

Developing Digital Library Visual Services for Building a Lesson-Design Environment Prototype

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Abstract

In this paper we describe the development of a prototype for: (a) a digital library visual query and discovery results presentation services and (b) teacher-centered Web-enabled lesson-design environment – *Visual Knowledge Inquirer* (VKI) – that integrates these services with cognitive and semantic outcomes within the educational practice.

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1. Introduction

To find appropriate instructional materials within the National Science Digital Library (NSDL) collections, teachers must formulate their query, locate sites, analyze search results, adapt the materials, and organize them for the needs of their particular classroom and individuals. Despite advances in NSDL services over recent years, a significant gap exists between the user's actual needs and how the present DL system processes queries and conveys results. Existing DL services do not differ from general Web-based query and display operations and are still weakly focused on particular clients, such as teachers, learners, and educators.

A new query service with a user-centered interface that employs a semantic-based graphical format to map the user's information requirements and navigate to the desired information, must be created. Current digital libraries and most Web search systems, including those utilizing powerful ranking algorithms, do not meet user needs. This is because existing search systems expect users to submit well-specified queries what can be a difficult task for non-specialist users. Teachers and students with weak technical skills often search the DL with poor understanding of how to specify their infor-

mation needs.

It is vitally important to develop a service that will assist educators and students in sifting through multiple pages of metadata identified by their query. Some NSDL collections and Web-based learning resources are growing rapidly. This complicates the processes of analyzing DL search results, since they are simply presented as pages of metadata lists. Optimizing the delivery system of NSDL educational services is a substantial step toward that goal.

A multitude of factors hinder K-12 science reform efforts in the classroom. These difficulties were identified in *A Report to the Nation* [1], which highlighted three major strategies to enhance science education reform. This paper is congruent with one of these strategies: improving the teachers' working environment by developing crucially important educational DL services, thus making the profession more appealing, productive, and creative for all K-12 science teachers.

The VKI project explores if our ontological approach to science information modeling allows us to develop appropriate technologies for:

- ***Visualizing DL concepts' space*** (controlled vocabulary, thesauri) and their interrelationships via a prism of the VKI ontology;
- ***Transforming a traditional Digital Library query*** from menu selection or form-filling into a visual, concept-map-like dynamic environment;
- ***Modifying the traditional Digital Library discovery results display service*** from plain metadata-derived lists to an ergonomically appropriate, visual display.

In parallel with exploring above, the project investigates the opportunity for ***designing a high-tech, user-centered, simple-to-use, Web-enabled lesson-design environment*** that will integrate digital library, cognitive, and semantic Web outcomes within the educational practice.

2. The VKI Resources

VKI is an integrated system, which is designed upon the synergy of following research outcomes and technological innovations:

- **Visual navigation** advantages for the query and discovery results presentation;
- **Semantic and Educational** assistance of the ADEPT Virtual Learning Environment (VLE) and P2P technology Edutella
- **Metacognitive and Pedagogical benefits** of a ChemDiscovery Learning Environment;
- **Cognitive** advancements of the newly revised Bloom's Taxonomy of Educational Objectives and other lesson-planning resources, which are based on the appropriate organization of a knowledge and cognitive processes of effective learning and understanding.

2.1 ADEPT. The foundations for the core VKI architecture are the educational and semantic services from Alexandria Digital Library (ADL)/ Alexandria Digital Earth Prototype (ADEPT) (Smith '02a).

The ADEPT project has developed a Client for a Virtual Learning Environment [2,3,4] for teaching an undergraduate physical geography course. The Client includes three main components: (1) *The Lecture Window* –for a template-based view of the lecture notes. From this window the lecturer can control the Knowledge and Collection windows. (2) *The Knowledge Window* –for concept-map-like illustrating the organization of physical geography and science concepts, that are represented in the Lecture Window; and (3) *The Collection Window* –for displaying DL objects from ADEPT collections. Each component is supported by corresponding services for on-line input, editing, and display.

The ADEPT virtual learning environment has dual nature:

- a) Educators experience it as a tool for lecture and lab preparation/presentation, which is supported by DL resources. The Central part in the learning environment is the Lecture Window. It is used for designing a lecture plan that is based on the teacher's mental model of the topic. The Knowledge window is supplemental. It is used for illustrating the lecture's structure and concept's organization.
- b) Digital library developers could experience this tool as a visual query/display service, when corresponding redesign of the ADEPT services and additional development will be done by VKI.

VKI focuses on developing the second aspect of the dual nature of the ADEPT virtual learning environment. During the development, the importance of the components will be redistributed: The Knowledge Window

will come to be a central part of the VKI system in the role of the semantic-based, visual, advanced NSDL query and discovery results presentation service.

In ADEPT the process of teacher interaction with the DL starts from the building of the mental model of the lecture structure. In contrast, VKI will operate with DL resources through the prism of the VKI ontology. The latter provides a rich semantic background to new service, which helps to assist users in advancing query formulation.

2.2 Edutella is a P2P Networking Infrastructure based on RDF databases. It provides VKI with opportunities to extend the domain-oriented RDF Knowledge base, created by experts in science domain, into a collaborative teachers' information environment, capable of providing effective "community memory" for managing educational information within constantly evolving collaborative contexts [5]. The Edutella project and infrastructure [6] allows for direct and simplified sharing of educational resources. However, simple keyword matching is usually not enough for finding sophisticated resources such as instructional materials. Therefore a metadata query infrastructure for the P2P system is necessary. Several metadata query languages have been developed within the Edutella project, which are used to query the network for educational resources.

2.3 Visual Technologies. Concept maps are powerful tool for teaching and learning. Concept and Vee diagrams help students to learn and teachers to instruct via the visualization of knowledge structures and relationships among the scientific concepts. This approach is driven by cognitive processes such as Classifying, Comparing, Analyzing (organizing and attributing), and Constructing [7]. CM is a power-learning tool that stands on the human constructivist theories.

Concept maps have successfully been used, both individually and in teams, with young children and adults in schools and universities [8]. Chemistry students, ages 16-18, were taught concept mapping to aid their visualization of knowledge structures and to document and explore changes in their knowledge structures as a result of learning. After four years of experience authors found, that: "...we have grown more and more impressed by potential of this metacognitive tool to help chemistry teachers and learners to improve teaching and learning."

There are significant amounts of visualization tools for representing concepts and data resources. The most important including examples of software are summarized in a matrix shown below.

Table 1. Knowledge visualization tools

Type/Special Arrangement	2D	3D	Hyperbolic
Graph	Microsoft Office	Microsoft Office, GT-VGIS,	
Tree	Cluster tree, Mondesa's Navigator, Empolis K42 Topic Map Engine, Techquila: TM4J, Mind Map from Axon Idea Processor, Map Gallery Kartoo	Cone, UNIVIT, ADEPT	Sphere, Fish-eye H3/H3Niewer libraries, Site Manager
Map	Tree-Map, MDS-Map, Themescape Map, Self-Organizing Map,	Virtual-City, Landscapes, Perspective Walls, Rooms	

Research has shown [9] that among graphs, trees, and maps representations, trees are the ones that are most understood. Trees are easier to interpret than graphs or topic-maps since they are hierarchical and explicitly show the semantic trends. Moreover, trees traditionally use for educational concept map representation. They are habitual and recognizable. We will use graphical software called Grapher from ADEPT project to represent VKI concept space in 3D constructions of nodes.

2.4 ChemQuest (copyrighted name ChemDiscovery)

Teaching/learning Environment

ChemDiscovery is presented in a new educational format—a computerized, open-learning environment on a Web-enabled CD-ROM with accompanying student and teacher materials [10]. The curriculum can accommodate the needs of students with different abilities, interests, and levels of preparation. It can also be adapted to different teaching styles [11].

ChemDiscovery introduces a highly effective “Understanding via Design” approach to teaching chemistry. The approach engages students in active learning for deep understanding of the chemistry content via computer-based design of a virtual world from a chemistry perspective. Students design chemical structures such as atoms, and large, complex systems such as compounds, chemical reactions, and objects found in everyday life. The design process is scaffolded by the interactive learning tools. *ChemDiscovery* is organized into a series of eight projects called Quests. Each Quest has overlapping content and context that offers the opportunity to learn chemistry content directly and/or through the motivational context. The concepts and principles of chemistry build upon one another in an easy-to-understand, logical fashion. Because all important chemistry concepts are hyperlinked to one another in several ways, teachers and students can either construct their own sequence of topics or use the recommended paths through the *ChemDiscovery* learning environment.

ChemDiscovery effort is based on the substantive achievements of the ChemQuest project over the past

decade [10]. *ChemDiscovery*’s controlled vocabulary (index) includes all concept names from NSES content standard for chemistry and has an extension, which was created from a controlled vocabulary of most popular names in US chemistry textbooks. The technology-based, design-oriented learning environment *ChemDiscovery* contains more than 1000 students’ interactive tasks, based on a diverse spectrum of teaching strategies and methods. It includes more than 2000 definitions and explanations of chemistry concepts and rich databases of chemical properties.

These sources provide a perfect start for cataloging chemistry concepts for the VKP knowledge base and alpha testing the VKP semantic components.

2.5 Bloom’s Taxonomy and Other Resources.

Hypothetical ontological models of the standards-based learning objectives, pedagogical strategies, and cognitive processes of the understanding were derived via analysis, restructure, and generalization of several approaches:

1 The taxonomy, also known as Bloom’s Cognitive Taxonomy [12], provides the possible framework for improving teacher effectiveness in designing lesson plans and composing student tasks and activities.

Usability. Over the past 40 years, studies were conducted regarding the use of Bloom’s Taxonomy by teachers. The Taxonomy was translated into more than twenty languages and became popular and widely used among teachers and researchers in the United States and throughout the world. Its impact nationally and internationally was the subject of a National Society for the Study of Education yearbook.

Revision. Bloom’s Taxonomy was recently revised and published [12], not just as an historical document, but also as a powerful classification tool that, in many respects, was ‘ahead of its time’. This revised version was updated by cognitive psychologists, curriculum theorists, instructors, and testing/assessment specialists.

Table 2. Bloom's Taxonomy of Educational Objectives Matrix

The Knowledge Dimension	Cognitive Process Dimension					
	Remember: Recognizing Recalling	Understand: Interpreting Exemplifying Classifying Summarizing Inferring Comparing Explaining	Apply: Executing Implementing	Analyze: Differentiating Organizing Attributing	Evaluate: Checking Critiquing	Create: Generating Planning Production
<i>Factual</i>						
<i>Conceptual</i>		Activity 1	<i>Objective</i>	Activity 2	Activity 7	
<i>Procedural</i>				Activity 3	Activity 6	
<i>Meta-cognitive</i>	Activity 4			Activity 5		

Functionality. General steps in using the Taxonomy include: (a) formulation of the objective; (b) alignment of it with the appropriate knowledge type and cognitive processes; (c) placement of the objective in proper cell; (d) decomposition of the objective; (e) selection of the activity; (f) decision about and examination of the assessment; (h) analysis of evidence of both alignment and misalignment (see table 2 above).

2. Assessment site. Next major source for describing the cognitive processes and different forms of understanding for the VKI models came from assessment site. Wiggins [13] brings in the process of understanding via six facets: Explanation, Interpretation, Application, Perspective, Empathy, and Self-knowledge. Innovative assessment that reveal students' understanding of important concepts in science and mathematics have also been developed.

3. Other components of understanding process that were found descriptions are: (a) establishing relationships among scientific concepts; (b) setting up reasons for the properties; (c) figuring out prioritizing knowledge; (d) representing and visualizing scientific concepts; (5) Applying the knowledge via understanding when, where, and why to use new knowledge

2.6 Memory Types and Models. Five memory pathways have been suggested by current research as the roads to success for learning and knowledge manipulation. There are Semantic, Episodic, Procedural, Automatic, and Emotional memories [14]. All five-memory lanes can help solve the problem:

Semantic – Here are the rules.

Episodic – Thinking back to solving problems are stored here.

Procedural – The steps to solving problems are stored here.

Automatic – Basic science facts are in this lane.

Emotional – Good or bad, success or failure, these are stored here.

Semantic memory provides a central idea for KP functionality. The semantic memory is a lane for words and their relationships. Facts and lists we get from books are stored here. The semantic lane is found in the hippocampus.

campus. Important information in the form of facts must be cataloged through the hippocampus if it is to be held in long-term memory.

There are several semantic memory models, such as:

- a) Network Models: (Quillian/Spreading Activation.
- b) Semantic Feature Model: A concept is defined as a set of features. The semantic features of a concept combine to provide its meaning.
- c) Adaptive Control of Thought model, ACT: Proposition is a combination of concepts the smallest unit of knowledge that can stand alone as a separate assertion; corresponds to the meaning of an event; abstract, an idea rather than a set of words or an image; rule governed; has truth value.
- d) Connectionist Model: The model sets up a network representing knowledge where each element or instance unit is a neuron linked or connected together, excitatory connections. Retrieval is the activation of the unit corresponding to the item, which activates all the properties for the item thus creating a pattern of activation and the greatest activation leads to retrieval).
- f) Parallel Distributed Processing and Information-based Model [15].

3. Vision of the VKI Prototype

The VKI is an integrated, high-tech, teacher-centered, easy-to-use, on-line Lesson Design Environment. The Environment supports teachers' classroom preparation and practice with:

- Visual, semantic-based, on-line planning, searching and discovery of quality materials at a school server, digital libraries, and on the Web.
- Pedagogically and cognitively appropriate graphical integration of these materials into classroom settings via the design of high quality, coherent composition of lesson materials.
- On-line, interactive presentation of the lesson plan, knowledge network, and supporting instructional materials.

5. Description of the VKI Prototype

Vignette I. Ms. Jones decides to prepare her next lesson from home. She opens the VKI on-line lesson preparation interface. Yesterday, as a learner, she used the system to investigate a topic unfamiliar to her regarding Quantum Numbers; today she works with the system as an instructor. The VKI interface involves three windows. Ms. Jones enters the name of tomorrow's intended lesson, "Nature of the Atom." The system automatically builds a Topic-Subtopic map of the lesson congruent with NSES. She clicks the Previous Knowledge button, and checks whether she missed any key points from her previous lessons. Then she selects Objectives. The system splits the lesson objectives into knowledge units and cognitive processes. Again automatically, VKI builds interactive (a) multi-relational teaching concept maps and (b) lesson templates for up to seven possible teaching strategies to match the specified learning objectives most effectively. Ms. Jones edits and rearranges concept maps in her own way; checks their congruence with NSES/AAAS Benchmarks; makes decisions about her teaching strategies by selecting a Discovery Method template; and saves the results in the Lessons folder on her school's server. After that she activates the Query mode and requests the learning tasks and illustrative materials from the digitally-stored, state-approved, curriculum materials on the Web. Soon, icons for tasks and materials appear, clustered around each node of her teaching maps. The VKI sorts student activities into several groups: for students with low/medium/advanced motivation and achievement. Ms. Jones checks the tasks. In conclusion, she finalizes and saves her lesson plan. Done! Ms. Jones glances at her watch. It was three times faster than completing the same planning without the assistance of VKI.

4. Current Approach

At the present time the lesson design process is supported by [16]: (1) Collections of lesson plans on the Web; (2) Applications technologies such as word processor, spreadsheet, database, PowerPoint, HyperStudio, multimedia encyclopedias; etc.; (3) Tutorial or exploratory technologies such as Teachers Curriculum Assistant, MathFinder, or CreateStudio; (4) Communications technologies such as WWW, Email, web-based video-conferencing, and (5) Lesson plan templates.

To create the lesson plan teachers have to search the DL, locate sites or instructional materials, adapt items, and organize them for the needs of particular classroom on his/her own. All those activities require from teachers to be familiar with wide spectrum of weakly related technological tools and to spend significant time for lesson preparation.

To reach the functionalities described in Vignette I, the VKI architecture has to have two main modules: Knowledge Processor and Client, both supported by corresponding services.

The structure of the VKI prototype and the distribution of KI educational functionality between teacher performance and KI system operation represent at Diagram 1 and in Table 3. Table 3 also contains the explanation of the system path numbers found in Diagram 1.

5.1 Knowledge Processor. Activities of the Knowledge Processor (KP) are similar to the workings of human memory. KP knowledge base is defined by several ontological models for the lesson-design environment such as:

- Standards-based learning objectives: cognitive processes and knowledge units;
- Personalization: Teaching/Learning strategies and Learner's characteristics.

These models will make up a knowledge base for the RDF/DAML format.

To present background knowledge that supports VKI pedagogical functionalities, RDF/DAML [6] representation format has been chosen. Specific modeling technologies which will be used in VKI are: (a) the Resource Description Framework (RDF), (b) ontology representation languages for RDF, specifically DAML and (c) the Ontology Web Language (OWL). RDF and OWL are technologies developed by working groups of the World Wide Web Consortium (W3C), the standards body overseeing the Web and Web related information standards [17].

Model of Standards-based learning objectives was constructed from the perspective of Bloom's Taxonomy (table 2). It contains two parts: the model of a knowledge unit and the model of a cognitive process.

Model of Knowledge Unit. To represent the Model of a Knowledge Unit (factual, conceptual, and procedural), the initial ADEPT Strongly Structured Model (SSM) of a scientific concept [2-4] was redesigned into the Unit Knowledge Model (UKM). UKM's comprehensive XML schema includes about 80 elements and is implemented in XML. Two major parts can be highlighted in the structure: (a) identity of unit knowledge and (2) the semantic code of unit knowledge (see part 6.1 for details).

The model of teaching and learning strategies incorporates a wide spectrum of most effective methods of understanding.

Pedagogical functionality of the Bloom's taxonomy will be expanded by metacognitive options about teaching strategies and methods that support better understanding of chemistry and science inquiry and which can help teachers achieve academic objectives and evaluate the advantages and disadvantages during the planning phase [8]. The following sets of powerful and productive teaching strategies and methods for physical science

disciplines was chosen to be included into the model [18-20]:

- (a) Meaningful methods of instruction such as: Connecting with previous knowledge; Discovery method, Design strategy; Inductive/Deductive Method; and Concrete method.
- (b) Teaching by guiding cognitive processes such as: Adjunct Questions; Signaling, and Advance organizer,
- (c) Teaching by explaining examples. Also Collaborative learning, Mnemonic strategy, and Problem-solving strategies have been preferred. Each strategy or method is correlated with the corresponding cognitive process that has to be activated for learning objective achievement.

All three ontological models of the Knowledge Inquirer are currently implemented in the XML schema using the XML Spy authoring software

5.2 Client. The functions a teacher would like to perform call for a User Interface (UI). UI helps achieve the educational and technological functionality of the Knowledge Inquirer by direct graphical manipulation and visualization capabilities [7]. The UI is located at the client and provides two modes: *Lesson Preparation* (Objectives, Graphical Query, Tuning, and Planning) and *Lesson Presentation* (Lesson Outline, Interactive Learning Maps, and Illustrations).

5.3 Services. To achieve educational functionality the Knowledge Inquirer possesses additional local and Web services such as: *Query*, *Knowledge Manipulation*, *Advanced Query*, *Search*, *Filtering*, and *Display* services.

Diagram 1

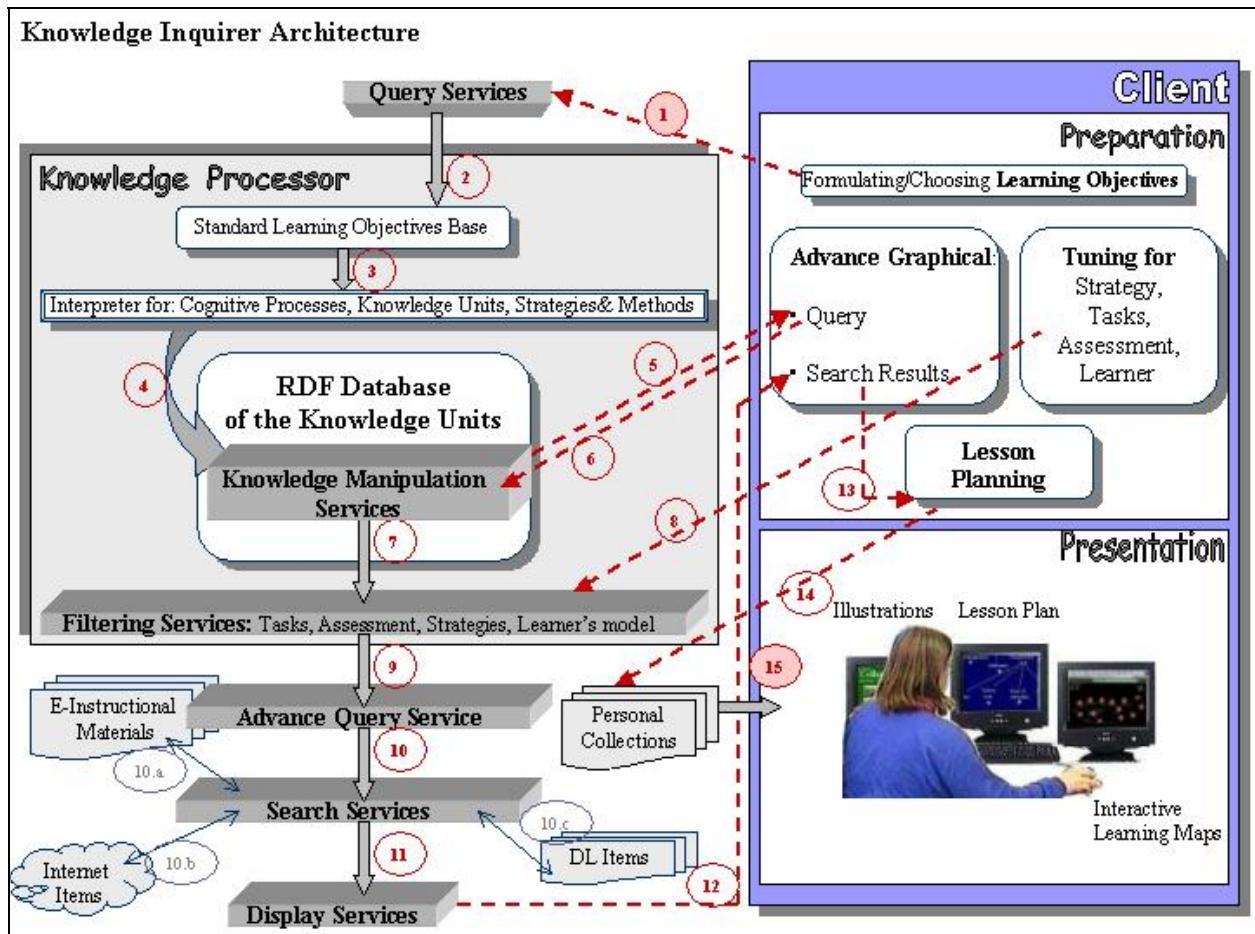


Table 3. Distribution of the KI educational functionality between teacher performances and KI operations

KI System Operations	Teacher Performances
	Identify and Analyze Learning Objectives
# 2, 3, 4, 5. Identifying learning objectives, a set of corresponding concepts and strategies for teaching with increased comprehension.	#1. Formulating the learning objective.
	Making Decisions on Adaptation
	#6,7,8. Tuning the designed plan with respect to the needs of individuals in the classroom (set of concepts and their relationships; students' and assessment tasks; teachers' methods and strategies).
	Searching for Relevant Materials and Displaying Them
# 9, 10, 11, 12. Use a graphical query language, targeting learning concepts and relationships to guide the attainment of learning objectives, and retrieve and present relevant material for designing the lesson plan.	
	Deciding on Tasks
	#13.Decide on the standards-based instructional materials delivered by KI.
	Developing Lesson Outline, Finalizing Lesson Composition, and Deploying
Use composer services to on-line teachers' operations.	#14,15. Finalize and save the online course/lesson plan and related materials on the school's server and edit them from any location on the Internet. Use interactive, standards-oriented course materials in the classroom via the Web.

6. Ontological Model of the Knowledge Unit and its Similarity with a Work of the Semantic Memory

The central element of the Knowledge Inquirer's ontological approach is a model of the Knowledge Unit that is related to other ontological elements.

6.1 The Knowledge Unit Ontological Model explanation.

In our ontological approach each knowledge unit model plays the role of some sort of a "Gene", in particular, a "Gene of Information".

"*Gene of information*" (*KU model*) keeps a comprehensive description of the concept itself and possible relationships of this concept with others. Each single concept expressed here from the perspectives of many different classification approaches, by listing its possible relationships. Types of possible relationships were selected from those present in natural and informational sciences and are used by librarians [21-2]

Flexibility. The above fact makes our ontological approach very flexible and adaptive. Concepts are not rigidly linked to one another during the KU records' creation, as would be in a relational database. Links are activated only in response to system query.

This method has been chosen because the nature of scientific and educational knowledge is incredibly complicated: (1) the knowledge was developed through the centuries; (2) it could be represented and classified in many ways; (3) scientific community tends to have contradictions and different perspectives on classification approaches.

Structure. Two blocks can be underlined in the KU ontological structure: (a) identity of a knowledge unit and (2) the semantic code of a knowledge unit.

The identity of a knowledge unit represents unique properties of the concept. This part includes the following complex elements:

Facet – macro area of reality to which a knowledge unit belongs;

Term – Unique name, Synonym, Antonym, Homonym, or Jargon name;

Explanation – Definitions and Examples;

Representations that include two modes – Represented By and Partially Represents. The first mode contains the elements: Visual/Graphical, Abstract /Mathematical, or Logical/Semantic.

The semantic code part of the model describes characteristics of unit knowledge and several ways (relationships) in which the unit could be incorporated into the scientific knowledge space.

This part includes three major components:

Changes of the unit in time and space;

Operations with and by the unit, such as Abstract, Methodological, Process/Functional;

Possible relationships of the unit to other concepts: Disciplinary, Properties, Hierarchical, Causal, Associative, Applications, and Classifications types of associations.

The model was developed on the basis of analysis and integration of several classification approaches for scientific knowledge [23,24]. It reflects the perspectives of both the natural science and informational science communities, rather than the vision of a few individuals.

The input form for creating concept records has been developed in XML SPY, alpha tested, and ready to be used to populate the VKI knowledge base. At the present time, the VKI contains 45 completed records of physical science concepts, which forms a VKI knowledge base prototype.

6.2 Similarity with Work on Semantic Memory. KP prototype could be described in terms of analogy with the semantic memory models:

1. Knowledge units and relationships among them are major and equal components of the ontological architecture.
2. Information about all possible relationships of each knowledge unit with others is coded inside the unit in a complex element called “Relationships”.
3. Until a knowledge process is activated, the system is static. Knowledge units and relationships exist independently. In static state the relationship itself is an element.
4. When it is activated, the system becomes dynamic. Its pattern changes constantly in space and time, involving interactions among the units via different types of the relationships. Many of them can occur in parallel. Communication among the units can spontaneously commence or pause depending on the problem the learner is trying to solve.

Some units of through the knowledge manipulation can become elements of positive knowledge transfer, while relationships, which emerge the units, can become semantic channels of knowledge transfer.

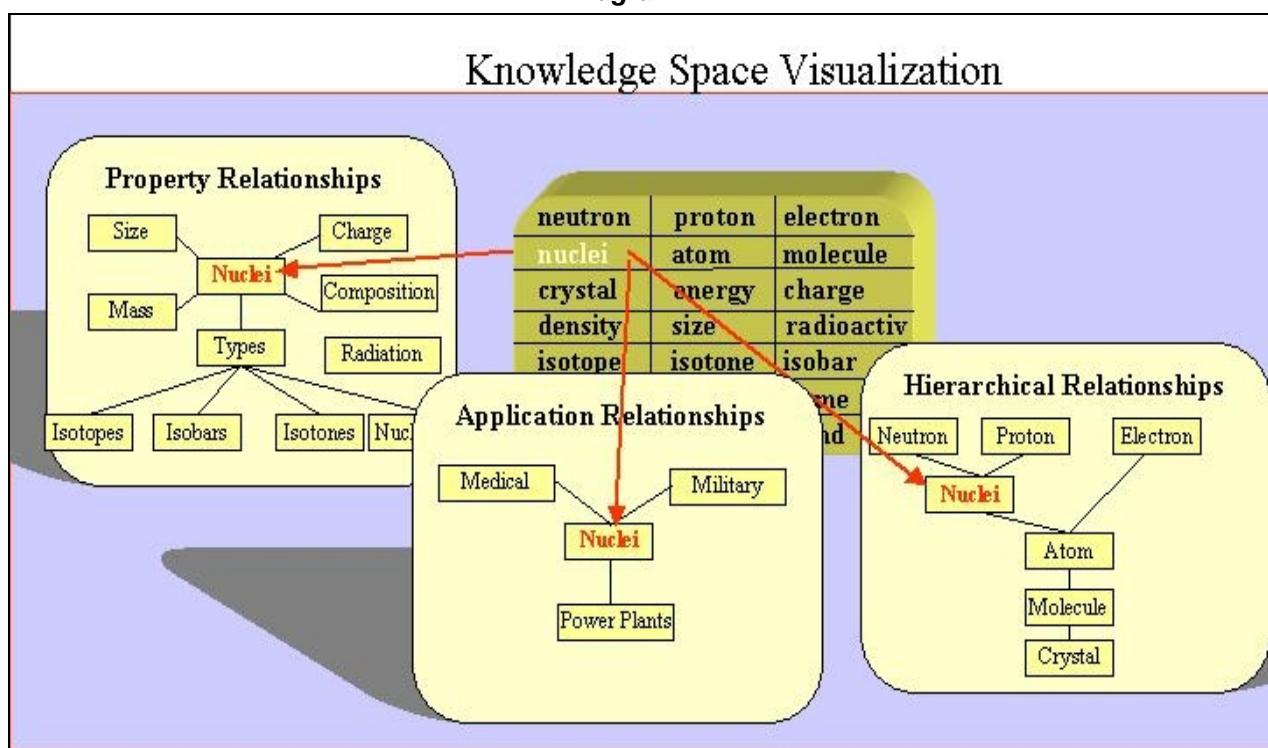
5. Knowledge is not stored in specific nodes. Knowledge consists of connections among simple units distributed throughout the network.

7. Knowledge Space Visualization through the Prism of VKI Ontology

The ontological approach described above provides vast opportunities to:

- Automatically present the knowledge base content in the form of interactive and multi-relational concept maps, which are approximated into semantic memory models.
- Use the interactive multi-relational concept map presentation for visual advance query formulation.
- Modify the multi-relational concept map presentation for graphical organization and presentation of DL discovery results.
- Make teachers' interactions with the VKI system ergonomically correct and positively influence teachers' thinking and productivity.

Diagram 2



The knowledge space visualization and manipulation approaches could be illustrated by the following example. **Vignette II** (see the Diagram 2 above)

Imagine the VKI knowledge base as a 3-D space that is divided by very small cubes. Fill in the base with records of scientific concepts such as neutron, proton, electron, nuclei, atom, molecule, crystal, binding energy, composition, charge, density, size, isotope, isotone, isobar, nuclides, symbol, name, half-life, radioactivity, stability, and etc and place one concept in each cube.

Put the imaginary screens at the front of the concepts' 3-D space.

Define the initial concept and it's relationship with others, for example, the concept of atomic Nuclei and Hierarchical type of relationship. Link them among each other and project the construction on a screen. You will see a hierarchical graph (diagram 2).

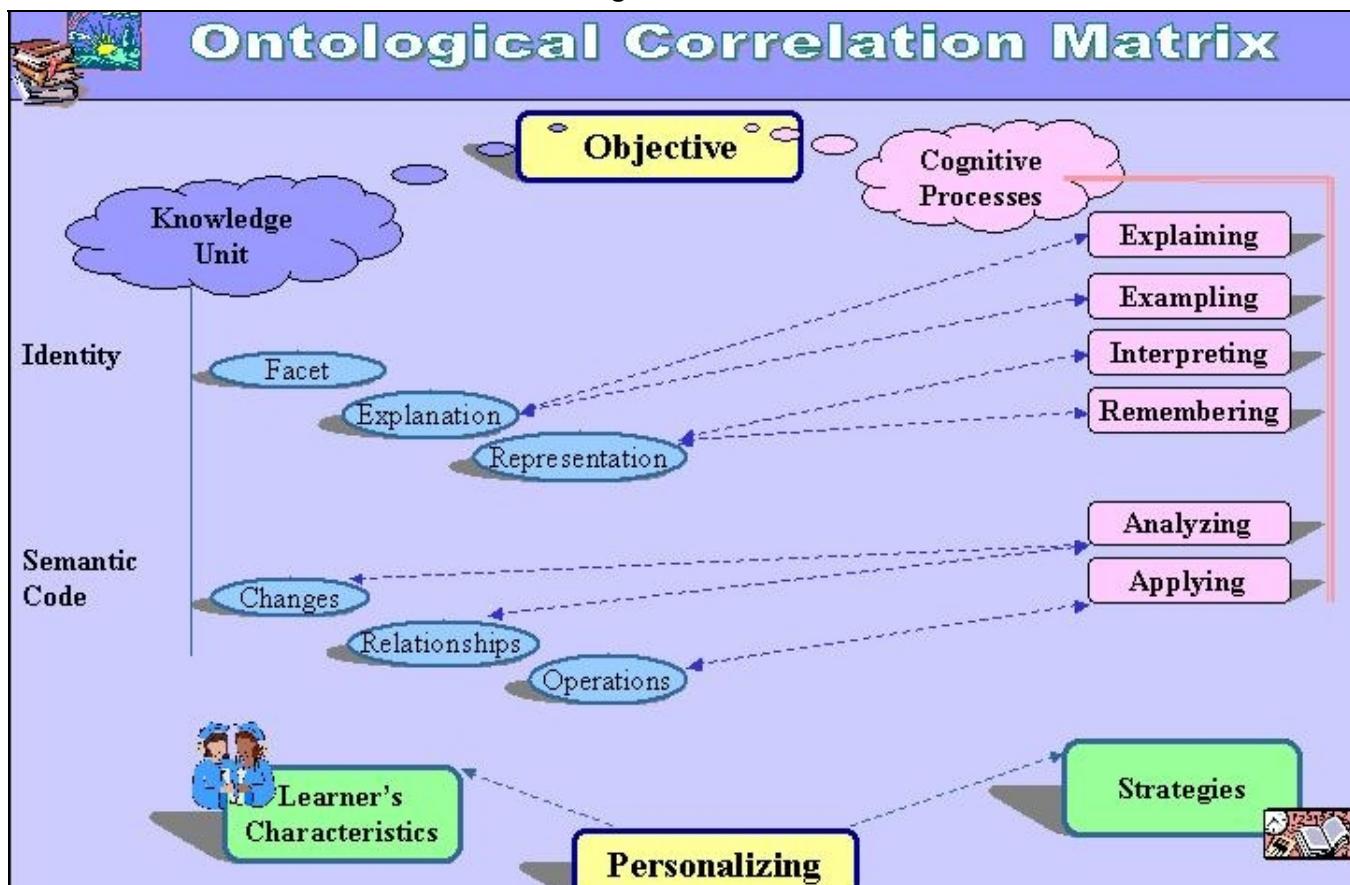
Then, choose another relationships, such as Properties and Applications, for example. Link the initial concept with another set of concepts, and project them on second and third screens.

8. Correlation Among Ontological Components.

The ontological models of the Knowledge Processor were created in the framework of Bloom's taxonomy of learning objectives and ADEPT SSM model of scientific concept. To understand how to integrate major VKI resources and components we have developed a Hypothetical Matrix of the Correlations.

The short version of the matrix (diagram 3) represents major components of the ontological models of (a) knowledge units, (b) cognitive processes of understanding, (3) Personalization (strategies/methods of teaching and Learner's characteristic. Correlation among ontological elements is shown using arrows. The short version of the matrix (diagram 3) represents major components of the ontological models of (a) knowledge units, (b) cognitive processes of understanding, (3) Personalization (strategies/methods of teaching and Learner's characteristic. Correlation among ontological elements is shown using arrows.

Diagram 3



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