Concept Mapping and Knowledge Modeling: A Multi-Disciplinary Educational, Informational, and Communication Technology

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ABSTRACT

Concept maps are useful in many disciplines for the representation and communication of structured knowledge. This article contains a description of concept mapping and knowledge modeling based upon concept maps that are used for a variety of purposes. It describes applications of concept mapping and knowledge modeling for education, for knowledge preservation and sharing, for knowledge creation, as an efficient means of creating documentation, and for the creation of knowledge formalisms from informal knowledge representations. Examples are drawn from several different knowledge domains.

Keywords: concept mapping, knowledge modeling

1. INTRODUCTION

Pervasive computerization and Internet access have created an explosive growth in the amount of technology available, and of the volume of content one might wish to communicate or explore. Web sites, blogs, and social media have all contributed to an environment in which the average person is immersed in an overwhelming amount of data, information, opinion, and knowledge. All this relatively recent capability and content calls to question ways to create, organize, present, and communicate information and knowledge in a reasonably efficient and effective manner.

The basic contention of this article is that concept mapping [1] and knowledge modeling [2,3,4] provide utility for a number of purposes in a general fashion that cuts across disciplines. Concept maps are graphical or pictorial representations of structured knowledge in which concepts (nouns - the things in a domain of discourse such as plants, sky, unicorns or calculus) are written down and linked together with phases that elaborate the relationships between them to form propositions. Concept maps might be linked together and populated with other media to form hierarchical knowledge structures that have been called knowledge models.

The remainder of this paper contains a brief literature review of various uses of these tools. This review is necessarily quite broad and not terribly deep because a lot of literature has been published on the subject. Following the literature, discussion of different ways in which concept maps and knowledge models might be created and examples of applications of concept mapping and knowledge modeling in different knowledge domains will be presented. A brief summary of specific technologies to create concept maps and knowledge models is presented. The paper concludes with a summary and discussion of when concept mapping and knowledge modeling are useful and when other representations might be of greater utility.

2. LITERATURE

Novak [1] was initially motivated by Ausubel's Assimilation Theory [5,6] to create concept maps as a means of fostering and assessing meaningful science learning in K-12 children. In seminal work on concept maps and concept mapping Novak describes the use of concept maps to assess learning. Much has been written on educational uses of concept maps since (online proceedings of the Concept Mapping Conferences, CMC 2004, 2006, 2008, 2010, 2012 and 2014 are available). For instance, the idea of building understandings with “expert skeleton” concept maps put forth by Novak and Cañas [7] provides a strong foundation for learning.

Early concept maps were generally created by pencil and paper methods, with post-it notes on

large sheets of paper for idea generation, etc. A long-term project has given rise to the development of CmapTools [8], which are dubbed "a knowledge modeling toolkit." The notion of a knowledge model is that of a collection of concept maps structured hierarchically and populated with additional resources that explicate the concepts in the map.

McNeese and Ayoub, [9] describe early work that diverged from Novak's original uses of concept maps – the transfer of knowledge from the person making the map to another who needs to understand the knowledge. They also described the genesis of other uses such as the comparison of two expert maps to look for what they termed "invariances" in the knowledge. In earlier work, McNeese [10] studied applications of concept mapping in aircraft design, crisis management, and intelligence analysis.

Advance Organizers are useful for a wide range of activities. Ausubel et al. [5] state that advance organizers facilitate the incorporation of new knowledge into existing knowledge. Novak [11] states that concept maps can serve as powerful advance organizers if they at the appropriate level for the students using them. Others have described the use of maps developed by experts as advance organizers in the teaching of undergraduate science courses [12], in pre-service teacher training in pedagogy and subject area content [13], in secondary school Physics teaching [14], and in mathematics teacher training [15].

Briggs et al. [16] from the Center for Mars Exploration at NASA Ames described the use of this approach to knowledge modeling to organize a large number of electronic resources. Arbea et al. [17] described the Comenius Project which utilized the concept of a knowledge model to organize materials pertinent to traditional Spanish festivities. Other studies of the use of knowledge models as organizing factors in more formal educational settings have been described as well.

Fernandez et al. [18] described a knowledge model that was used to teach movie (film) analysis and production. Coffey [19] described the use of a knowledge model in a computer science course on data structures, and Basso & Margarita [20] described the use of a knowledge model that actually integrated with the Plone open source Content Management System, which was also the topic being taught. The results presented in these studies were all preliminary.

Banchetti Cordeiro et al [21] describe a scheme for fostering "interdisciplinarity" making linkages between different disciplines explicit with the use of links between concept maps that pertain to diverse knowledge domains. Coffey [22] describes the use of concept mapping for security assurance cases. Skeleton maps were used as the starting point for sessions with a software developer, security expert and knowledge elicitor. The literature makes clear that concept maps and knowledge modeling are useful tools for the creation, assessment, and dissemination of knowledge in many different domains.

3. PICTORIAL/GRAPHICAL REPRESENTATIONS OF KNOWLEDGE

The homily that "a picture is worth a thousand words" has truth. Pictorial or graphical representations of knowledge are often more concise, unambiguous, and easy to understand than textual depictions of the same knowledge. Concept maps are comprised of concepts, defined by Novak as perceived regularities in objects or events, defined by a label, linking phrases which make explicit the relationships between concepts, and propositions – concept, linking phrase, concept triples that are held to be basic units of structured knowledge.

Figure 1 contains an example of a concept map on Java Programming. Starting at the top of the map in Figure 1, one can read "Java Programs contain Operators" and "Operators include Comparison Operators" two of the more basic propositions in the map. The concept map in Figure 1 comprises an advance organizer for the portion of the course it covers. It provides a concise, unambiguous summary of the knowledge it contains. It is reviewed in detail with the students of the course as preparation for the first examination.

4. USES OF CONCEPT MAPS AND KNOWLEDGE MODELS

Concept maps started as tools for education, following from Ausubel's Assimilation Theory [6]. As a concise, unambiguous, graphical representation of structured knowledge, additional uses became apparent. The following sections contain examples of several uses of concept maps and knowledge models including educational, for the capture and preservation of knowledge, for knowledge generation and brainstorming, and as the starting point for the creation of knowledge formalisms.

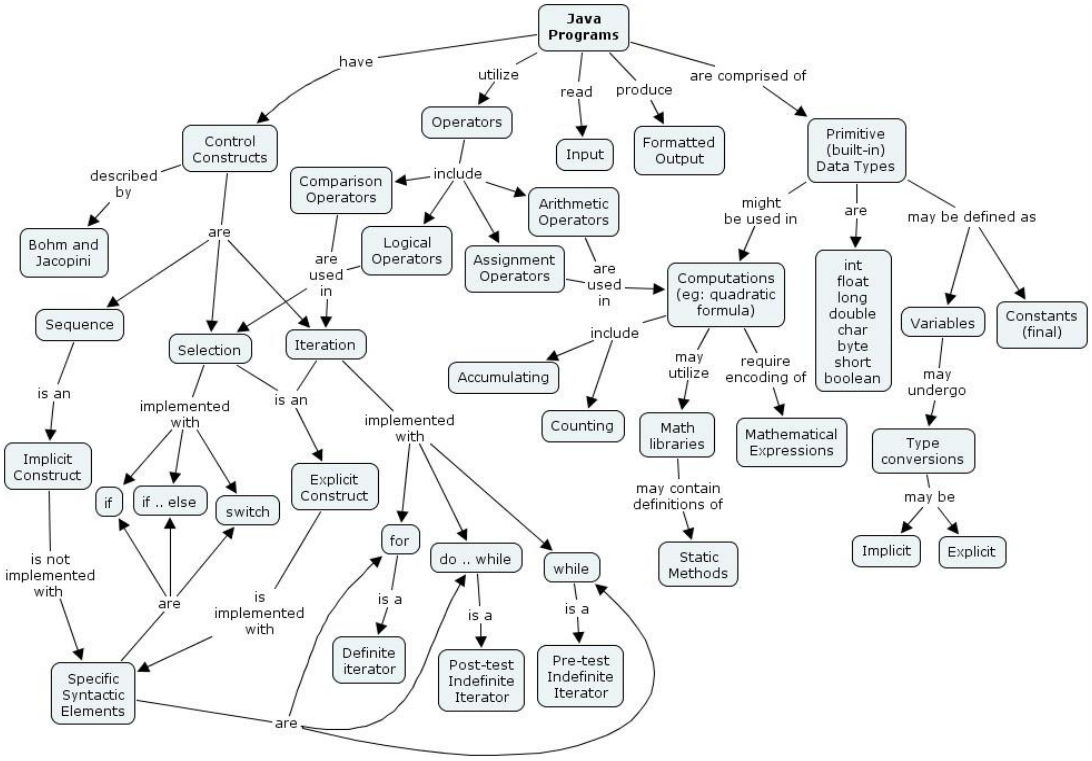

Figure 1. A concept map pertaining to the Java programming language.

Educational Uses

Novak originally envisioned the creation of concept maps by K-12 biology students as a means of obtaining a concise, unambiguous representation of what students understood (both correctly and incorrectly) about biology. Their use was strictly conceived to be for assessment. Novak actually observed graduate students who were working on his research creating concept maps to foster their own understandings, and their value as a learning tool quickly became apparent. Interestingly, this early research led to Doctoral students using concept maps to formulate dissertation research questions. Questions came out of hypothesized relationships (the linking phrases again) between concepts in the concept maps.

Students can create concept maps by first being given the concepts, which they are tasked with linking together, being given maps with concepts and/or linking phrases omitted, or simply by starting with an empty page. All concept maps are started with a focus question - a question that helps maintain focus on the issue to be discussed in the map. Other educational uses follow from Ausubel's idea of Advance Organizers. An advance organizer is introduced to the student before learning is to take place in order to provide a high-level, general, inclusive view of the materials to be learned. Given the global view of the knowledge domain, subsumptive learning, in which more detailed knowledge is learned, with progressive differentiation (increasing nuance in understanding the relationships among the concepts being learned) can take place. One might think of an outline as an advance organizer. It conveys superordinate and subordinate relationships, the high level items are superordinate to the more detailed, subordinate items beneath them. However, outlines do not make explicit the relationships among topics at any given level in the manner that concept maps can.

Capturing/Preserving Knowledge

As previously described, knowledge models are navigable, organized structures of linked concept maps with supplemental media attached. Individuals expert in knowledge elicitation work with experts in a knowledge domain in order to construct a knowledge model collaboratively. In a

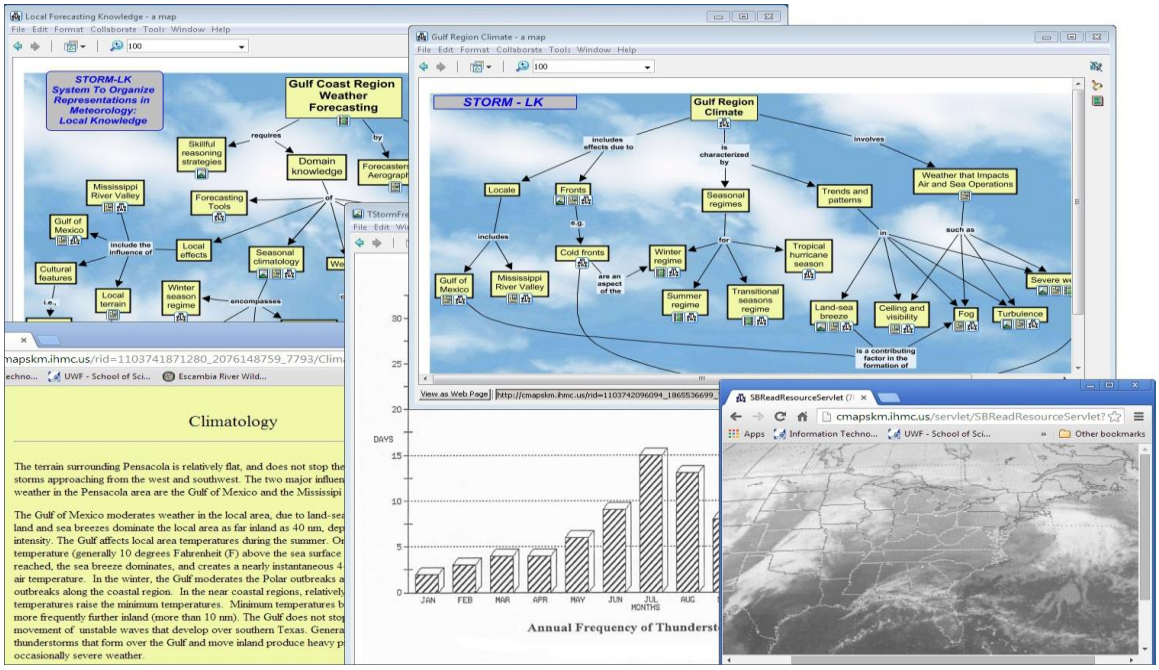

Figure 2. A Knowledge Model illustrating Concept Maps and Associated Resources.

method that was originated at the Institute for Human and Machine Cognition (IHMC) two knowledge elicitors (a moderator and a recorder) work with the domain expert to create a concept map in real time [23]. The emerging concept map is projected so that all participants can view it. The moderator serves as the primary interviewer of the expert, and the recorder operates a computer, creating the concept map in real time.

Figure 2 illustrates a knowledge model pertaining to Gulf Coast weather forecasting. The starting point for the navigation depicted in this graphic is the concept map in the top left, "Gulf Coast Region Weather Forecasting." This concept map is an overview of the entire knowledge model. From there, the user selected the icon under the node labeled "Seasonal Climatology." Selecting that link took the user to the concept map on the top right on Climatology in the Gulf Coast. From there, navigating via the icons below the concepts in the concept maps, the user accessed a textual description of climatology of the Pensacola area on the Gulf Coast, a graphic depicting the frequency of thunderstorms, and a real-time satellite image of the weather.

This knowledge model also contains significant amounts of digital video of expert weather forecasters discussing a wide range of important weather issues spanning such subjects as how the NexRad weather radar is configured for this installation to issues such as hurricane preparedness and reporting. Example videos have been omitted from the graphic because of permission issues pertaining to faces appearing in the videos.

The purpose of the weather model was to provide a resource for new meteorologists coming to the facility. New arrivals were required to study the resource in order to qualify first for the "Sub-regional Forecaster" exam and later for the "Forecast Duty Officer" exam. The goal was to include expert knowledge above and beyond the usual "boilerplate" of standard forecasting knowledge that appeared in the “Forecaster's Handbook,” the resource that had been used previously. Acceptance of the new organization of the knowledge was very good as were results of new arrivals passing the required examinations.

Knowledge Generation – Brainstorming

Knowledge generation may be viewed as an activity that is similar to brainstorming. Brainstorming is completely open-ended, recording uncritically any idea related to a problem. Knowledge generation is a bit more

constrained, possibly focusing on building consensus about ideas relating to a knowledge domain. For instance, the Navy carried out a significant initiative called a job task analysis to review the various ratings (positions), the responsibilities associated with each, and the advancement path for every enlisted Navy job category [24]. Group sessions were held to sort out overlapping duties and to enumerate anticipated changes and future challenges for these positions. In the course of a two-day workshop an expert knowledge elicitor was able to work with fifteen Signalmen, QuarterMasters and Boatswain's Mates to address these issues.

The Navy participants were the most senior in their ranks, strong willed, very direct regarding how they thought things should be, and very willing to argue. Nevertheless, the two-day sessions gave rise to good consensus on jobs, tasks, and duties of the three ratings, professional development vectors (progression of responsibilities and duties), progressions in certification and qualification for the three ratings, and a comprehensive assessment of future challenges.

Uses for Documentation

Since concept maps are minimal, terse, minimally ambiguous, and easily elicited, they serve well for the review of activities requiring documentation. As an example, a pilot study was performed regarding the use of the elicitation of concept maps to create security assurance cases for mission-critical software [22]. In the first step of this work, a knowledge elicitor worked with a security expert to create a "skeleton concept map," a minimal concept map with a focus question and a small number of concepts already present. In this case, the skeleton concept map contained the four security issues that were to be addressed in the study. In a second session, the knowledge elicitor and security expert interviewed the software developer to create the concept map documenting how the security issues had been addressed.

In the study leading to the security assurance case, two teams of elicitors and security experts worked with a total of four software developers to develop security assurance cases. Part of the documentation effort was to demonstrate where, in the actual design files, code, or log files, the security issue was addressed. Cases were developed at two "security touchpoints" in the process, the first after the design of the software was complete (with links to design documents only) and again after the programming and testing were complete.

As has been stated, concept mapping is an efficient process, particularly in the hands of an expert knowledge elicitor. Each of the security assurance cases (of which there was one for design and one for implementation for each of the four developers) required approximately one hour for the elicitation of the concept map. During that process, any unresolved security issues were documented by adding into a section of open issues in the concept map. Another hour of work was required to clean up the concept maps, improve structuring and wording, and to populate the concept maps with the resources (design documents, code and logs).

Generating Knowledge Formalisms

Concept maps were not originally meant to be used for formal representations of knowledge. The original idea for their use was very human-centric, created and read by humans and not processed by machines. Their informality stems in part from the unconstrained use of linking phrases that map the relationships between concepts, and the fact that the creator is free to spill over concept, link, concept triples to create quintuples (eg: "grass is brown in winter").

Knowledge formalisms can be based upon triples as is the case in, for instance, RDF. A concept map of a knowledge domain provides an informal representation of the constituent elements of the domain and of the relationships among those elements. The elements themselves require scrutiny for synonyms, groupings of related elements, and generalization/specialization relationships, all relatively simple judgment tasks. The linking phrases are a bit more difficult due to the unconstrained nature of linking phrases in concept maps and the need to adopt formalized relationships. As an example, the Web Ontology Language (with the slightly misspelled acronym OWL) features a set of relationships that can be used to define class hierarchies attributes, and constraints.

5. CONCLUSIONS

Concept maps and knowledge models can be used in many different knowledge domains for educational purposes as well as to create, elaborate, assess and communicate knowledge. This article describes educational uses as well as

uses to preserve institutional memory, to generate ideas and knowledge, to document work, and as the starting point for the creation of formalized knowledge structures.

The completely general, universal nature of the knowledge representation means that concept maps and knowledge models can be used in any knowledge domain. In this paper, examples were presented that included educational materials for computer science education, preservation of institutional knowledge pertaining to weather forecasting, evaluation of job responsibilities (ratings) in the Navy, assessing security concerns in software, and organizing knowledge about providers in health care. Thus, concept mapping and knowledge modeling are truly interdisciplinary tools to foster education, information and knowledge representation, sharing and communication.

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