represent the knowledge itself using technology.*"

Hence, in this section, we propose designing a system that uses a modified concept map approach to model aspects of tacit knowledge into either business or technical processes or procedures. Through externalizing this knowledge, a methodology is developed to achieve learning personalization.

3.1 Tacit Knowledge Elicitation and Personalization

Tacit knowledge exists randomly in society and is related to the context of a specific problem. So the first step in eliciting tacit knowledge is to categorize the tacit dimensions of individual knowledge into different academic domains. The tacit dimension of individual knowledge will first be modeled informally in a T-model that is based on a modified concept map approach. The T-model is a set of finite elements (process, procedure, functions, logical operators, unidirectional or bidirectional arcs) defined in a particular order. Mathematically, the T-model is characterized as a universal set that represents any complete model of a business or technical process or procedure. It is comprised of seven-tuples {S, E, F, O, M, A, R} with the following properties:

T-Model = {S, E, F, O, M, A, R} such that

- S is a finite sequence of steps to be followed by one individual to accomplish a task or to make a decision. This sequence of steps forms a procedure. A procedure contains directions or procedural tasks and contains actions that are done the same way each time.
- E is a finite flow of events that describes how something works. The flow of events forms a procedure. A procedure is not necessarily a task done by one person; many people or an organization may be involved.
- F is a finite set of functions.
- O is a finite set of operators (logical and comparative),
- M is a special function that maps each operator onto an operator type, such that the function M : F (o) is the type $o \in O \rightarrow \{ \oplus, \wedge, \vee, \leq, \geq, \equiv, \neq, \langle, \rangle \}$ of an operator type.
- A is a finite set of arcs (bidirectional and unidirectional) connecting procedure (S), process (E), operators (O), and functions (F) where: $A \subseteq [(S \times S) \cup (S \times O) \cup (O \times S) \cup (S \times F) \cup (F \times S)] \cap [(E \times E) \cup (E \times O) \cup (O \times E) \cup (E \times F) \cup (F \times E)]$ is a set of arcs.
- R is a finite set of relationships between the concepts and can only take on the following values: is associated with; is part of; is cause of; is composed of; contradicts; is an example; is a; leads to; is property of; utilizes.

The definitions above are the formal bases of our methodology and define any basic T-model. For example, as depicted in the definition of A, it shows that modeling both process and procedure in a single model is contradictory to our methodology. It is important to note that while R limits the relationship diversity, and hence the T-model's flexibility, this tradeoff is necessary, as a more formal definition of the model is required for comparing knowledge and the synthesis process.

In this initial, exploratory effort, the T-model only covers the elicitation of tacit business or technical process or procedure. The properties, S( ) and E( ), are targeted to describe, respectively, the procedures and processes on the logic abstraction level. The T-model makes use of these two distinct properties to model the control flow structure of a procedure as a chain of steps, functions, and operators, or a process as a chain of events, functions, and operators.

These two terms, borrowed from the publication called Reusable Information Object Strategy [Barritt and Wieseler 1999], aim to capture tacit knowledge on enhancing job performance. A procedure T-model is used to capture the sequential set of steps that a

SME would take to accomplish a task or make a decision. Given a particular situation, the actions within a procedure will be done the same way each time. A process T-model, on the other hand, is used to capture the "tacit" flow of events (seen through the eyes of the SME) that describes how something works. From the T-model, important conceptual structures among the data sets that are identified will be restructured and formalized through the use of formal concept analysis (FCA) [Cole and Eklund 1996; Ganter and Wille 1999].

FCA is a method of data analysis, knowledge representation, and information management is strongly based on mathematical theory, but its impact, success, and wide application cannot be explained solely by its mathematical nature. FCA can also be used to encapsulate and process the philosophical basis and social consequences of a concept. It follows naturally that these capabilities can also be extended to include rational communication, representation, and processing of knowledge. While FCA as a tool for knowledge representation and the discovery of knowledge has been proposed by many researchers (see, for example, Valtchevet al. [2004] and Wille [1992]; research linking FCA and e-learning has not been studied extensively).

We propose to exploit the FCA's rich mathematical semantics, couple it with our modified concept map approach, and extend its application to e-learning. Utilizing the FCA to produce visualizations of inherent data structures and its focus on the human-centered approach, the system extracts the implicit data structure from an SME's tacit dimension and characterizes it for external cognition. Using the T-model as an input to encourage the discovery of tacit information, FCA will be applied to the T-model through a restructuring process to facilitate the conversion of information into knowledge by converting the T-model into a T-map. The application of FCA on the T-model is necessary, as the T-model, which is based on our modified concept map approach, is not elaborated mathematically or formally enough to facilitate knowledge synthesis. Thus, FCA will be applied to "restructure" the concept map as well as correlate the salient concepts (fact, principle, and concept) into machine-readable and, more importantly, machine-understandable statements, which will be crucial when the system performs knowledge synthesis or inference.

With the basic framework of salient concepts and relationships realized, the explicit knowledge that is modeled in the subject domain master map (M-map) can be hyperlinked to each knowledge node in the T-map. The M-map will be formulated on the concept of learning dependency, which is defined as a dynamic cognitive- and pedagogical-centered approach to the mapping of a course structure. It is devised from the fundamental principles underlying both cognitivist and constructivist theorems that place utmost emphasis on the internal mental processes of the learner's mind and how it can be utilized to promote effective learning. Learning dependency relies on the explicit elicitation and externalization of the learner's cognitive structure. Such an explicit elicitation represents the learner's prior knowledge. Through a mapping of the learner's prior knowledge to his targeted knowledge point, a learning map of all the possible learning paths from the learner's current knowledge point to his targeted knowledge point can then be formulated. Thus, learning dependency establishes a learning sequence which states that certain prerequisite concepts must be mastered before higher level concepts can be learned. For example, in the control engineering domain, to fully master the concept of stability, the Routh-Hurwitz stability criterion, relative stability, and stability of state variable systems concepts must first be acquired (*MathWorld*, a Wolfram web resource). Each concept is depicted as a learning node in the M-map and contains the full and complete (explicit) knowledge that is required to comprehend a learning concept.

Essentially, the T-map will capture the required knowledge (tacit and explicit) for comprehending a particular business or technical process or procedure. The essence of our methodology lies in first extracting the tacit knowledge (usually part of the SMEs' accumulated learning process) into a subjective T-map, where the proximity and connectivity of concepts will provide the structure for effective ways of searching and viewing learning resources. The manifest of the T-map (nodes and relationships) will be used to enable a more systematic and scientific understanding and learning process.

With the T-map and the M-map manifests, learning personalization can be executed using agent technologies. Personalization is done in two stages. The first generates the exact learning paths that the learner must take to master a particular concept. These paths will be generated dynamically based on the learner's current expertise (via mapping his cognitive structure) and the expertise that is to be acquired. Initially, each new learner will be given an empty academic record categorized by the subject domains offered by the system. Each domain is an externalization of the learner's cognitive structure (C-map). The C-map, which initially is empty, will be filled with each successful acquisition of knowledge (by completing the post-assessment). Thus, an exact learning path can be mapped easily by comparing the M-map to the learner's C-map. The next stage is to select the type of learning approach by which to present the content. As a learning objective may be realized with different content structures and different assessment styles, based on the Index of Learning Styles (ILS), the system will have to dynamically match the learner's preferences to the ILS and select the type of learning experience that best suits the learner. In addition to learning style customization, other personalization considerations include constraints on the learner (cost and temporal restrictions) and the format for abstracting the content (overview-offering, minimum-effort-offering, or detailed-offering). The personalization variables are initially provided by learners (via learning profile surveys and empirical reasoning). However, the variables are constantly monitored by the learner's mentor (agent), who will alter the variables dynamically according to changing learner demands. While the system dynamically personalizes the course presentation style, based on the learning mentor's inputs, the learner can override these inputs at any time to suit his learning demands.

The following steps illustrate a typical learning scenario that describes how learning personalization is done when a learner wants to enhance his knowledge on a particular business process; this learning scenario is also depicted graphically in Figures 1 and 2.

(1) The learner's preset preferences and constraints will be retrieved once he logs in;
(2) the learner uses the domain-specific ontology to search for the business process that he wishes to master;
(3) the T-map that depicts the business process is retrieved;
(4) based on the T-map, the system identifies the number of learning concepts (and their respective domains) that must be mastered;
(5) the learning concepts are sequenced into a P-map via the concept of learning dependency;
(6) the C-map that stores the learner's expertise in the specified domain is retrieved next; the C-map is then compared to the P-map to identify the learning concepts that have not been mastered. The learning concepts represent all the knowledge points that the learner has to master;
(7) then, the first learning concept that is mastered is selected and assigned as the first partial-end point of the personalized learning path (EP_1);

(8) the system will search and retrieve the entire M-map that the first concept resides in, limited to that specified domain;
(9) the next most immediate prerequisite concept in both maps will be selected based on comparing the C-map and M-map and the theory of learning dependency. This concept, which represents the learner's current knowledge point, is assigned as the first partial starting point of the learning path (SP_1);
(10) the system will then route dynamically and provide all possible routes from SP_1 to EP_1;
(11) the system will then retrieve the learner's preferences and pick the presentation approach (based on ILS) that best suits the learner's preferences; and
(12) finally, the routes allowed will be presented to the learner, limited only by the system's restrictions (e.g., course fees or SME recommendations) and the recommended scope.

Once the first concept is mastered (successful completion of the postassessment), all the prerequisite concepts that the learner has understood will be recorded in his cognitive structure. The next learning concept will be selected and steps 6 to 12 will be repeated. The learning process will cease once all concepts in the entire business process are mastered

The routes are displayed as a metaconcept map (P-map). That is, any node selected in the P-map will act as a hyperlink and bring the learner to the beginning of either a course or a module. When the node is hyperlinked to a course, the course concept map is presented. Now the learner can begin the learning process by selecting the course nodes that will bring him or her to the personalized module. On the other hand, if the node of the P-Map corresponds to a module, the learner can immediately begin personalized learning by clicking on that node.

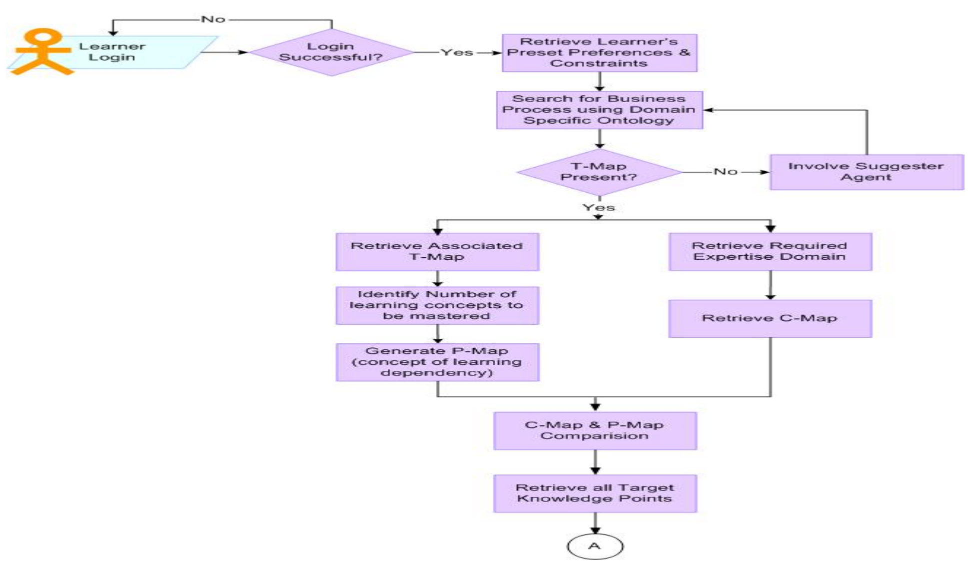

Fig. 1 Learning scenario (target knowledge points identification flow).

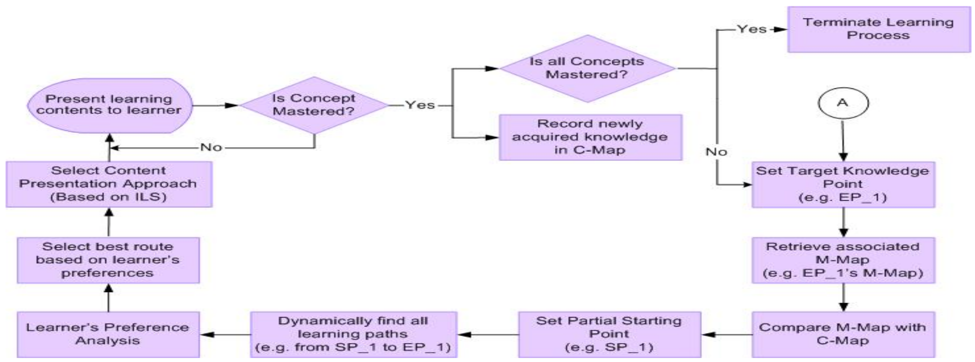

Fig. 2 Learning scenario (personalized routes flow).

Each concept and relationship in the M-map represents the standard for a particular piece of knowledge in a particular domain, i.e., expert-level knowledge gathered from experts in a subject domain; a level that the system aspires to impart to the learner. However, requiring every learner to possess perfect in-depth knowledge of a concept might not be necessary or practical. Instead, most learners are only interested in an overview of a subject domain, and thus the requirement to completely master all the pre-requisite concepts before moving on to others might be more of a constraint than an advantage. Thus, depending on the learner's expertise and learning objectives, different types of constraints and requirements will be personalized and imposed.

3.2 Learning Continuum

The learning continuum is used as a form of knowledge modeling. Although learning is more accurately depicted by its progress from signals → data → information → knowledge → "wisdom," it is actually a continuum with many grey areas and there are often overlaps between the levels. Even though it has been widely acknowledged that each continuum level is not the same (especially between data, information, and knowledge), many researchers still use these terms casually. Besides the lack of proper definitions, the relationships between the terms create yet another intricate and challenging area of intertwined and interrelated concepts. Their relationships are often portrayed in an oversimplified image of linear relationships (see, for example, Ackoff [1997] and Choo et al. [2000]).

In our work, both the learning continuum levels and their relationships are formally defined. In the context of our knowledge model, some of the overlapping areas of the general learning continuum are combined to present a learning continuum that is made up of three distinct levels: data, information, and knowledge. The grey areas that still exist between the three knowledge levels will be eliminated by proper definitions and boundaries for each level.

3.2.1 *Data Resources*

Data resources are defined as a collection of raw representations of facts, concepts, or instructions in a formalized manner suitable for communication, interpretation, and processing by humans and computational methods. The representation can be integers, real numbers, strings, characters (including mathematical symbols), or analog quantities to which meaning is or might be assigned.

Data is the most primitive form of "knowledge" in the system, and often exists as a single mass entity without any relationship to other data, context, or logic. Raw data is usually of little or no use when it exists by itself, and thus is often used in combination with other data to establish a basis for reasoning, inference, discussion, or calculation at the second level of the learning continuum. Operations can be performed on the data to obtain or derive substantial (new) meanings from the raw content.

In the context of e-learning, a data resource is the smallest granule in the knowledge synthesis process. In our knowledge model, the data resource is also termed a reusable asset object (RAO), and is stored as the most basic form of knowledge building block (structured records of transactions) in the database.

3.2.2 *Information Resources*

Information resources are defined as a collection of data in which no explicit semantics is assigned. It acts on the (primitive) set of RAOs to derive a meaningful flow of messages that can be organized to describe a situation or condition. Compared to RAO, information resources is more informative, as it supplements the data with meaning, relevance, and purpose. However, it is constructed without engaging or considering the intended audience or context, and so is seen as a form of presentation that aims to inform the mind about something. As such, different conclusions can be drawn (from the same set of information resources) by the learners, who will interpret the information based on their own understanding of the presentation. Hence, the information's relevance and purpose are not unique (as it is not housed in a particular context), and there may be multiple interpretations of the same set of information resources.

In the context of e-learning, each of these information resources is termed a reusable information object (RIO), which is the most useful reusable fragment in the development of knowledge. RIOs guide knowledge generation and sharing, and as a form of meta-information, RIOs are stored in the database.

3.2.3 *Knowledge Resources*

A knowledge resource is defined as any information that is acted upon cognitively in a conceptual framework. As opposed to a RIO, which is context-free, a knowledge resource contains a piece of information in a specific context. The context and the use of ontology create a formal and explicit specification for a shared conceptualization of a domain. Thus, knowledge resources give a formal description of what terms and relations in a particular domain mean. The formal description is machine-executable, and hence enables easy manipulation and knowledge synthesis for other cognitive learners.

Knowledge resources are formed by wrapping the RIO in an interpretative context to associate a piece of information with a subjective and undisputed meaning (based on the context). The value of the knowledge resources resides in the relationship between the contents of information and subject. On its own, a piece of information is useless, but when it is coupled with context and customized to a learner's perspective, representational reasoning and knowledge synthesis are enabled. With knowledge synthesis, new knowledge can be inferred from existing knowledge. It is an important factor that places knowledge resources above information resources in the learning continuum.

A formal contextual setting enables the use of ontology-based metadata for knowledge classification. This is important, as its use not only eliminates the ambiguity of semantically identical concepts in a particular vocabulary domain, it also eliminates the need to specify a particular keyword when searching for a learning object. This will certainly enhance the reusability of learning resources, as knowing the content of the learning resource will no longer be a prerequisite for efficient searching. This will realize one aspect of e-learning, that is, the relative independence of the learning experience, since the learner not longer needs to have some prior knowledge of the subject content in order to efficiently retrieve the learning object.

In the context of e-learning, these knowledge resources are termed Reusable Learning Objects (RLOs). Ontology will be used to define the relationships of these RLOs by annotating the content of the knowledge resources thereby allowing the system to make queries based on the ontologies and metadata.

3.3 Designing the Knowledge Model

The full knowledge system is shown in Figure 3; but owing to the limited scope of this article, only an overview of the knowledge system is discussed. From a functional view, the knowledge system consists of different subsystems that operate independently. Communication among subsystems takes place through a broker. Access to the system by learners or SMEs is via the information access points. One of the most important advantages of such an "agent-like" architecture is that computational resources can be used optimally. Furthermore, considerable design efforts are being made to ensure that as the system matures the infrastructure, at the very least, is interoperable, robust, and flexible enough to support future advanced services and elaborations.

3.3.1 *Knowledge Elicitation Subsystem*

A major challenge in constructing a comprehensive Web-based knowledge management system is to reconcile the human-machine language dilemma. The knowledge elicitation subsystem is crafted to address this challenge. This subsystem is a highly interactive program for the acquisition, development, and synthesis of knowledge on a conceptual

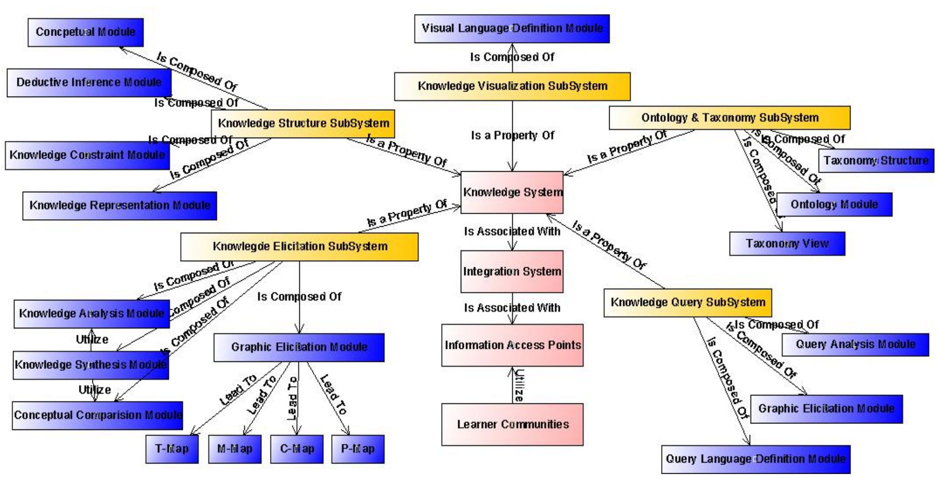

Fig. 3. The knowledge system.[4]

[4] Figure 3 is drawn using the developed prototype.

level. Learning personalization, which is an important aspect of e-learning, is also realized by this subsystem. Through a negotiated process among the *knowledge synthesis module*, the *knowledge analysis model,* and the *conceptual comparison model*, knowledge (tacit and explicit) is made explicit and represented in a formal way; knowledge is presented and visualized in a computer-understandable way by means of the *graphic elicitation module*.

3.3.2 *Knowledge Structure Subsystem*

The knowledge structure subsystem consists of the *knowledge constraint module*, the *knowledge representation module*, the *conceptual model*, and the *deductive inference module*. By constraining the database knowledge structure, this subsystem supports the basic retrieval and query operations of the knowledge bases. It governs the process of organizing acquired knowledge into knowledge fields, which show the main domain concepts and the relationships among them.

Great emphasis is placed on the *conceptual model,* which supports the development of conceptual knowledge structures. Empirical induction from datasets of cases as well as domain-specific rules can also be incorporated into the conceptual knowledge structures through the *deductive inference module*, which, besides providing knowledge inference, will play a key part in knowledge automation and synthesis.

3.3.3 *Knowledge Visualization Subsystem*

The knowledge visualization subsystem consists of a *visual language definition module*. This subsystem supports the specification and application of knowledge structures made of graphs of nodes and links and a wide variety of other domain-specific nodes and link types. The domain-specific visualizing elements must be predefined in the ontology and taxonomy subsystem before it can be used by the system developer or learner to visualize the knowledge concept maps. In short, the subsystem acts as a customized tool for knowledge visualization without requiring users to develop the codes.

3.3.4 *Knowledge Query Subsystem*

The knowledge query subsystem consists of the *query language definition module*, the *query analysis module*, and the *graphic elicitation module*. This subsystem handles all queries by using the query analysis module, which provides text analysis through a variety of tools for lexical and semantic analysis.

3.3.5 *Ontology and Taxonomy Subsystem*

Learning resources must be specified explicitly. To have an interoperating medium for communication, it is vital for different machines to use and share knowledge. This is made possible by means of ontology. Ontology is the explicit specification of some topic. Using a concept-based approach, concepts are described by classes, and classes are the main focus of the ontology. Thus, ontology, together with a set of individual class instances, constitutes a knowledge base. While the *Ontology module* serves only at the knowledge resources level in the learning continuum, the *taxonomy structure* and *taxonomy view* form the conceptual framework for organizing and structuring all the content in the knowledge system.

4. CONCLUSION

This article describes existing research in implementing knowledge management techniques to e-learning. Extending our previous work on concept maps, this article provides further details of this approach and introduces a knowledge model that enriches learning by creating a platform for continuous dialogue between learners and knowledge resources. A novel methodology to elicit certain aspects of tacit knowledge is presented here, as well as a technique to achieve learning personalization via the concept of learning dependency and the externalization of tacit knowledge. The originality of the proposed system lies in its specific approach of visualizing the SMEs' tacit knowledge via algorithmically traversable concept maps in order to personalize e-learning, and not in the attempt to automate instruction. Lastly, due to length constraints, we discuss only the skeleton of our document, which spans the entire design process of our knowledge system.

A prototype system that performs a subset of functions (learner profiling, knowledge visualization, and learning route mapping) is being developed. The implementation of the prototype is currently realizing only a minimal environment for experimenting with the concepts in this article. To personalize the learning routes, all course offerings must be in the form of a concept map. Hence, to provide the visualization and structural aspects of the course offerings, a part of the knowledge visualization subsystem (graphic elicitation model) was developed first. To date, the prototype is able to depict the course offerings in a concept map format, and a simple algorithm has been developed to generate the learning routes based on a reduced set of constraints.

Future work includes the continuing development of prototypes and research on incorporating new methods into the system design. Further research to extend the capabilities of our T-model will also be conducted. We also aim to work towards benchmarking our knowledge system so that we have a standard method to evaluate the effectiveness of our methodology. The prototype system is targeted for completion by the second quarter of 2006. The proposed system will then be assessed for its effectiveness through competency evaluation and feedback from two randomly assigned groups of learners at an appropriate alpha level.

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