Atlas of Nanotechnology

The Atlas of Nanotechnology is a 'super-ontology' of nanoscience, nanoindustry, and nanoeducation. The goal of the Atlas of Nanotechnology is to link nanoindustry work skills to nano curriculum and training for intelligent design and management of workforce development efforts. The central terminology or domain topic map ensures that the entire space of nanotechnology is mapped, including both foundational subjects as well as technology specific areas, such as nanobiotechnology, nanoelectronics, and nanomedicine. Each of the topic maps is mapped through the knowledge and skills attributes of a topic, as determined from the various industry surveys and environmental scans performed by the Centers for Applied Competitive Technologies (CACT), Center of Excellence (COE), the Employment Development Department (EDD), and Foothill-De Anza Community College District (FHDA).

Nanotechnology is a multidisciplinary subject, requiring foundation knowledge in chemistry, biology, physics, mathematics, and engineering. Nanoeducation builds on this foundation, but developing courses that are streamlined for fast skilling or remedial learning in nanoeducation is a complex task. The goal of the Nanotechnology Taxonomy Project is to define the technical concepts and terms that populate nanotechnology. From this list, we will determine where those concepts and terms would be most likely taught (disciplines). Mapping those topics to courses and or lessons that teach this material will help to develop a logical path (certificate) to support nanotechnology education.

Process

The Nanotaxonomy Project will identify nanotechnology topics from both a bottom up and top down approach. In the bottom up method, current literature, including books, publications, and websites, are examined to put together a large topic and terminology list. In the top down approach, key topics from each of the foundation subjects are listed; a set of 'critical success factors' to a strong foundation for further learning. These foundation subjects—chemistry, physics, biology, and math—have ontologies that can be derived from exiting topic domains, and also through textbooks. Already over 2,500 terms and topics have been identified. Each will have a definition, and a Knowledge, Skills, and Abilities (KSA) dimensional approach to introducing and teaching that topic. The KSA dimensional approach includes knowledge, skills, and abilities, also taught as declarative, procedural, and cognitive components (Cormia & Singh, in preparation).

The data model for each topic, written in XML, will include definitions, hyperlinks to Web references, and XLinks (an XML specification for describing links between resources in XML) to Web based lessons and courses that teach those topics. Using XSL (a language for expressing stylesheets) to visualize the links, the connections between and among topics can be navigated. These paths can constitute a logical map to nanoeducation, helping students find the most efficient path to learning. The KSA attribute links between topics also connect to the topic database records, and additionally to the outer IEEE Learning Objects Metadata (LOM) for the learning object resources (London, 2005).

Effort for help in the topic mapping process would need to come from both faculty and subject matter experts (SMEs) that are able to 'carve out' a section of the map, help identify terms and their proper associations, and build out local ontologies. Using FreeMind™ (http://freemind.sourceforge.net), this process still requires substantial effort, and grants proposals to the National Science Foundation (NSF) and International SEMATECH Manufacturing Initiative (ISMI) are in progress to help support this process. Ontologies will be converted into the Web Ontology Language (OWL), and then into an XML topic mapping format, described below.

Using XML topic maps (http://www.topicmaps.org/xtm/), a navigable Web based system can be constructed which would serve at least three needs. The first is a to create a taxonomy based description of nanotechnology that can serve as a lexicon for technology and scientists seeking updated links to news and information. The second is the more fundamental topic map (based on concept maps and taxonomy) description of core concepts in nanotechnology needed for industry and academic pursuits. The third is to integrate an XML hyper linking system to connect topics with open source learning objects. This component facilitates use, and requires input, by nano education (students and faculty) across the globe. This latter effort also builds on the concept of learning object repositories, with metadata written in IEEE LOM, and deployed (in course management systems) using the Sharable Content Object Repository Model (SCORM).

Atlas of Nanotechnology

The Atlas of Nanotechnology is a compilation of six topic maps, which each capture a critical component of nanoscience education and workforce development.

- An ***Atlas of Nanoscience and Nanoskills***
- Six separate maps ***interlinked*** through ***K&S attributes***
    - Domain map - the domain specific terminology of nanoscience and technology
    - Knowledge map - the pivotal concepts and knowledge that describe nanotechnology
    - Skill map - the skills inventory for the nanoskilled industries
    - Industry map - the industry map of companies within nano-industry
    - Course map - a course map showing titles and departments where nanoscience is taught
    - Resource map - a map into open source learning objects that faculty can use for preparing curriculum in nanotechnology.
- Topic maps are a ***'network of topics'*** that are ***interconnected*** in an ontology
- Nanoscience topic maps includes the ***top level subjects*** (physics chemistry, biology, materials science, electronics)
    - Also includes the ***'nano specific' terminology*** – self assembly, carbon nanotubes, molecular manufacturing

The Atlas project starts with a simple concept-mapping tool called FreeMind™, which is available open source (Windows, Macintosh, and Unix) at http://freemind.sourceforge.net. FreeMind™ creates visual concept maps that can be exported to HTML (they use XML as their native code). The tool can be learned, at almost an expert level, in less than 15 minutes. FreeMind™ mind maps have a .mm file extension, and are portable across all three platforms (as they are written in XML). The draft version of the Atlas of Nanotechnology had roughly 2,000 topics in the terminology map, comprising at least 20 level one ontologies, and 400 level two ontologies. These maps are printed to .pdf files and printed in Appendix one.

We are working on a series of XSL transformations and scripts that will convert the base XML files and associated data models (in FreeMind™) into a format that approximates the XML Topic Maps (XTM) version 1.0 model. From here, we next plan to create a navigable Wiki that connects nodes in the topic map with HTML pages. Rather than scanning a linear web page, users are navigating a multi-level ontology, presented as a hypertext document.

Top Level Ontology - Nanotechnology.mm

Our top-level map in the Atlas contains 15 nodes to the core subjects and topics in nanoscience and technology, including the core foundation subjects. The ontology was thus broken down into two halves – basic subjects and 'nanotopics'. Each basic subject, such as chemistry, links to a separate map, e.g. chemistry.mm. These 'submaps' each contain 25 to 50 level one topics, and each of those 10 to 20 subtopics, or about 1,000 total nodes per submap. A lexicon of 100 key concepts would comprise a total of about 1,000 index terms, showing how the 'basic subject maps' can easily be constructed literally using a 'textbook' approach.

The nanotopics map is quite a bit more effort. The top categories here comprise major focal areas, such as nanostructures, nanodevices, nanofabrication, materials characterization, thin films, semiconductors, nanobiotechnology, and nanoelectronics. These are generally agreed upon as the major areas that comprise 'nanotechnology'. For each of these areas, an SME will be needed, although it is very possible that no more than three to five persons can build all of this out, but it will be a lot of work to develop what is estimated to be another 2,500 terms in these specialized areas. Once the terms are identified, and linked to their associated topics, the even harder work of developing a definition list for each, and then links into courses, will occur. This is the effort that will eventually lead first to an ontology, which the Taxonomize tool can then assemble learning modules to, and then later to a navigable topic map (using XSL and HTML) allowing users to navigate a topic map that is connected to learning objects.

Basic subjects

- Biology
- Chemistry
- Physics
- Mathematics
- Engineering
- Computing

Each of these subjects represents a key foundation for developing a life-long career in nanoscience and nanotechnology. Chemistry, physics, and biology are now certain requirements for nanobiotechnology, a key emergent area in nanotechnology. Additionally, mathematics, engineering, and computing are essential for modeling the structure and properties of nanostructured materials. Each of these key subject areas is considered a level one ontology, with at least 50 subtopics in each subject's level two ontology. Using both table of contents and index of textbooks as a guide, level three ontologies can have an additional 20 key concepts. This for each subject, there are easily 1,000 topics, bringing the total topic network for the foundation subjects to over 5000 nodes. Subjects represent one of the two key ‘knowledge maps’ of nanotechnology, the other being a map of subjects (topics) that emerge from interdisciplinary associations of topics. Interdisciplinary topics include nanobiotechnology, quantum computing, self-assembly, biophysics, molecular modeling, computational chemistry and computational biology, etc. By correctly identifying the key topics in the foundation subject map, the emergent interdisciplinary topics can emerge as associations. Further, each of the topics in the knowledge map will contain links to resources, i.e. textbooks, courses, or independent learning objects, which contain material for teaching those topics. In this manner, a navigable knowledge map of nanotopics will only be two links from a learning object that teaches the foundation subjects for that topic.

Nanotopics

- Nanostructures
- Nanodevices
- Nanofabrication
- Surface chemistry, colloids and particles
- Materials characterization
- Thin films
- Semiconductors
- Nanobiotechnology
- Nanoelectronics
- Materials science

The structure of this ontology also follows the approach of the foundation education map, shown in basic subjects, but builds more towards nanotopics, which comprise specialized training and education, and the emergent association of foundation topics. The ten categories of nanotopics also derive from the familiar nano-related courses now offered in some colleges and universities. Mapping these topics into both the foundation subject map, through knowledge attributes, and into learning objects (XLink and RSS, a format originally used for syndicating news and the content of news-like sites) provides a mechanism to connect very specialized topics to learning resources. For workforce development, and ‘fast skilling’ in particular, links from XTM topic nodes in specialized nanotopics directly to learning objects would facilitate both on the job education, as well as ‘self-assembly’ of properly metadata labeled SCORM objects into course curriculum.

The nanotopic map described above also serves as a structured taxonomy and a checklist for learning outcomes taught in many current courses that are not a part of ‘formal’ nanotechnology programs. As will be described in more detail below, using topic maps to develop formal ontologies facilitates the comparison of courses, though their learning outcomes, as a more objective method of articulation, and possibly a foundation for building logical certificates. The latter effort involves self-assembly of learning outcomes, as interchangeable objects, as an atomic component of course objects.

Connecting topic maps

- Nano terminology

    - Nano ontology (categories)
    - Nano taxonomy (terminology)
- Nano 'work' (skills)
- Nano courses (knowledge)
- Nano curriculum (course objects)
    - Courses contain K&S learning outcomes

XML Topic maps are connected through various attributes, the most common in the Atlas of Nanotechnology being the knowledge and skills attributes. A principle value of topic maps are the connections through associations, and by using KSA for associations, the entire Atlas is essentially linked through the Knowledge and Skills theme. For education, the Knowledge attribute is most critical, and for workforce development, the skill attribute is most critical. The goal of the Atlas project is to identify knowledge from the subject and nanotopic areas, and determine where specific knowledge (learning outcomes) are provided from courses. Implicit in this goal is that course (objects) have properly written learning outcomes, and even better, use a KSA schema as a metadata to describe these learning outcomes. In this respect, the course map (topic map of science and technology courses in both foundation and nano specific areas) is linked to the nanotopic map (key nano-specific terms and concepts) through the knowledge attribute. As a formal ontology of nanotechnology does not yet exist, a goal of the Atlas project is to build such an ontology, and include in the formal data model attributes of knowledge and skills, such that direct associations between and among nodes in each of the maps are connected through learning outcomes.

What problems are we solving?

- Pathways for intelligent workforce development
- Pathways for formal nanotech education
- Are two courses similar?
- Recognizing 'aggregated learning outcomes' from disparate institutions

The primary problem that we are solving is that the design of curriculum for meeting the needs of workforce development is not done through an intelligent analysis of the requisite knowledge and skills required by industry, as expressed in clear definitions of knowledge and skill. Starting with a definition of work, broken down into critical work functions comprised of tasks, each task has a skill, and also a knowledge foundation. Skills may be derived from on the job training (OJT) or from a college laboratory. Knowledge is almost always derived from a college, university, or extension course. An additional effort is building a KSA schema (a schema built with knowledge and skill attributes) that can be used to describe each learning outcome in terms that can connect college courses with industry needs.

The five other (dependent) maps

- Knowledge map
- Skill map
- Course map
- Industry map
- Resource map

Connected to the nanotopic map, are the knowledge maps, skill map, course map, industry map, and resource map. As described in detail above, the knowledge map is the topic map of key knowledge terms needed in areas of nanotechnology. The skills map is the map of tasks that are performed in various nanoskilled industries, and these tasks are mapped as jobs (or work function concentrations) in the industry map. The industry map itself is a network of companies, core competencies, and intellectual property (use patents) that are concentrations of skills, knowledge, and IP, respectively. The course map is a network of courses found in various colleges and universities that either teach a foundation subject (chemistry, physics, biology, math, engineering, etc.) or a nano-specific concentration (materials science, surface chemistry, materials characterization, etc.). Finally, the resource map is a network of independent (and interdependent) learning objects, at some point using metadata for learning outcomes (knowledge and skills) that is linked through knowledge and skills attributes into the knowledge (nano concepts) map. Nanoscientists wishing to 'self assemble' a course from SCORM and other learning objects can follow a nanotopic from the knowledge map into the resource map. The resource map is also an inventory of 'open source learning objects', with RDF metadata to aid their 'findability'.

Knowledge Map

- What are the ***key concepts*** that students and working professionals need to know?
- These are both ***prerequisites*** to learning new concepts in nanoscience, as well as ***key learning outcomes*** from coursework
- Knowledge map is connected to 'courses' through the ***knowledge attribute*** in KSA

The knowledge map of nanotechnology is a critical component of the Atlas. It represents not only the collection of key concepts in the foundation subjects of chemistry, biology, physics, mathematics and engineering, but adds nanotechnology specific terms, such as self-assembly, carbon nanotubes, and micro-electro-mechanical systems (MEMS). Additionally, for each knowledge term, there should be an association with a knowledge attribute from a learning outcome in a course object. Mapping the 'knowledge map' into the 'course map' facilitates an analysis of what courses should (or could) be included in a program of study to ensure that a given area of focus, i.e., bionanotechnology, or nanoelectronics, is adequately covered. Ideally, this same exercise could be done to see how much of the knowledge map is covered by any one program, through aggregated learning outcomes. Additionally, if an area of the knowledge map is not covered in a program, mapping the required knowledge though the KSA attributes can help locate, wherever they exist, the best course for that knowledge.

Skills Map

- What ***skills*** are needed to do ***work*** in nanoscience? What ***tasks*** are practiced in the course of 'doing' nanotechnology?
- Skill map is derived from ***interviews*** with industry and nanoscience workers
- Skill map is connected to ***'courses'*** map through the ***skill attribute*** of KSA schema

The skills map is constructed in an analogous method to the knowledge map, but focuses on analysis of work performed in industry, especially as it relates to nanotechnology. There are three key steps in building out the skills map. First, through an industry survey, locate industries, companies, jobs, and job titles where nanoscience and nanotechnology is being performed.

Second, conduct interviews that lead to job analysis, and determine the critical work that is performed, and tasks associated with that work. Third, from work and tasks, what skills are either gained through performing this work, and or are required to perform this work? Those skills, called 'skill attributes' serve as associations to link the jobs (industry) map into the course map. Ideally, we would either find courses with labs, and or experiential learning (internships), that provide a base of skills that, in addition to knowledge, qualify job applicants for technical positions in industry. As with the knowledge map, where the skills map has no associations in the course map, a method of providing those skills would be needed. It is possible that skills associations with one job might be 'inherited' from another job, meaning that on the job training (OJT) might be a source of particular skills that are difficult to obtain in a normal course of study. If this is the case, nanostudies might need to include specific experiential learning. Many programs, including Penn State and University of Minnesota, already include an internship / externship as part of the learning activities.

Course Map

- Course map is a **comprehensive list of courses** (starting in CA Bay Area), their descriptions and ***KSA learning outcomes***
- They appear in engineering, physics, chemistry, materials science, electronics
- Each course has a knowledge and skill (KSA) attribute for ***each*** learning outcome

The course map is a both a comprehensive list of courses (starting in the San Francisco Bay Area) and their organization into departments, such as chemistry, biology, math, engineering, including finer grain detail, such as materials science, biotechnology, electrical engineering, etc. Next, using either a course outline of record, and or a syllabus, determine the learning outcomes as stated in terms of knowledge and skills. Using a KSA schema, learning outcomes from each course serve as knowledge and skill attributes that interconnect other maps in the Atlas, most importantly the nanotopic map itself, and the industry map. Starting from a known list of KSA requirements from industry, a certificate, program, or logical course of study can be chosen to prepare persons for technical and or scientific employment in industry. As will be developed further, given a completed course of study, the KSA learning outcomes from a series of courses could be aggregated, serving as a more granular description of learning than a transcript. Last, if all courses used a KSA schema to describe learning outcomes, a student could simply present evidence of satisfactory completion of those courses, and an inference engine would be used to aggregate and organize those learning outcomes into a composite statement of learning. This will be developed later into the concept of a 'logical certificate', and also as a methodology to rank the effectiveness of a program of study.

Nanocourses.mm – a Certificate Map

- Introduction to Nanotechnology
- Introduction to Materials
- Nanostructures and Nanofabrication techniques
- Materials characterization
- Surfaces and colloids (or Surface Chemistry)
- Nanodevices and applications
- Nanobiotechnology
- Nanoelectronics

- Thin films
- Internship / Experiential Learning / Co-op education

Nanocourses form a map of academic offerings from local colleges and universities. An analysis of offerings from Stanford, FHDA, San Jose State University, University of Santa Cruz, and Santa Clara University showed over 500 courses in chemistry, biology, physics, engineering, mathematics, and materials science that relate to nanoscience and nanotechnology. It is further of interest that none of these institutions offers a formal degree program, yet together; all of these courses can provide a number of rich and diverse learning outcomes. This is one of the outcomes of applying a KSA schema to course outlines, so that learning outcomes from diverse courses can be aggregated. The courses above represent the proposed ten-course certificate for Foothill DeAnza Colleges, and also from analysis of prominent nanotechnology programs including Penn State, University of Minnesota, University of New South Wales, and Leeds University. Many of these courses are taught through extension or professional development, however their inclusion in a full course of study, particularly an academic certificate, is uncommon. One of the goals of the Atlas of nanotechnology is to build a system of organization such that learning outcomes, aggregated from courses in any certified instructional program, should be able to transfer into a 'logical certificate, especially when those learning outcomes are characterized and described using a KSA schema.

Industry Map

- Companies and what they do
    - Core technology / IP
- Names of key individuals in the company
- Job positions (and typical positions)
    - Links from jobs to knowledge and skills
    - What K&S is required for nanoskilled work?
- Products manufactured or in R&D
    - Links into the future nanodevices topic map

The industry map contains a list of vertical markets, companies, competency, core IP, and links to jobs, to build out an anatomy of the industry requirements for knowledge and skills. Additionally, the industry map can have links (attributes) to manufactured products and services, further adding information and 'texture' to the Atlas of Nanotechnology'. The main purpose of the industry map is to organize the technical work and nanoscience related activities in industry, and map them into jobs, job titles, and eventually into an inventory of knowledge and skills. As forward looking projections of where nanotechnology may be employed in the fields of chemistry, materials, semiconductors, electronics, biotechnology, and medicine, a gap analysis of current (aggregated) workforce knowledge and skills can be compared to the anticipated need. In that way, training programs can be designed and deployed to meet the future needs of industry.

Industry map – Job connections

- Job
    - Work function concentration
    - Knowledge and skills attributes
    - Companies have Workers who do Work and need Knowledge and Skills

A key activity for the industry map is doing a thorough analysis of jobs employing 'nanoskills'. A job, or 'job object', is essentially a 'work function concentration', comprising groups of tasks. Each task can further be described as employing specific foundation knowledge, and a specific set of skills. Industrial psychology describes this as 'know and do', respectively. Each task, in a topic map for that job object, has a specific knowledge and skill requirement. Those requirements, expressed as knowledge and skill attributes, link each job in the industry map into learning outcomes from academic courses, and or experiential learning (OJT) and specific industry experience and training. As eluded to earlier, it might be possible that certain jobs may show associations with other jobs, meaning a 'career path', especially when looking at the temporal component, i.e., 'sequence' of jobs within nanoskilled industries. We would expect to see this within a vertical industry segment, especially biotech, electronics, chemistry, and materials.

Putting it All Together

- Job objects are divided into critical work functions (WF) a series of discrete tasks
- Each task has a requisite knowledge and skill (K&S) requirement (typically education and experience on a resume)
- Career certificates should have courses with ***K&S learning outcomes*** that map into the critical workforces needed in industry

Knowledge and skill attributes are the glue that interconnects all of the individual maps. The goal of the Atlas is intelligent workforce development, including mapping of job requirements into course objects (KSA learning outcomes) and or OJT competencies. The goal of the Atlas is 'intelligent workforce development', meaning the organization of work requirements, expressed as knowledge and skills, and the learning outcomes of academic programs and or experiential learning, also expressed using a KSA schema. As we develop experience with both job analysis, as part of our nanosurvey of industry, and further develop our KSA schema for expressing learning outcomes, the Atlas of Nanotechnology will serve as a navigable map of career and workforce development.

Mapping Work Skills to KSA Learning Outcomes

- Each job is a concentration of tasks, or a 'work function concentration'
- Each task has a requisite knowledge and skill
- Where does that knowledge come from?
- Where do the skills come from?
- Ideally courses can be mapped to knowledge
- Training for skills might be more difficult (OJT)
- Knowledge and skills attributes link work with learning

Using a DACUM approach to job analysis (see http://www.dacum.org/), each job is broken up into a concentration of tasks, or a 'work function concentration', and each task has a requisite knowledge and skill. Using primary survey data (say in an environmental scan) the source of a worker's knowledge is mapped into courses he or she had taken, and this allows us to interconnect the job map into the course map. The same exercise is done for mapping skills into OJT learned competencies, such that we can trace a path for nanoskilled workers into industry.

Understanding Nanoskills

- Map of companies and competencies
- Include map of job title and work function
  - What ***'work'*** do people do? (WF)
  - What ***knowledge*** (K) do they need?
  - What ***skills*** (S) do they need?
- Link K and S from above to either learning objects from course objects, or learning objects
- ***Remedial*** learning and / or ***fast skilling***

As we develop the skills map further, we hope to gain an idea of how nanoworkers gain differentiable skills that are built on top of a traditional chemistry, biology, physics, and engineering foundation. Where possible, we will attempt to find small, self-contained learning modules that allow working professionals and students alike to 'fast-skill' into knowledge to help with day-to-day work related conversations, i.e., 'nano-terminology'.

Linking XML Topic Maps

- Nanotopics
- Nanocourses
- KSA outcomes
  - Knowledge attributes
  - Skill attributes

XML topic maps are linked through associations, which can connect the nodes of one map into the nodes of another map. Typically associations occur through common attributes in the data model, which are Knowledge and Skills. Thus the KSA model is really defined as Knowledge and Skills Attributes of learning outcomes.

KSA From Job Objects

- KSA requirements
  - Knowledge
  - Skills
  - Abilities
- Linked to job objects

Every formal job description usually includes education and experience, which roughly correlate to knowledge and skills. Knowledge and skills from job objects are usually expressed as requirements, however a job can provide knowledge and skills through OJT – on the job training. As persons invest time in a career, they are likely to attend workshops, short courses, and or formal education at a college or university. This knowledge, when applied contextually, often contributes significantly to reflective learning. Story centered curriculum, knowledge in context, is a trend in workforce development, especially for working professionals seeking specific knowledge and skills.

KSA From Course Objects

- Knowledge

- Skills
- Abilities
- Linked to course objects

The KSA schema will be developed further as both an IT approach to codifying a formal description of learning outcomes, as well as a practice for describing the methodology of a learning outcome. As applied to course outlines of record, a KSA schema, written in XML, would be machine-readable. Using a simple parsing and inference engine, we hope to build a prototype system to encode, aggregate, and compare learning outcomes from diverse and disparate courses. The goals of this project are to develop a 'Center For Articulation' (Sabelli and Singh, 2004). This Center would train faculty in developing a rigorous practice of defining and declaring learning outcomes in terms of knowledge and skills, and more importantly, to document the method by which a student-learning outcome is produced. This process is currently being developed at Foothill College in the Learning Outcomes and Assessment Network (LOAN) committee. As a practice, we are applying this to requirements to describe the resources, activities, and assessment of learning outcomes in chemistry, physics, and math. The practice is not a technology, but rather a process not unlike ISO 9000 requirements for manufacturing.

Learning Object Map

- Map of free standing learning objects
- Eventually will be 'Web deployed'
  - o SCORM standards / LOM (KSA) schema
- Each 'object' will have three attributes
  - o Knowledge
  - o Skills
  - o Assessment
- Navigate a learning-space for a K&S

As knowledge and skill requirements are further broken down into discrete learning outcomes, it is possible that Web deployed learning objects, i.e., learning modules including hypertext lessons, PDF and PowerPoint files and lectures, and Flash animations, might serve to provide discrete learning outcomes. This serves two immediate and related needs. The first is a method to describe learning outcomes in metadata beyond what is employed with IEEE-LOM and SCORM. The second is to help build a repository of open source learning objects, which can be 'self-assembled' into courses for rapid deployment, and or filling gaps where curriculum is needed. Given the complexity of nanotechnology, it is very probable that courses will someday build learning outcomes from independent sources, like an open source repository, and will require a KSA schema to organize and document the learning outcomes of each object.

Learning Object Map

- Course topics
- Learning objects
- Learning outcomes
- KSA schema
- Knowledge

- Skills Curriculum Course Map

Learning object maps, the last of the Atlas, would be a representation of learning objects that could be found, assembled, and organized based on learning outcomes. These learning outcomes would be organized in a KSA schema, and further described using a metadata model like the Resource Description Framework (RDF), part of the Semantic Web Initiative (http://www.semanticweb.org) and http://www.w3.org/2001/sw/). In this way, faculty involved in building out nano-curriculum could find and integrate learning objects into a course (IEE_LOM), and course management system (SCORM), as well as design learning outcomes which are validated using a KSA schema.

Are Two Courses 'Similar'?

As the KSA schema is developed further, we hope to employ an inference engine that can compare the aggregated learning outcomes from two different courses to see how similar they are. Two courses that are 80% similar would be seen as almost equal, and thus a 'logical articulation' status might be assigned. As we look to design very flexible and dynamic certificates, especially in allowing for differentiated learning outcomes, the KSA schema, and a logical articulation process, would allow for two related innovations. The first is substitution (or addition) of a course into a certificate, no matter where that course originated, given that a KSA schema and a documented methodology for student learning outcomes was provided. Second, we could allow certificates to 'describe and define' themselves, based on the aggregated learning outcomes of the constituent courses. Both of these innovations require a KSA schema, combined with a parsing and inference engine for aggregating and comparing learning outcomes. Also implicit is a practice of documenting the methodology of the student learning outcomes. All three activities comprise the basis of the Center For Articulation (Sabelli and Singh, 2004).

Learning Outcomes as Interchangeable Parts

In order for course objects to be interchangeable, dissection of the course into segmented learning outcomes, each described with a methodology (i.e., resource and activity) and an assessment tool is needed. If a course isn't articulated, perhaps learning outcomes are still valuable, as further described in Center For Articulation (Sabelli and Singh, 2004).

Course Objects as Interchangeable Parts

As courses adopt the KSA schema, the Center For Articulation (Sabelli and Singh, 2004) allows for exchangeability of courses into certificates. Course objects are just a unit of student learning outcomes, and one of the goals in the Center For Articulation (Sabelli and Singh, 2004) is to determine how similar courses need to be for full articulation.

Aggregated Learning Outcomes

As mentioned above, using a parsing engine to collect learning outcomes from disparate courses allows a student to collect knowledge and skills, not just courses, as units of currency for completing a program. Even when a certificate of completion is awarded, the variation in course substitutions can lead to two approved certificates having very different learning outcomes. When factoring in reflective learning, the completion of an internship, and or OJT (co-op education), can lead to significantly different outcomes.

Logical Certificates and Logical Certificate Map

- Concept map nano outcomes
  - Materials, nano-bio, nano-opto, etc.
- Map (KSA) nano topics to classes
  - Locate courses that ***teach nano topics***
- Map (organize) classes into outcomes
  - ***Self-assemble*** logical certificate tracks
- •Nano-***certificate*** = nano-topic ***roadmap***

The end goal of all these activities is the realization that students and working professionals will weave a complex path through formal education, and work experience, and a certificate should reflect the aggregated knowledge and skills of that individual.

*It is **probable**, not just **possible**, that we are **already** teaching*
*the **principles of nanotechnology**, but we haven't **organized it!***

Timeline / Resources

- Summer 2005 Build out topic map in FreeMind™ to about 5000 nodes
- Build a data model (in Access) for each of those nodes
- Experiment with a conversion tool for FreeMind™ and / or Access into XTM
- Build out a master 'Atlas of Nanotech' in XTM in fall 2005
- Build a navigable wiki, in hypertext, for the nanotechnology XTM topic maps
- Convert the key knowledge maps into OWL ontologies for Taxonomize Engine

People

- Robert Cormia
- Neha Choksi
- Anthony Chang
- Deb Newberry
- Jack Park
- Sukhjit Singh

Grants

- NSF (submission in Fall 2005)
- ISMII (submission in Spring 2005)
- Other… (help from SRI in locating resources)

Partners – Collaborators – Proposed SMEs

- Carnegie Mellon University West
- Stanford Research Institute
- NASA-Ames Research Center
- San Jose State University
- University of California Santa Cruz
- University of Minnesota
- University of Pennsylvania

Definitions

RSS – RSS has two definitions. Rich Site Summary and Really Simple Syndication. The latter definition refers to XML channels that typically connect two resources on the Web through a mechanism of content integration, which is indexed and defined through XML linking mechanisms. Using XML topic merging, the system can ultimately be built and maintained through machine assisted discovery and integration of new content.

Open Source Learning Objects - Loosely defined as content, which is bought and licensed or made available by publication companies, content authors, faculty, and or students interested in building out a distributed and interlined nanoeducation resource.
Two persons with nanotechnology training built out the first draft of the map, with about 15 to 20 linked maps from the first level of the ontology, and roughly 20 linked maps from each of those ontologies (400 second level ontologies) leading to about 10,000 to 20,000 leaf nodes – individual topics that describe keyword topics in foundation subjects including biology, chemistry, engineering, physics, and materials science.

Nanotechnology Curriculum Project using XML Topic Maps (XTM)

In the past six months Foothill DeAnza Colleges has been developing a nanotechnology certificate built around the program organization of University of Minnesota - Dakota County Technical College, University of Pennsylvania, and University of New South Wales. Additionally, we have developed a nanotechnology curriculum map from courses taught at Stanford University, University of Santa Cruz (UCSC), UCSC Extension, and San Jose State University (SJSU). We are proposing a collaborative certificate involving course objects from FHDA, SJSU, UCSC, and UCSC extension, coordinated through the Collaborative at NASA-Ames.

Our emphasis has moved towards using Topic Maps as an organizing process for mapping the key topics in nanotechnology (in the eyes of industry and academia) into 'course objects'. The goal is to logically build, from existing course objects, the right learning outcomes in nanotechnology, independent of where these courses are taught. These efforts have been encouraged and supported by both the nanotechnology education group at SRI, and their AI group (knowledge organization).

We've started a project that includes an NSF grant proposal to get funding to both build as complete a topic map in nanotechnology as possible, and use that methodology to construct a curriculum certificate for various nanotech outcomes, i.e., nanomaterials, nanobiotechnology, nanoelectronics, etc. Additionally, we plan to build an inference engine to use topic maps and meta-encoded course outlines to logically design other curricula, e.g. bioinformatics and biotech.

The process and infrastructure from this effort will be used to implement a curriculum map for nanotechnology, and be extensible to build both curriculum maps and programs from properly constructed topic maps, and course objects meta-tagged with KSA learning outcomes.

These efforts will require expertise from SMEs in nanotechnology to build out the topic map, and evaluate the terminology and definitions for completeness. Three Universities in California, Minnesota, and computer scientists involved in the original XTM specification have indicated interest and or participation in the project. Additionally, Carnegie Mellon University (CMU West) will participate in the software development of both the Topic Map and inference engine architecture.

The timeline for the project is to begin the topic map with help from local faculty and industry experts that can help define the critical knowledge and skills in nanotechnology industries, and the sources of academic learning where working professionals and students can obtain this knowledge. This process is expected to take at least a year to develop a reasonably refined map. Funding will be sought for this effort, but will start regardless of the NSF grant proposal outcome.

Work on the software engineering effort that includes taxonomy and ontology generation, as well as Semantic Web tools for abstracting meta data associated with course objects, is expected to take two to three years. Funding in excess of one million dollars will be required to build out the IT infrastructure as a fully implemented process tool.