Bringing Knowledge Technologies to the Classroom

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Abstract

The Semantic Web initiative offers us an opportunity to examine applications of web technologies in the light of many diverse domains, an important domain being education. In this paper, we examine ways in which the collaborative and ontology-based nature of e-commerce solutions can be combined with new technologies that support constructivist epistemologies to further enhance the many ways in which the Semantic Web will benefit education. We explore ways in which the new XTM Topic Map standard can be combined with Issue-based Information Systems (IBIS) and features of the Semantic Web to provide opportunities for the development of critical thinking skills to classrooms everywhere. We further outline an approach to enabling classrooms to provide such learning experiences in a worldwide collaborative fashion, enabling learners to become world-class thinkers.

Introduction

> "It is strange that we expect students to learn, yet seldom teach them anything about learning." Donald Norman, "Cognitive engineering and education," in *Problem Solving and Education: Issues in Teaching and Research*, D.T. Tuna and F. Reif, editors, Erlbaum Publishers, 1980.

We follow the argument made recently by Douglas Engelbart[1] [EN 2000] that there is an "unfinished revolution" in the application of personal computing to the enhancement of human intellect in relation to finding solutions to complex, urgent problems. His Open Hyperdocument System [OH 2000] is a project intended to develop and exploit technologies that will work in harmony with the Semantic Web initiative started by Tim Berners-Lee[2] [BE 1998]. It is this author's belief that knowledge technologies growing out of initiatives like those of Engelbart and Berners-Lee will be of greatest value to the education of children.

Evolution of the Semantic Web (SW) provides the opportunity to examine the necessary tensions between many theories of learning. We are faced with a deluge of names for these learning theories, some of which are objectivist, interpretivist, constructivist, reductionist, developmental, and so forth. This paper will make a few 'big picture' statements about each, then proceed to discuss one particular theory, constructivist, and its relations to critical thinking. We then connect that theory to its relations with the SW initiative.

[1] http://www.bootstrap.org
[2] http://www.w3.org/DesignIssues/Semantic.html

David Schafersman [SC 1991] says this of critical thinking:

> "Critical thinking means correct thinking in the pursuit of relevant and reliable knowledge about the world. Another way to describe it is reasonable, reflective, responsible, and skillful thinking that is focused on deciding what to believe or do."

Objectivist, and reductionist theories assume that knowledge can be transferred by teachers or by interactions with technologies and therefore can be acquired by learners. Accumulation of facts and data precedes critical thinking about them [DA 2000] [JO 1998]. Developmental theories withhold critical thinking exercise until certain levels of maturity are demonstrated. Constructivist theories assume that learners construct knowledge both individually and through social interactions. Indeed, in the constructivist view, critical thinking lies at the heart of teaching and learning process [DA 2000].

Each theory suggests different approaches to instructional design; this paper intends to focus on those aspects of instructional design that couple the emerging technology of the SW to constructivist learning environments. We begin by examining the principles of constructivist epistemology; we then discuss knowledge technologies useful in constructivist environments, and link those tools to the SW initiative.

Constructivist Epistemology

> "What biology shows us is that the uniqueness of being human lies exclusively in a social structural coupling that occurs through languaging, generating (a) the regularities proper to the human social dynamics, for example, individual identity and self-consciousness, and (b) the recursive social human dynamics that entails a reflection enabling us to see that as human beings we have only the world which we create with others – whether we like them or not."
> From: Maturana, Humberto R. and Francisco J. Verala, *The Tree of Knowledge: The Biological Roots of Human Understanding*, New Science Library, 1987 Page 246

Three names (though, many others exist) come to mind in relation to the constructivist stance: Peirce, Piaget, and Vygotsky. Charles Sanders Peirce established a foundation for pragmatism, the evolution of meanings negotiated within a social context. Jean Piaget established an order in which children develop, and Lev Semyonovich Vygotsky argued with Piaget, holding that children, through social interactions (typically with adults) are able to achieve higher levels of knowing; development is enhanced by learning [PH] [HI 1997]. Our plan here is to outline what can be mined from a base of literature established by those and other individuals, and to connect that information to learning environments and the Semantic Web.

Principles of Constructivist Learning Theory

We enumerate the key points discussed in [CO], and briefly expand on a few of them.

- Knowledge and beliefs are constructed within the learner. Learners both *create* and *own* their knowledge. The kind of *ownership* discussed here relates to *pride of ownership*; the learner's ability to learn is reinforced with each discovery.
- Knowledge formation involves constructing *meaning*. Learning must be self-regulating; the learner must take control of the process and progress at his/her own level of competence. The problem space must not be over-prescribed; the learner must have the opportunity for discovery.

- Knowledge formation involves integration with prior knowledge. The integration process, itself, is rich in opportunity for new discoveries.
- Learning is a social process, greatly enhanced by shared experiences and shared memory.
- Learning involves reflection and metacognition. In order to form meanings, learners must reflect on their own methods of learning. Learners must also participate in the assessment of their own learning. Assessment must take into account alternative views and contexts.
- Learning outcomes are varied and often unpredictable. Individuals are likely to form meanings from experiences that are unique to and guided by their overall experience.

These points are suggestive of use cases and eventual requirements involved in instructional design. We turn now to a view of constructivist learning environments.

Towards Constructivist Learning Environments

> "Children are natural mimics, who act like their parents despite every effort to teach them good manners" unknown

Learners need an environment that supports both individual and collaborative projects intended to provide opportunities for *discovery*. Such environments are often designed around thematic projects that provide a uniform *context* for learning. Context includes features of the world expressed in the learning environment such as structural, political, social, and other features.

Equally important are the learner's own relationships with the environment. A goal in constructivist learning is the learner's *ownership* of new knowledge. The role of the instructional designer is less that of author of prescriptive lessons, and more that of creator of environments that engage learners and which enable and require them to create meaningful knowledge.

A constructivist environment will provide opportunity for critical thinking. Logical thinking is one of the mechanisms of critical thinking. Puzzles, like those suggested on the web[3], form a basis for development of logical thinking. In that problem, you are given a 3-gallon can and a 5-gallon can, and water; the objective is to load 4 gallons into the 5-gallon can. I can still remember when that problem was hard!

Next to the logical thinking involved with solving puzzles are aspects of logical reasoning that permit one to participate in debate, or argumentation. Classrooms around the world are quite used to the conduct of debates; one imagines that such debates could be taken online in such a fashion that debate skills will be honed against members of other cultures, leading to world class thinking skills. In order to facilitate what Nikos Karacapilidis [KA 1995] calls *Computational Dialectics*, the Issue-based Information System (IBIS) [TO 1958] provides computer support for responses to questions while tracking arguments both pro and con with respect to the responses. IBIS provides one of the tools we believe important to the evolution of constructivist environments.

[3] http://207.106.82.89/puzzles/cans/cans.htm

A tool for tracking and visualizing the argument process is a required component of a constructivist environment. Some existing tools offer visual presentations. For example, QuestMap™[4] [QM 2000] offers visual tools as illustrated in figure 1.

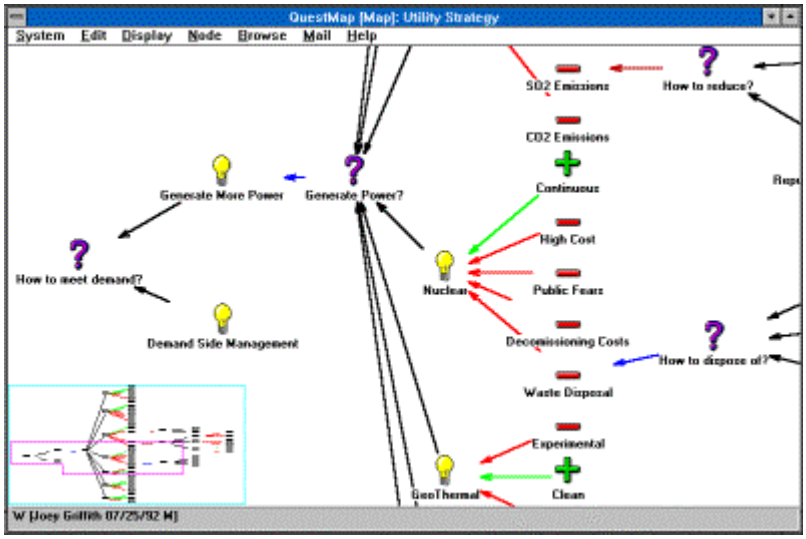

Figure 1. QuestMap™ visual interface for IBIS
(with kind permission of Joe Conklin)

Graphical tools have a long history in the classroom, starting with Concept Map tools [NO 1998a][FI 2000a][FI 2000b]. An instance of a classroom concept-mapping tool is SemNet®[5] [SE 2000], which allows learners to construct Concept Maps (also called semantic networks) graphically, as illustrated with figure 2.

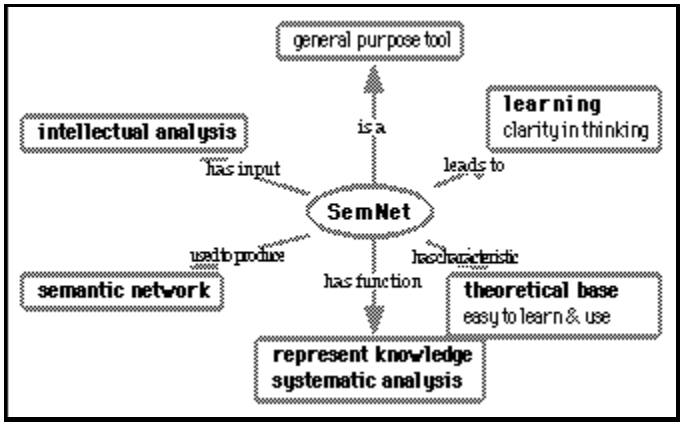

Figure 2. A SemNet® semantic network.
(with kind permission of Kathleen Fisher)

[4] http://www.gdss.com/wp/VIMS.html
[5] http://trumpet.sdsu.edu/semnet.html

We believe that a combination of structured argumentation and visual representation of discourse will provide in important part of a constructivist learning environment. We now look a bit closer at these technologies. We will see that Topic Maps, with their XML syntax, the XTM standard [TO 2000a], can be applied to the task of providing both a Concept Map-like graphical interface for visualizing the topics and their relationships involved in argumentation, and a serialization scheme that supports comparison and merging of learning experiences.

IBIS

> "Even in highly sophisticated modern knowledge organizations, the most valuable knowledge – the know-how in terms of what really gets results and what mistakes to avoid – often resides mainly in people's minds."
> From: "What is Knowledge Management" http://www.oneworld.org/thinktank/id/index.html

Consider the issue of critical thinking. Joseph Novak [NO 1998b] refers to the structure of knowledge expressed in any work as outlined by five questions proposed by D.B.Gowan:

- What is the telling question
- What are the key concepts and conceptual structure
- What are the methods involved in answering the question
- What knowledge claims are made
- What value claims are made

Gowan reduced these questions to a diagram, known as Gowan's *Knowledge V*. A sketch of the *V* is reproduced in figure 3.

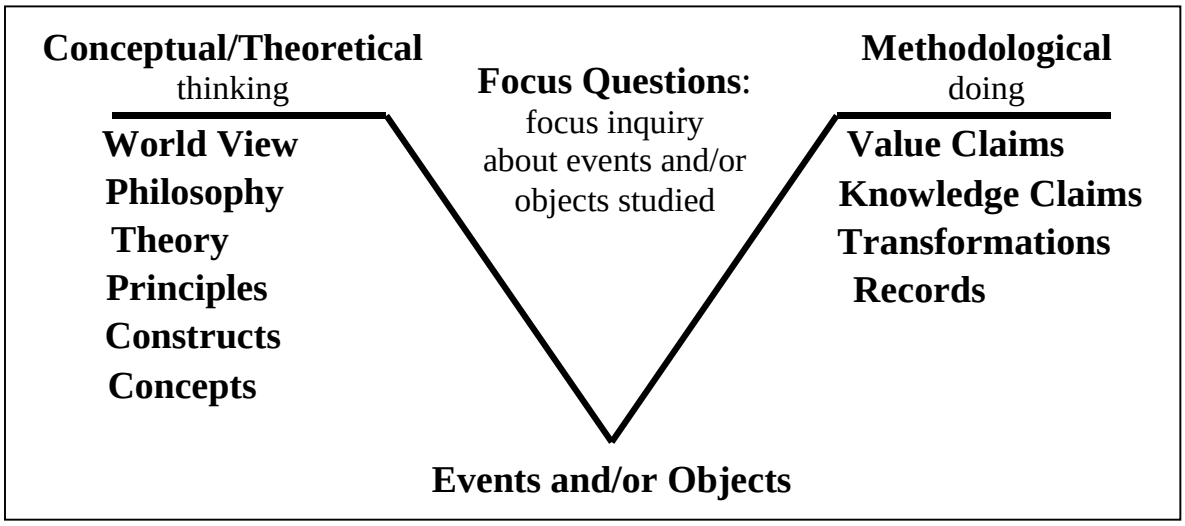

Figure 3. Gowan's Knowledge V. after [NO 1998b]

A key instrument in inquiry as depicted here is a focus question. Learners are expected to apply the thinking skills described on the left-hand side of figure 3, and are expected to perform operations described on the right-hand side: recording (research), transformations (responses to the question), summarize (make claims), and evaluate

(discuss the value of the knowledge claims). A useful way to formalize this process is through the application of IBIS technology.

IBIS provides a tool that supports users making statements, adducing reasons, inferring conclusions, and discussing exceptions. IBIS does this by

- Managing the argument process
- Tracking issues that are raised and assumptions made
- Tracking reasons, counterarguments, and conclusions
- Tracking evaluation of justifications
- Enforcing the rules of argument.

In an IBIS dialog, a question is posed. Each participating learner is expected to formulate a response, an *idea* in the terminology of the QuestMap™ manual [IB 2000]. Once responses are presented, the discussion begins. Learners formulate responses to the ideas. These can be in the form of *for* or *against* arguments, *justifications* for various responses, or just further commentary.

An IBIS discussion is a search for relevant and reliable knowledge, but IBIS, or any formalized interactive knowledge management tool, does not exist without open issues. Of particular note is the notion that formal systems tend to inhibit full participation among users. Shipman and Marshal [SH 1999] discuss issues related to the use of formal systems from the perspectives of cognitive overhead, tacit knowledge, and prior structure. Indeed, cognitive overhead exists for any learner and some of that overhead lends well to at least partial mitigation through appropriate user interface design. Gaining tacit knowledge is what learning is all about, and just about everything constitutes prior structure to learners. I believe that I am suggesting that, with care, these issues need not interfere with classroom activities, though they certainly might interfere in applications of the technologies discussed here other than learning.

Topic Maps

> "The standard philosophical conception of knowledge defines knowledge as a *true well-justified belief* or *proposition*. Knowledge is achieved, at least in standard empiricist dogma, by some learning process, either through perception or through the adoption of such a tradition that contains previously gathered knowledge. In the tradition of EE followed here, an analogy between evolutionary *adaptation* through natural selection and the increase in *environmental knowledge* is emphasized. More specifically, this knowledge is not simply about the environment, but rather about the relationships between the knower (e.g. organism) and its environment. "
> From: Vehkavaara, Tommie, "Extended concept of Knowledge for Evolutionary Epistemology and for Biosemiotics", 1998[6]

In the beginning, there was the Concept Map. Later, there was the Topic Map. Now, there is XTM, an XML dialect for expression and serialization of *Topics*, *Associations*, and *Occurrences*. Concept Maps have their roots in pedagogy, while Topic Maps have their roots in the SGML field and find application in, among other things, indexing documents, as for example Infoloom's indexing of GCA conferences[7] [IN 2000]. The Mondeca Topic

[6] http://www.uta.fi/~attove/vehka-f.htm

[7] http://www.infoloom.com/tmweb.htm

Navigator[8] (figure 4) is an example of a Topic Map engine that provides graphical representation of its contents.

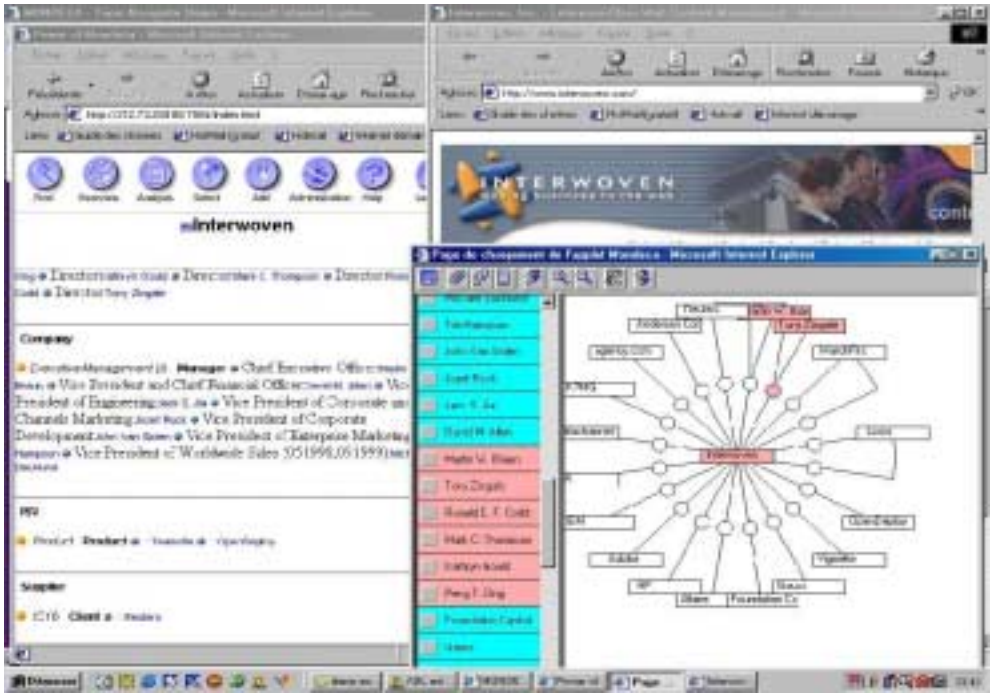

Figure 4. Mondeca Topic Navigator

An application that both Concept Maps and Topic Maps are well suited for is that of knowledge representation (KR). There remains the open question whether XTM can serve as a primary KR system; XTM was most certainly not designed with intentions of serving as a KR system, but recent work (e.g. [FR 2000] and [RA 2000]) indicate that semantic networks and inference capabilities can be implemented within the XTM specification. In his chapter in a forthcoming book [PA 2001], Eric Freese discusses the similarities between XTM and the Resource Description Framework (RDF) being developed as part of the SW initiative.

Given that Concept Maps and Topic Maps are capable of serving the same purposes, it seems reasonable to call for a migration of Concept Map technology towards the XTM standard. This move will provide the capability of Concept Map interchange. I further believe that Topic Maps, when applied to the presentation of argumentation developed in IBIS dialogs, and that, combined with collaborative projects on the Web, will, in turn, create a constructivist environment conducive to the evolution of world-class thinkers.

Semantic Web Initiative

[8] http://www.mondeca.com/

The Semantic Web initiative [BE 1998] exists with the purpose of rendering information on the Web into a form that enhances the capability of computer programs to automate much of the knowledge work associated with the Web. Indeed, the SW initiative has taken a web life of its own[9].

Consider the structure of the SW, (also called Seweb), as described by Tim Berners-Lee in his XML2000 talk[10] [BE 2000b]. Figure 5 is a sketch of the salient features he envisions.

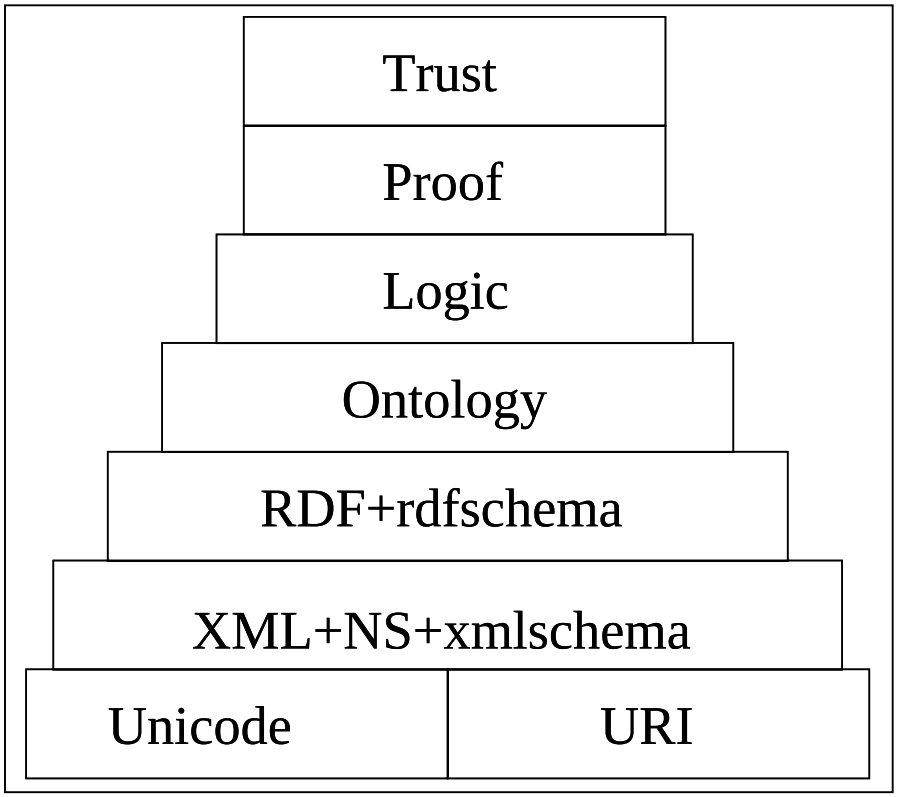

Figure 5. Semantic Web Features. (after [BE 2000a]).

We see that Unicode and URIs make up the backbone of readability and addressability in the SW initiative. Above that reside XML and Namespaces. We know that modern browsers are beginning to support XML. XML can be transformed, using XSL, to HTML for rendering. Above those two levels, we now enter the arena of 'semantification' of the Web. I may not be the first to coin that word, and my spell checker really hates it, but the message is this: we need to put something called *semantics* into the Web. The (Webster's, English) dictionary defines semantic as to *signify*, to *mean*. Play with a dictionary long enough and you soon find that there are strong circularities in the definitions associated with these words. Let us accept the notion that we wish to put *meaning* into the Web. By using the word *meaning*, I am saying that if I mention some concept on my Web page, the minds of my readers should be triggered

[9] http://www.semanticweb.org/
[10] http://www.w3.org/2000/Talks/1206-xml2k-tbl/slide1-0.html

to experience the very same concept that I experience when reading the same page. Here, I am thinking of one experiencing some concept when one forms a mental image of that concept.

How can the Web be turned into an environment in which we share meanings? Our imaginary pointer is now aimed at the RDF level of figure 5. Imagine popping up to the next level, Ontology, while keeping in mind RDF. Ontology is the study of *being*; its philosophical roots go way back. Today, we tend to think of an ontology as descriptions of things in our universe, and relationships that exist between those things; an ontology is a kind of vocabulary. If you have an ontology, you need a means by which that vocabulary can be represented for both computer programs and humans to read. RDF supplies a structure well suited to this need. The suggestion has been made that XTM, the Topic Map standard may satisfy this need as well. Indeed, there are discussions ongoing at this time to find the commonality between RDF and XTM [BE 2000c]. XTM calls for the creation of Published Subjects [TO 2000b], some of which are mandatory to establish precise semantics of the XTM details, and some of which are optional, serving as a kind of ontology for users of Topic Maps.

We have seen that the SW initiative is all about making things meaningful on the web. It remains to think about how IBIS, Topic Maps, and the Semantic Web fit together.

Discussion

> "The only sustainable advantage an organism can have is the ability to learn faster than its competitors."
> http://www.mindspring.com/~happyjac/site/ba/gen2/TechnologyGrid.html

As Douglas Engelbart says, there exist an enormous number of problems looming in the future of humanity. Engelbart's vision is all about enhancing human capabilities as a means for rising to the challenges we face. He speaks of increasing the 'collective IQ' of humanity. That's a collaborative project, one that is perhaps best started at the same time learning capabilities get started in humans, practically speaking, as soon as possible. I am not the first to propose a coupling of various tools to support the acquisition and use of critical thinking skills, but I do come along at an appropriate time to 'fume and shout' about it.

Figure 5 suggests that there is an ontology layer in the machinery of a Semantic Web. We hear discussion on the many lists (e.g. XML-DEV, XTM-DEV, GlobalBrain, and so forth) about the notion of a common ontology, one that would satisfy all users. The counter argument is almost always that such a thing is not possible; I am not arguing either way, here. But, I am thinking that, with the tools I have outlined, it becomes possible to envision some narrow ontologies emerging from the many debates that will arise as these tools are used. And, the notion of emerging ontologies mirrors the growth of a childs vocabulary; there are, indeed, many more benefits to these learning tools than perhaps meets the eye.

Can these tools be implemented? Have they already been implemented? The answer to both questions is: Yes. Among others, the researchers Brian Gaines and Mildred Shaw stand out as members of a small group of individuals who have contributed an enormous body of literature to the field we have to mine. Figure 6 is a screenshot of one of their projects that just happens to couple Concept Maps to IBIS[11] [GA 1995].

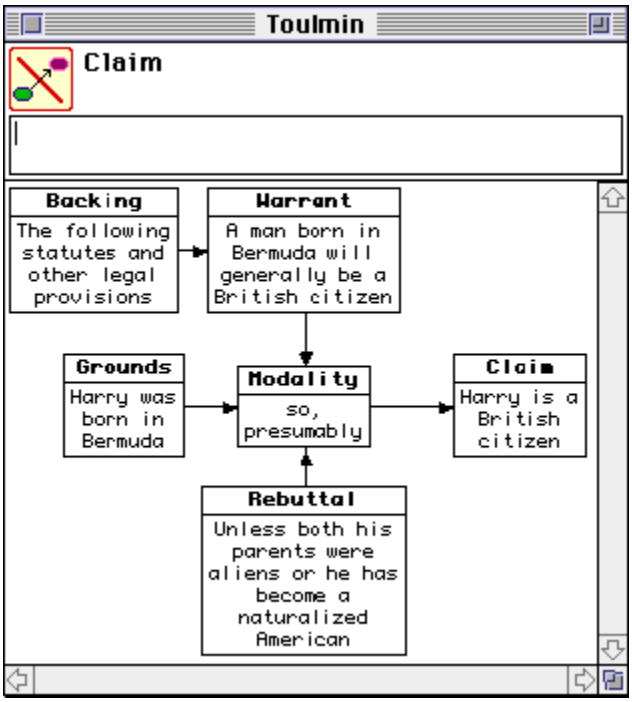

Figure 6. Concept Map of an IBIS discussion
(from [GA 1995] with kind permission of Brian Gaines)

How, then, do we fit all these tools together? Answers lie in the many tools already available, and in the many research and open source projects starting or ongoing at this time. Perhaps, say, QuestMap™ or SemNet® could be adapted to the purpose. In any case, one can imagine using one of the many XML servlet engines (e.g. Apache Cocoon, Enhydra, or others) to construct a suitable web engine. We envision a kind of expansion bus architecture that allows users to plug features into the servlet environment. Figure 7 is a simple illustration of an architecture similar to that of the Protégé 2000 [PR 2000] Ontology Editor; a plug-in buss affords adding functionality to the system. The objective here is to construct an environment that can evolve over time. Here, I am taking the following stance: if we are building an environment that supports a constructivist epistemology, then, in fact, we are supporting an *evolutionary* epistemology, one that learns along with the learners. This capability requires that we construct our systems such that they are easily enhanced with newer or better technologies as they are discovered, while maintaining the appearance of continuity to the users. Figure 8 illustrates the beginnings of an IBIS implementation in Java™ intended to couple to a persistent XTM implementation. The pictured implementation is an application that uses the JTree widget for displaying a growing issue tree. Eventually, a Topic Map will

[11] http://ksi.cpsc.ucalgary.ca/articles/ConceptMaps/CM.html

replace that widget. The tree widget illustrates the ability of a user to enter a session by clicking on any node at any time.

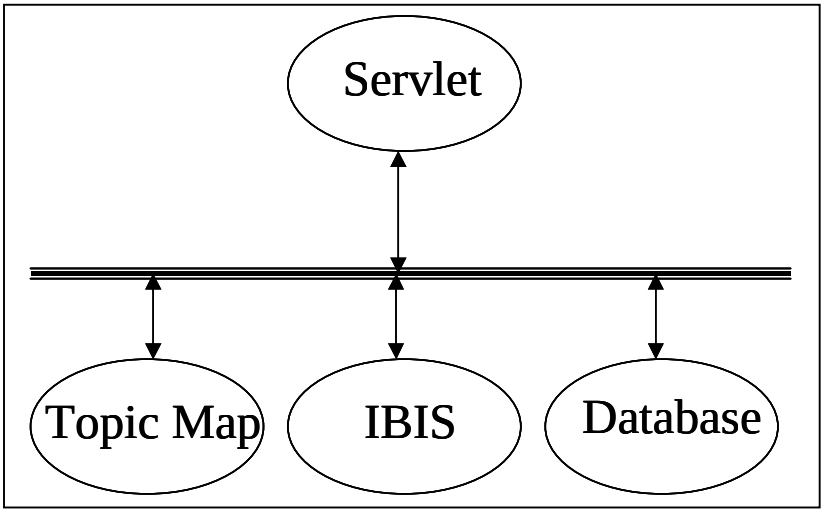

Figure 7. A Plug'n'play Buss Architecture

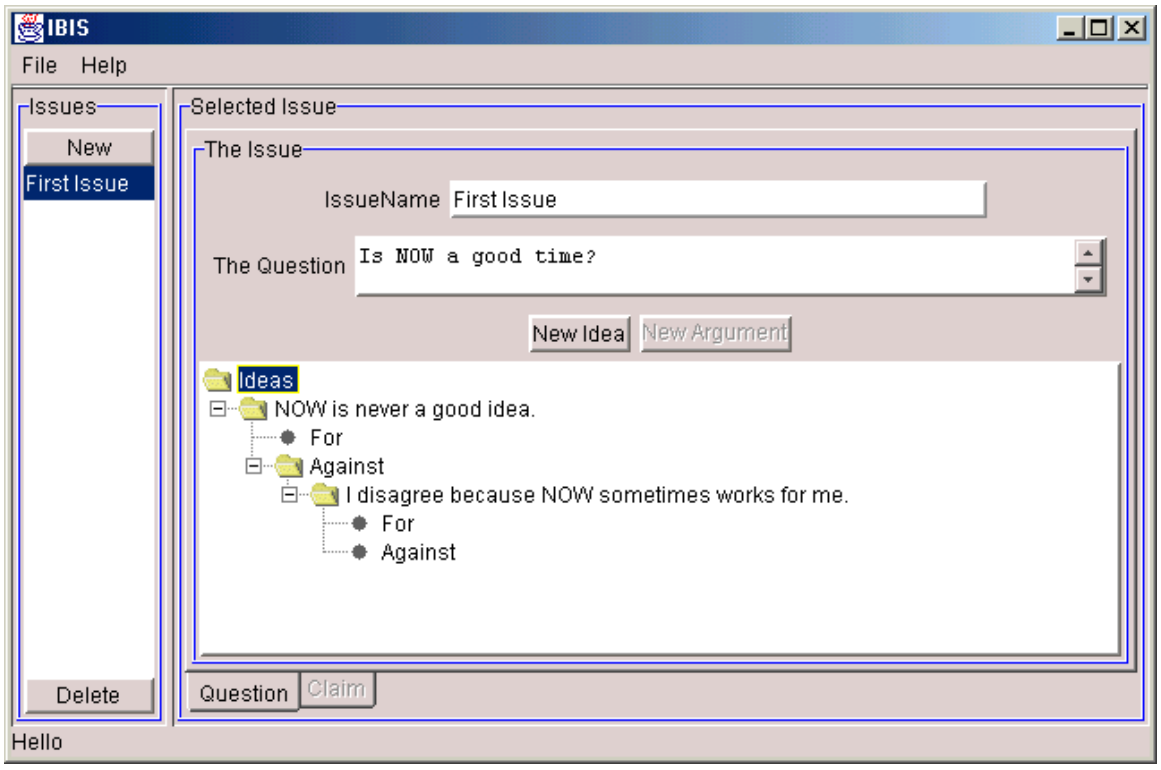

Figure 8. An experimental IBIS presentation layer implementation

Where do we go from here? Let us assume that an IBIS/Topic Map system is made available, and that some structures for representation of an ontology emerge. It then seems reasonable to assume that our efforts will lead deeper into the issue of knowledge

representation, management, and learning. Indeed, John F. Sowa [SO 2000] and others who have followed the work of C.S. Peirce offer us an arena rich in directions to extend our development of constructivist learning environments. If Engelbart is right, we must begin this process now.

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