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Interactive Training Through Knowledge Navigation

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Interactive Training Through Knowledge Navigation (a Preliminary Project Report)

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ABSTRACT

This paper describes the initiation of our project to study three-dimensional navigation through manufacturing knowledge domains suitable for training. In summary we are organizing and representing knowledge from the NIST Manufacturing Engineering Laboratory (MEL) and associating that knowledge with virtual objects within a virtual, three-dimensional environment. We are using the MEL Shop as a metaphor to represent the top-level spatial structure that houses the virtual objects. The Virtual Reality Modeling Language (VRML) standard plays a key role in our initial work. However, the role of interoperability standards, in general, will be significant in this project, both for implementing the navigational platform and for populating it with manufacturing domain content. The main goal of this paper is to describe the information we have studied, our thought process in defining the project, and the preliminary prototype we have developed to show our initial ideas.

KEYWORDS

ISAM, knowledge navigation, manufacturing training, meta-data, RCS, SCORM, VRML

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1 INTRODUCTION

The Intelligent Systems Division began the project, Interactive Training through Knowledge Navigation, in June 2000 and we anticipate that the project will continue for two more years. We explored a large amount of information at the project's inception so we could direct the project to maximize our contributions. In this paper we will describe some of the information we explored, our thought process in defining the project, and our initial results.

The objective of the project is to enhance online education and training capabilities with virtual three-dimensional, interactive navigation through a knowledge domain.[1] Many research organizations are studying online educational experiences in virtual 3D space. However, the NIST Manufacturing Engineering Laboratory has unique knowledge and expertise to enhance the capability to access appropriately configured manufacturing knowledge for training purposes.

One of our planned deliverables for this project will be a web site (actually a sub-web in the MEL web site) that will accomplish a number of objectives for us to manage the project and to disseminate the results. Specifically the web objectives are the following:

- Describe the project, including its goals, rationale, and results
- Indicate our approach via a demonstration
- Function as a project-management system, evolving from the initial plan to the final product

The last point is worth further clarification. We will use the web as an information repository to collect, compile and organize the information relevant to the project as it evolves. There will be several main uses for the information. For one, the information will include the content information (or links to it over the web) that we can use to populate the navigation system we are developing. Also, we will use the web site to collect information about the learning-technologies industry—its customers, stakeholders, major issues, etc. Once we actually publish our web at the end of September 2001, we will use it to communicate with the industry. Our intent is to make it a useful industry resource for finding relevant information that is related to our role—in particular, our input to the standards arena.

Basically the web site will become an "effective communication platform" that maintains the knowledge acquired and developed during the project and enables communication of the project as needed [Moncarz].

1.1 Stakeholders and Customers

We are determined to create results that will be useful to our customers and stakeholders. To ensure that, we want to state who they are up front and to clarify what their needs are that we can address. A key objective of this paper is to accomplish exactly that. However, we expect that our understanding of our

[1] Historically, educators have distinguished between the terms "education" and "training." Education has been considered a broader and more intellectual pursuit that is practiced in universities, whereas training has been considered a narrower and less intellectual pursuit (and practiced in vocational and trade schools). However, the distinction has blurred over time as the types of courses taught in universities, trade schools, and corporate training institutes have overlapped notably.

customers and their requirements will focus and clarify as the project progresses and we will pay careful attention to maintaining and updating that information (on our web site) over time.

Our first obligation is to our sponsor, the Advanced Technology Program (ATP). Their priority is that we address **their** customer which, in general, is industry. Specifically, for this project, the industry customer is the learning-technologies industry. To us, that mainly includes software vendors, trade associations, and standards organizations. From our experience we consider collaboration with industry trade associations as a key mechanism to disseminate our contributions to industry.

In addition, our own organization is also a stakeholder and customer for this work. We hope to use the technologies we develop and discover (from exploring the learning-technologies industry) in our own organization, the Manufacturing Engineering Laboratory at NIST.

1.2 Project Rationale and Justification

The original thrust of the ATP focus program, Adaptive Learning Systems, addressed performance-type issues for the delivery of education and training content. This project addresses another issue where large obstacles are blocking industry progress. That issue, identified by DoD for its own training needs (and other industry stakeholders have named this as well) is content interoperability. This is largely a standards issue, and our expertise at the National Institute of Standards and Technology should enable us to contribute to that effort.

We will address the issue of content access and interoperability from our own niche of manufacturing technology and metrology as well as our knowledge of relevant standards in those areas. In particular, we will address the capability for a learner to access manufacturing-content resources via intuitive, three-dimensional knowledge navigation. We will study the organization and representation of manufacturing knowledge to facilitate that access.

One final note—this project will also help our Manufacturing Engineering Laboratory (MEL) at NIST deal with some major issues. Those are stated in the following thoughts.

- It is often difficult to communicate our work, but essential to do it from multiple perspectives—from a detailed, technical perspective to a broad, programmatic perspective.
- The technical objectives of our research often require visualization and other sophisticated communication technologies to interact with and to analyze the prototypes we develop.

We believe that there is a wealth of valuable knowledge to mine in the learning-technologies domain that can be applied to these issues.

1.3 Objectives

The project objectives are to create a platform that can be used to explore the navigation of knowledge domains for training (and possibly educational) purposes. The platform will serve the following goals:

- Demonstrate virtual 3D navigation through knowledge domains. Furthermore, the platform will enable NIST to investigate issues concerned with navigating those domains for training purposes. Communication is a key pedagogical technique; this project will focus on interactive navigation for communication purposes.
- Identify interfaces where standards could be appropriate as well as determine other standardization opportunities, for example, the use of standard metaphors for knowledge representation in the manufacturing domain.

- Demonstrate how the platform can enhance the communication of various NIST projects ranging from a broad programmatic perspective in a business case point-of-view to a narrow but comprehensive perspective that can offer deeper technical insights.

2 CONTEXT

There are many organizations that are contributing in one way or another to the development of online education and training. (Refer to Appendix A for a list of some of those organizations.) There is a great deal of work going on. We don't want to repeat work that others are doing; we want to apply our own unique and significant resources to issues where we can provide the most impact to the industry. We need to understand the industry sufficiently to identify the industry leaders and the issues and challenges facing the industry. From our understanding of the industry, we've identified what expertise and knowledge we can bring to bear to address some of the industry's pressing problems.

2.1 Background

To show how the work we plan to do fits into the larger context of learning technologies, we present here a brief discussion of some of the considerations involved for developing and delivering courseware over the internet.

Learning technology vendors need a large enough market in customer volume and dollars to warrant the large investment required. Currently, that means courseware for industrial training must predominate. However, the lines between education and training are beginning to blur as the complexity that the average worker deals with in a normal workplace increases. In fact, corporate training increasingly provides courses which have more intellectual and open-ended content. For now, we need to address training needs within our project even though our system will eventually be able to handle more than that, and the future industry requirements will demand more as well.

Developing content for courseware is time consuming, difficult, and complex. However, beyond just the content, there are many more aspects and components that need to be considered and developed along with the content. They include the pedagogical techniques themselves which, once selected, must be implemented. There are varying types of lesson structures, different learning activities, course administration and management, all of which are required to develop and deliver a course for profit [Horton]. Reuseable components, for the components described as well as for the content area itself, are needed to reduce costs sufficiently and enable the learning technologies industry to prosper and provide for the needs anticipated. This whole idea of interoperable content is one of the key drivers for the standards organizations in the learning-technologies industry and has been identified as a key obstacle to online training by DoD.

Interoperable content is the general area in which we expect to make our contributions. Our goal is to put together a manufacturing knowledge repository that is organized for intuitive navigation and access. Two popular metaphors used for knowledge resources on the web are virtual online libraries and museums. We will discuss these further in Section 3.

2.2 ISD Capabilities

From the perspective of the Intelligent Systems Division (ISD), we are applying our expertise in manufacturing knowledge representation and our capabilities in interactive visualization within a 3D manufacturing domain to create the platform. We will draw upon a broader perspective to develop and compile the content to be utilized by the platform.

First, let us present a perspective of ISD itself. ISD is a division within the NIST Manufacturing Engineering Laboratory (MEL). The domains of interest to MEL include:

- Manufacturing technologies
- Metrology
- Manufacturing and metrology standards

The focus of ISD is the study and improvement of intelligent control. To that end, ISD has directed significant effort to control architectures for real-time control, in particular, RCS. RCS is the acronym for Real-time Control System, an architecture pioneered and developed by ISD over the last twenty years [Albus]. The study of RCS led to the development of the Intelligent Systems Architecture for Manufacturing (ISAM), a specialization of RCS for the manufacturing domain. A paper that fully describes that architecture is just being prepared [ISAM]; however, a paper published in July 2000 provides a useful summary of it [Huang]. A key goal for us in this project is to incorporate principles of control architectures and specifically ISAM in the content that is instantiated in the platform.

2.3 Scoping Project

Putting it all together, the objectives, the context, our specific expertise and knowledge, we have defined how we will scope the project. Our plan is to create a manufacturing knowledge repository that is navigable in virtual 3D space and may be used with existing web browsers. We will refer to the system as a virtual online museum of manufacturing knowledge. The system consists of two parts, the navigation platform and the knowledge content to populate it. The platform is discussed in detail in Section 3; the content is discussed in Section 4.

The content will be based on MEL and ISD knowledge. However, the content will include manufacturing technologies and dimensional tolerancing which are important subject areas for the vocational training needs of machinists and technicians. The content will include RCS and ISAM which are important to ISD and can be utilized to help disseminate knowledge about modern control systems for intelligent machines. Standards for the domain (which are required to achieve interoperability of control system components) will be an important aspect of the content knowledge. In addition, we will be interested in ideas concerning standards for reusable courseware.

There is a great deal of knowledge within MEL that we can draw upon that should be useful for training and educational needs. We plan to expand the content material that we draw upon if future support for this project is sufficient.

3 PLATFORM

The thrust of our initial work is to create a knowledge access and delivery system and the content to populate it and enable us to demonstrate our approach. So, our prototype will consist of two parts:

- platform (to enable knowledge access and delivery) and
- content (i.e., a knowledge repository) to populate it.

This section, describes the platform[2] and what thought, information, and technologies have gone into it. Section 4.0 describes the content we are creating to demonstrate the platform.

[2] The only required hardware is an "ordinary" PC as described in Section 6. We are using the term "platform" in Section 3 to refer to a functional requirement without a specific hardware configuration in mind.

The platform consists of several key components:

- main metaphorical framework of a virtual online museum that "houses" virtual objects and associated knowledge;
- standards that allow us to represent, access and navigate the virtual objects in a standard, open-architecture format for wider dissemination;
- and widgets or interactive virtual objects (2D and/or 3D), that enable the learner to access the knowledge attached to the virtual models of physical objects in an intuitive manner.

3.1 Virtual, Online Museum for Manufacturing Knowledge

The definition for "museum" from [Webster] is "an institution, building, or room for preserving and exhibiting artistic, historical, or scientific objects." We are using the metaphor of a virtual, online museum to package a manufacturing-knowledge repository of information associated with virtual objects that we can navigate through in the museum. In a sense, the museum is a large, comprehensive set of virtual objects that can provide access to additional knowledge. That knowledge can reside in virtual online libraries as well as other resource types, such as glossaries, online conferences, simulations, etc.

The term, Virtual Online Museum, is used in the learning technologies field. Generally it is an end in itself to be explored for its information content that is associated with virtual artifacts (usually based on physical objects). In this project, we anticipate that training courses could be constructed as a layer on top of a knowledge repository packaged as a virtual online museum.

We are using a model of our own Machine Shop at NIST as the top-level spatial structure for the museum that will house the "manufacturing artifacts" that comprise and link to information in the knowledge repository. We have created a simple, virtual mockup of the shop floor for visitors to explore and access the knowledge we've incorporated. Our intent is that the objects and behaviors of those objects (i.e., the models and model interactions) will enhance the information conveyed beyond textual descriptions, as well as provide links to further information.

The knowledge repository will be built mainly on the knowledge that resides in MEL. A key contribution will be the organization and representation of that knowledge so it can be accessed intuitively for training purposes through navigation in 3D space. MEL as well as other national laboratories create a great deal of new manufacturing knowledge; but what happens to all that "intellectual capital?" If organizations that house valuable manufacturing knowledge have a way of archiving that knowledge that is accessible by standards and is integrable with knowledge of other organizations, that type of repository could become a valuable resource for commercial vendors of learning technologies to utilize.

The knowledge accessible from this demonstration is tied to virtual rather than physical objects. Many of the virtual objects are based on direct physical counterparts; however, many are also based on abstractions of ideas that are transformed to virtual objects by means of metaphors we will borrow or invent. This might be considered the crux of this work, i.e., *the creation of a knowledge base that is rooted in virtual objects that are navigable in a virtual three-dimensional space that is more familiar and intuitive than a text-based, hyperlinked system.*

3.2 Standards

The subject of interoperability standards for manufacturing is a key competency area in the NIST Manufacturing Engineering Laboratory (MEL). Our platform will employ a number of open-architecture standards that can be considered the second main component of the information repository. We are using the standards for their technologies and also to enhance the dissemination of our results. Our goal is to enable as widespread dissemination of this work (and the use of it) as possible. The two main standards used in this regard are the Virtual Reality Modeling Language (VRML) and Learning Object Meta-Data.[3] It is likely that other standards referenced in SCORM will play a major role in the future, and we will investigate that over the next fiscal year (FY 2001). Currently, VRML is the main standard being used in the system.

3.2.1 VRML

Name	Acronym	Purpose	Key Organization	URL
Virtual Reality Modeling Language	VRML	Represent three-dimensional scenes on the web	Web3D Consortium	www.vrml.org

The Virtual Reality Modeling Language is a standard and a scene description language used to represent three-dimensional scenes that contain objects and their behaviors (including interactive behaviors among the objects as well as with the user) over the web. There are three basic methods to view and navigate a VRML file—a plugin to an HTML browser; a helper application (that is launched by the HTML browser, usually in a new window, when it encounters a VRML file); and a separate, standalone application.

A key goal of VRML is to support the best performance possible over the web, which has led to design goals to minimize the size of VRML files and to maximize display and animation speeds. Furthermore, VRML provides for extensibility through its PROTO and SCRIPT nodes that enable the language to be as flexible as needed in support of new applications. Because of its growing popularity, an array of authoring tools that support VRML have been developed and are offered as commercial products. It is fair to say that VRML has taken root as a key technology on the web, and its continued support and evolution seem assured (as will be discussed further below).

In this project we have chosen to use VRML to represent the objects in our virtual, online museum as well as for the museum itself. We will rely heavily on the authoring tools that are available to speed our development efforts, but will work directly with the VRML files as well. Because we are basing our system design on framed HTML pages with careful control of the windows and page frames, we will be using a VRML plugin.

VRML was originally released as the VRML 1.0 specification. That version included static representations of scenes and objects. VRML 2.0 added behavior and animation capabilities to the language, enabling objects to interact with each other as well as with the user. Finally, VRML97 was created as an international standard by ISO in December 1997 (with the identification, ISO/IEC-14772-1:1997) and is identical to the final VRML 2.0 specification.

An initial strong supporter of VRML was the VRML Consortium which was established in 1994, maintained a web site, and was the primary mover of the initial standardization efforts. In 1998 the VRML Consortium reorganized as the Web3D Consortium and broadened its scope to represent all aspects of 3D technologies on the Internet. Web3D maintains a web site at www.vrml.org. Web3D is the main official voice of the VRML community . Recently the large VRML repository at the San Diego Computer Center was transferred to the Web3D web site.

VRML is a very large and complex standard—i.e., it is composed of many parts and it is constantly being extended by various working groups (WGs) that advocate new aspects for the standard. The scope and complexity of the VRML effort can be appreciated by a quick perusal of the Web3D web site.

Currently, Web3D is working to evolve and extend the VRML standard with XML, and will ultimately be named Extensible 3D, or X3D. The new standard will contain a minimum core and extensions. It will be fully downward compatible with VRML97 by including a VRML97 extension that is layered on top of the

[3] We are also developing web pages using the Hyper Text Markup Language (HTML) standard, but HTML is not a key study area for this work and is not mentioned further in this paper.

core. Other extensions will be added over time through the effort of working groups to extend the standard as well as to add capabilities for particular domains. That will reduce the baggage of a comprehensive "be everything to everybody standard" that ultimately is impractical. This structure is similar to that of the STEP standard with its layering of "Parts" of the standard, including Application Protocols that sit at the top of the standard and make it specific to different types of applications, products and industry domains.

The brief description and history of the VRML standard was included in this section for the following reason. Because of the scope of the standard and how the effort is organized, there are a number of ways we can use the results of our work to contribute to the VRML standard. The primary scope of our VRML contributions will be in the manufacturing domain for manufacturing artifacts and their behaviors. We can create VRML models, or package models we have previously created, for contribution to the national VRML model repository. We can provide input to various VRML working groups based on our study on using VRML models. More directly, we can join the appropriate working group or suggest a new one be created if there is sufficient interest and our main scope of work does not fit into current efforts. For example, there might be interest to create an extension to the VRML core that captures the behavior of various control architectures that could facilitate the use of VRML models of machine tools.

3.2.2 Meta-Data[4]

Name	Acronym	Purpose	Key Organization	URL
Meta-Data for Learning Objects	LOM	Develop standards for interoperability of courseware content and management systems	IMS[5] Global Learning Consortium, Inc.	www.imsproject.org

As "chunks of knowledge" were thrown up onto the web from individuals and organizations all over the world, the gems of knowledge and how they fit together or could fit together with other gems were in danger of becoming totally lost. An effort was initiated to deal with this issue by the creation and standardization of meta-data that characterizes chunks of knowledge or other divisible information pieces (for example, a training course about a particular subject) to facilitate their discovery, access and use over the internet.

To standardize meta-data, registries have been set up for different knowledge domains; interested parties develop, specify and standardize meta-data for those domains. One of the registries established is for Learning Objects. In this registry, meta-data is specified for the content as well as other information that categorizes educational and training online courses from multiple dimensions and perspectives to help someone choose and access an appropriate course that fits his or her needs.

We plan to work with the NIST Information Technology Laboratory, which is working with the IMS Global Learning Consortium, Inc. and the IEEE Learning Technology Standards Committee, to enable us to incorporate meta-data in our system to access relevant courseware and hopefully, smaller chunks of domain knowledge. Our hope is that meta-data (or something similar) may enable course content to be interoperable at a level that we could integrate it seamlessly within our virtual, online museum.

We plan to incorporate the use of meta-data into our system to access information through the use of widgets which is the third main component of our platform, discussed in Section 3.3.

[4] Note, a hyphen is used in the term meta-data because the term metadata has been copyrighted and is currently unavailable for use.

[5] IMS is the acronym for the Instructional Management Systems Project. IMS was originally an initiative within the National Learning Infrastructure Initiative and eventually split off as a separate organization.

3.2.3 SCORM

Name	Acronym	Purpose	Key Organization	URL
Sharable Courseware Object Reference Model	SCORM	Facilitate interoperable courseware	Department of Defense	www.adlnet.org

The Department of Defense has a critical and immediate need to train its employees. DoD has identified online training as a key technology to accomplish that and believes that content interoperability is a key enabler. However, DoD has been disappointed in the slow progress of industry towards accomplishing that goal, in particular the range of organizations involved that were creating different standards for similar interoperability problems. In addition, the White House issued Executive Order 13111, "Using Technology to Improve Training Opportunities for Federal Government Employees." Consequently, DoD and the White House Office of Science and Technology Policy launched a major initiative, Advanced Distributed Learning (ADL), in November 1997. DoD was tasked by the White House to work with voluntary standards organizations to develop a framework called the Sharable Courseware Object Reference Model (SCORM) to enable content interoperability for courseware. SCORM is an umbrella for interoperability standards in the learning-technologies industry. In particular, Meta-Data is a major component of SCORM. We are reviewing the SCORM specification now and anticipate that it will have a strong impact on our work.

3.2.4 Other Standards

For completeness there are other organizations that are developing standards for learning technologies, including content interoperability. Those are included in the listing of relevant organizations in Appendix A. We will monitor these efforts as applicable but don't anticipate a collaboration with them at this time.

3.3 Widgets

We refer to the third main component of our framework as widgets. By the term, widgets, we mean a set of 2D or 3D virtual knowledge manipulation objects that we can interact with (e.g., by mouse click, drag, etc.) to access different types of information. We will select and invent virtual objects and behaviors for the widgets that will provide an intuitive sense for the learner. During this project we will maintain a compilation of the widgets we have obtained or invented on our web site and attach them to various objects in the museum to study their effectiveness for intuitive, information access. Widgets are discussed further in Section 5.6.

4 CONTENT

The content used to demonstrate the platform will be taken from knowledge that MEL has developed or with which it is intimately familiar, with particular emphasis on ISD's work. In broad terms the MEL domain encompasses manufacturing technologies, metrology and interoperability standards—all for the discrete, metal parts industry. ISD's work focuses on intelligent control of complex systems applied to manufacturing systems.[6]

[6] ISD has also applied its work in control systems to intelligent, autonomous vehicles; however, that work will not be considered for this project at the current time.

4.1 Domain

We plan to utilize work done by MEL in a number of application areas including those shown in the table below.

Application Area	Comments
MEL Machine Shop	The Shop fabricates one-of-a-kind equipment that is used by the engineers and scientists throughout NIST. It functions as a small business unit that is progressing towards world class operation as a fully self-supporting job shop. There is a wealth of knowledge to be mined here for small manufacturing companies in particular. We will be using the Shop as the main metaphorical framework for this project. From here we can branch to conventional knowledge stores that are of use to a typical manufacturing company. Alternatively we can branch to knowledge on the cutting edge since the Shop also houses and supports machine tools that are used in MEL research.
Real-time Control System (RCS)	RCS is a control systems architecture that supports hierarchical control applications for manufacturing and other types of systems by establishing a generic set of processes for successive levels of decomposition. A higher level control with a longer time horizon is successively decomposed to more detailed levels of control with shorter time spans as you successively traverse down the hierarchy. ISD has studied this paradigm of control for over twenty years and has developed tools and software libraries to support the approach as well as many implementations for a variety of applications. RCS embodies a great deal of knowledge about control systems in general and is a valuable knowledge base to mine for this project. A more recent invocation of this architecture is the Intelligent Systems Architecture for Manufacturing (ISAM), which is a specialization of RCS for the manufacturing domain.
Feature-Based Inspection and Control System (FBICS)	FBICS is an ISD research project that implements RCS for dimensional inspection and machining processes that incorporates integrated planning and execution control at each hierarchical level [Kramer]. We plan to incorporate FBICS into our project as a basis to disseminate knowledge about RCS as well as to link product and process information together.
Dimensional Metrology	Dimensional metrology is a complex subject because it requires an understanding of the relationships of part features to each other in three dimensions to realize design functionality within the constraints of manufacturability. The knowledge and system features brought together in this project can enable a perspective on this subject from a three-dimensional, interactive environment.
Inspection Process	The inspection process utilized by this project will incorporate a coordinate measuring machine to measure points on a part to verify specified dimensional tolerances. The task decomposition to create and execute an inspection plan for a part using a coordinate measuring machine (CMM) is implemented in the FBICS system and provides a detailed example of an implementation of RCS, in addition to a detailed example of a dimensional inspection process using a CMM.
Algorithm Testing System (ATS)	The ATS project was initiated to develop a system to measure the accuracy of the numerical fitting algorithms used by CMM manufacturers. The system has been enhanced over several versions and now consists of three main parts — an error generator to create the type of errors likely to occur in practice, very-accurate fitting algorithms that can hold up as a reference standard to generate a fit of a feature given a set of data points, and results presentation that will produce textual or graphical results that a user can understand. ATS could provide a method to introduce realistic-type errors into the system, either on-line or to generate an error database offline, that could be used in this project to create

	errors that could be traced back to a manufacturing process based on the CMM inspection of the part.
VRML models for manufacturing	A fair number of VRML models of machine tools have been developed by ISD over the last several years. These will be used in this project as applicable. Furthermore, they will be repackaged to facilitate their use for this project as well as to disseminate their usage by others.

4.2 Concepts

Drawing from the application areas in Section 4.1, there are a number of general categories of concepts that we would like to communicate, and the knowledge repository will be organized around those ideas. Each of these categories is organized with a top-level concept that is successively decomposed to component concepts that correspond roughly to the ISAM levels of control in a typical manufacturing process hierarchy (for example, for an inspection or machining process).

In addition to the separate main concepts and their decompositions, the component concepts (at successive layers in the hierarchy) interact with or are related to other component concepts from a different main concept decomposition. To have an understanding of modern manufacturing which is heavily dependent on information technology, a person needs to understand the main concepts and have a sense for how the whole system of concepts integrates together. Manufacturing within an information technology world is complex and having a viewpoint where the multiple concepts can be seen in context with one another could enhance a person's intuitive understanding of the domain. This is another way of expressing the main idea of this project—associating the domain knowledge to objects in a three dimensional context could enhance the intuitive understanding of the domain and enable access to further information to be more intuitive.

The main concepts we want to incorporate in our platform are shown in the table below. For each concept, the decomposition levels for it are listed in the order of approximate hierarchical level from top to bottom. For some concepts, this breakdown is somewhat tenuous and subjective discretion has been taken to arrive at a reasonable decomposition.

Concept	Decomposition
The shop's physical embodiment (3D layout and machine tools)	shop spaces (which house the shop's core processes such as work order processing, estimating, engineering/design, production), production floor (one of the core processes), machine tools, main components of machine tools, probes/tools
Production processes	decomposition based on RCS and FBICS (for dimensional inspection and various machining processes to make discrete metal parts)
Interoperability standards	linked with processes in hierarchical fashion—ALPS, RCS, STEP AP 224, DMIS, RS274. (These standards are briefly described in the next section, 4.3.) Each standard has its own levels of decomposable hierarchy
Parts (to be manufactured)	part, tolerances, features, datums, surfaces/edges/points
Metrology (tolerances)	design goals (function), tolerances, call-outs, features/datums/tolerance zones, interaction of these, feedback of tolerance errors to production processes

We plan to represent these concepts and their interactions as virtual objects within the shop floor. In addition to enhancing a person's intuitive grasp of the overall domain space, we hope that these objects will represent a sufficiently robust set of links to attach a large breadth and depth of knowledge that can be used to serve training purposes.

4.3 Standards

The previous section, Section 3, discussed design of the platform and how certain interoperability standards form a key component of the design. In this section that discusses the content, interoperability standards are useful in helping to scope out the content domain and to enable access to the domain's knowledge base. In fact, a great deal of the knowledge that MEL uses as well as develops is encapsulated in or associated with a number of interoperability standards. Furthermore, in the domains of manufacturing technologies for discrete parts and the associated metrology issues and knowledge that goes with those, the applicable interoperability standards could be considered excellent encapsulations of the knowledge base and enable them to be keys to information for a large part of the manufacturing domain space.

In other words, the museum containing the manufacturing artifacts and interoperability standards associated with those could be an excellent framework for access to a very large manufacturing knowledge base. The next step would be to determine metaphors for components of the standards to serve as the robust set of linkages to the knowledge store. One possibility for the metaphors is the "planes of concepts" metaphor described in Section 5.9.

The standards that are relevant to the MEL domain base that we hope at some point to include in the platform are listed in Appendix B. We expect to employ three of the standards listed, i.e., AP224, Y14.5, and RCS (plus ISAM) in our current work through September 2001.

A key standard we are using for the manufacturing domain content is STEP AP224. This standard specifies the representation of a part that includes its geometry, topology, features, and tolerance information. That information is then transformed to a set of VRML models that can be utilized in the platform. Preferably those VRML models could be created online when the part is selected and the STEP AP224 file is retrieved. Currently, that transformation has been created manually offline to use for the demonstration.

5 CONTRIBUTIONS

We believe there are a host of potential contributions that could derive from this project. Those are described in the following pages, in Sections 5.1 through 5.10. Each section begins with a table that summarizes the contribution by naming it in a brief phrase; stating an issue that presents an obstacle, challenge or question; and presenting the proposed solution for how the contribution can resolve the issue. Further discussion follows each table where warranted.

5.1 Knowledge Navigation

Contribution	3D Navigation through Knowledge Domains
Issue	Can navigating through knowledge that is associated with objects we are familiar with provide a more intuitive access to that knowledge and a better retention of it?
Proposed Solution	Answer this issue by experimenting with the platform once it is completed. Basically, the main goal of this project is to study 3D navigation through the manufacturing knowledge domain and to gain insight on the associated issues and parameters.

The final analysis to answer this issue will likely be done by others outside NIST; this project will mainly explore the issues involved to enable the navigation of the manufacturing knowledge domain with which MEL/ISD is most familiar. Development of a platform to do that will enable the question posed in the "Issue" to be studied.

5.2 Reuseable VRML Objects

Contribution	Reusable VRML Objects for Manufacturing
Issue	Creating VRML objects for manufacturing tools and other manufacturing related objects is labor intensive and very costly. This is a barrier for easily using three-dimensional manufacturing objects as part of courseware that can be disseminated on the web.
Proposed Solution	Collect the relevant VRML objects (e.g., of manufacturing machine tools) that have been developed in MEL, enhance as needed and package them in a way to facilitate their use by the public. (Add VRML objects to this collection that are being developed specifically for this project, for example, VRML models of standard parts such as the TEAM part.) Contact the VRML community (via the Web3D Consortium) to arrange for the eventual transfer of these objects to a Web3D repository. Also gage the interest of Web3D for our participation in VRML extensions to the standard that are based on manufacturing objects and behaviors.

5.3 VRML Objects With RCS Behavior

Contribution	Enhance the exposure and understanding of RCS and ISAM
Issue	Intelligent control systems that utilize modern control-systems knowledge are needed to satisfy the ever-increasing demands on manufacturing capabilities. Unfortunately, modern control systems are not being broadly adopted. One possibility for this failure is that current knowledge about intelligent control systems is not being sufficiently disseminated. ISD has been studying intelligent control for the last twenty years. The Real-time Control Systems architecture (RCS) was developed by ISD and embodies many modern ideas for intelligent control systems. More recently, RCS was generalized by ISD and reincarnated as the Intelligent Systems Architecture for Manufacturing (ISAM). ISAM is a specialization of RCS for the manufacturing domain and it is up to date insofar as current thinking on intelligent control systems is concerned. Throughout the years ISD has written papers, presented demonstrations, and participated in standards development efforts. Yet the subject is complex, and it is not clear that the information has been disseminated successfully.
Proposed Solution	Incorporate RCS (and perhaps ISAM) behavior into VRML objects representing manufacturing machine tools. RCS is a hierarchical control systems architecture. Provide an interface to the user to interact with the model of the machine tool at the top level to control and monitor the tool. (Interactions at other levels in the hierarchy could be useful as well.) (The effort to generate this contribution is substantial and depends on future project funding.)

5.4 Dimensional Metrology

Contribution	Intuitive understanding of dimensional metrology
Issue	Tolerances as expressed by the ASME standard, Y14.5, are complex and difficult to understand. However, it is important for a machinist to understand the standard to make a part correctly given the part geometry and tolerance information.
Proposed Solution	Graphically represent the feature to be toleranced, any datum features required, and the tolerance zones as expressed by the tolerance in 3D space. By changing certain tolerance values and observing how that graphically affects the tolerance could provide an intuitive feel for the tolerance. Use the STEP AP 224 standard to play a key role here. An AP 224 exchange file for a part will contain the information to represent the three-dimensional geometry of it as well as feature and tolerance information. The standard, ASME Y14.5, specifies how to represent particular tolerances in human-readable form. Tying the information from the two standards together in a 3D navigable environment could provide training benefits in manufacturing metrology.

5.5 Product-Process Integration

Contribution	Integration of product and process information for training purposes
Issue	The shape and tolerances of a part are tightly linked to the processes that make the part. Nominal shape and tolerances drive the choice of processes and then the processes determine the actual shape and whether shape errors are within tolerance. The two domains of product information and manufacturing process need to be tied together within a training environment to provide the full understanding required.
Proposed Solution	Leverage the Feature-Based Inspection and Control System (FBICS), developed in ISD and based on the ISD-RCS architecture. (FBICS also includes machining and might be renamed in the future to reflect its broader scope beyond inspection alone.) FBICS provides a hierarchical control system implementation where we can issue commands to make a part and the system will access the model of the part, plan the manufacturing execution, and then control the manufacture of the part. Afterwards the part can be inspected within the same control system to compare the part made to the model of the part planned. As mentioned above we are also using AP224 to select part features and tolerances to analyse. (AP224 is also being used by FBICS.) We plan to show how an error introduced into the manufacturing system, for example, tool wear that has thrown the machine tool out of calibration, can be observed as a particular type of error pattern in the part manufactured.

5.6 Widgets

Contribution	Widgets that provide intuitive access to various types of manufacturing knowledge
Issue	How can we attach information to a 3D knowledge domain that can be accessed in a generic and intuitive manner?
Proposed Solution	Create 2D and/or 3D interactive virtual knowledge manipulation objects (widgets) that can be tied to virtual physical objects throughout the 3D knowledge domain that can be used to access different types of information in a generic, intuitive fashion. Begin by a compilation of metaphorical objects that are used currently in the MEL web site to access information as well as in other MEL projects that navigate and access manufacturing information using VRML models. (For example, the metaphor of a file cabinet has been used in an MEL demonstration to access text files of project summaries when the user points the mouse at the file cabinet and clicks.) In the same fashion, develop a set of widgets to access learning objects using meta-data. Based on an analysis of the widgets we've compiled, we will specify a generic set of widgets that we can use throughout our prototype.

There are a number of ways we can organize information for access via the context of the MEL Shop floor. One simple way is to organize it by media and format types. For example, information can be encapsulated as a text description, a brief animation clip, a simulation, a data flow during a simulated or actual experiment, etc. When a widget set is invoked, for example, by clicking a button on the coordinate measuring machine (CMM), a set of controls could pop up (as simple as a pop-up menu or as complicated as a set of three dimensional objects) to access a type of information in the context of that object, the CMM. Our hope is we can do a bit better in organizing the information to reflect its meaning and not just its format.

For meta-data there is a fairly extensive set of fields that can be used to specify a particular type and format of courseware. We could set defaults for many of these fields in the context of a particular location in our museum, and create a widget set to allow the user to set remaining fields in the query.

5.7 Access To MEL Knowledge

Contribution	Facilitate access (via the web) to knowledge acquired and maintained by the NIST Manufacturing Engineering Lab (MEL)
Issue	MEL, over the years, has acquired a vast store of manufacturing knowledge and currently maintains that knowledge on a web site that is accessible by the public. The site is mainly organized on a project basis and is searchable in several ways, including by keywords. Nevertheless, a fairly extensive insider's knowledge is necessary to mine the site for useful knowledge about a particular subject. Furthermore, there may be leveraging possibilities among the different stores of knowledge on the site but those often are invisible due to the project-oriented organization of information.
Proposed Solution	Look at new methods for organizing MEL's knowledge by subject rather than project that can be more intuitively accessed by 3D navigation. We plan to analyze the existing MEL web site to compile the metaphors that are used currently to access MEL knowledge and to use those as appropriate, along with inventing or extending our own creations, to use in the prototype demonstration we are creating. Perhaps the insights we gain from studying meta-data use for learning objects could help us here as well.

Unfortunately, the sad truth is that a great deal of potentially useful knowledge is languishing on the MEL web site, known about only by a few researchers. A fresh look at that knowledge in an explorative manner might yield useful insights that would enhance the value of the knowledge created and maintained by MEL. Furthermore, some knowledge no longer of use to MEL researchers still could be of use to outside researchers if they could find it.[7]

This lost potential is not unique to MEL or to NIST but is likely true at public (as well as private) laboratories throughout the country. Insights gained in this project could lead to new methodologies and organizing principles for storing knowledge developed at research sites and improving access to it.

5.8 Interoperability Standards

Contribution	Enhanced intuitive presentation for how interoperability standards fit within the context of the manufacturing domain
Issue	There are many interoperability standards used to integrate the components of a manufacturing system together to enable the entire system to function in the most efficient and effective manner. There is a great deal of work still to be done to complete the specification of the standards needed, not to mention the considerable effort to disseminate the results so they are incorporated in actual manufacturing software tools and environments. The standards are very complex, each in its own right, and it is not at all easy to grasp how they fit in an overall context together. The whole system is very confusing. An interactive presentation technique that could dispel some of the complexity and confusion would be valuable, not only to disseminate the efforts of researchers (and standards developers) to their customer and stakeholder communities, but in fact to help the researchers themselves have a better perspective on how everything fits together.
Proposed Solution	Attach the information components from various standards to virtual objects in a 3D navigable space (including virtual objects that represent process information). Additionally we plan to use the idea of "Concept Planes" described in the next contribution listed. In either or both of these two methods we plan to show how individual standards fit within a larger context and how they fit together with other standards in context.

5.9 Concept Planes

Contribution	Concept Planes to help a learner achieve an intuitive feel for how different decomposable concepts relate among each other at various levels of decomposition.
Issue	Part of the complexity of manufacturing technology stems from the fact that the key concepts are hierarchical, and understanding them includes understanding how the concepts are related at successive levels of decomposition.
Proposed Solution	Represent a concept that has multiple dimensions in 3D space using a simple block representation to distinguish the divisible components of the concept and to provide a perspective for how those components fit together within the hierarchical decomposed space. (Refer to the discussion following this table for additional explanation and example to describe this approach.)

[7] I found it very interesting that in writing this paper I had great difficulty in finding simple and general information about the standards I was referencing over the web (e.g., simple information such as a brief description and purpose for the standard and even the official title of the standard). That included a search over our own MEL web site as well as beyond. It reconfirmed my belief that science and technology information are not organized very well nor packaged very well to facilitate their access over the web.

	Create similar representations for other concepts in a similar 3D space but related spatially to those of the already-represented concept planes in accordance with their logical relationships. In addition to giving a feel for how different concepts relate to each other at various levels of decomposition, the planes of objects can function as widgets to access further information concerning those concepts.

For example, ISAM defines a computational node in its reference model architecture. A hierarchical control system can be implemented by instantiating the appropriate ISAM nodes at successive levels of the hierarchy, with a single node at the top and one or more nodes at each successive level of control. Each ISAM node consists of five basic processes that are named behavior generation, sensory processing, world modeling, value judgement, and knowledge database. Using this approach a machine shop could be implemented with a seven-level ISAM hierarchy that includes shop, cell, workstation, equipment, elemental move, primitive, and servo. (Refer to [ISAM] for further details, including the example cited here.) Using the concept-planes idea, this example could be mapped to seven parallel concept planes for each shop control level with each plane containing five blocks that represent the five basic processes for an ISAM node. Color could be used as an added dimension to highlight certain relationships among the concepts.

Other planes of concepts could include hierarchical controls systems for specific manufacturing processes, for example, an inspection process; interoperability standards; a part's hierarchical structure; etc. A useful application for this idea includes the presentation for how different interoperability standards within a control system hierarchy are related to each other; furthermore, the blocks representing those standards could be used as widgets to access information about those standards.

5.10 Project Development Approach

Contribution	A new project development approach
Issue	For a large, complex development project, the specifications can change or evolve as the project is progressing and it can be difficult to keep track of the relationships among the components specified. Furthermore, the knowledge gained during project development often is lost. (That is particularly unfortunate for a research-type project; the project plan is virtually a throw-away after the project is complete.)
Proposed Solution	Create a local web site to serve as an information repository for the project from its initial conception to its final implementation and presentation. Some of the web pages would serve as repositories for information that needs to be collected during the project's execution. The project plan, the information needed during the course of the project, the demonstration of the implementation of the project could all be collected within the web site. If organized properly, the web site could enhance communication and understanding of the project to the participants during the course of the project as well as provide a useful presentation of the project at its completion. This is basically an effective communication platform as described in [Moncarz]. This is the approach we used for this project; it has seemed to work well up to now, and we offer it as a suggestion to others.

6 SYSTEM REQUIREMENTS

We are using several different PC/Windows computers for this project, but the computer with the minimum specifications is quite sufficient for the task, both as a course-delivery platform as well as a platform development system. The minimum configuration we are using is a standard off-the-shelf 300 MHz PC running Windows 95 and connected to the internet. A graphics accelerator is not being used.

The configuration is sufficient for our initial prototype, but clearly a higher-powered PC with graphics accelerator would be desirable for smooth 3D animations, particularly as the "worlds" we create get more complex. For the continued development of this project, we will see whether our current configuration is sufficient or whether a higher-performance PC is necessary.

In addition to the hardware, an HTML web browser and VRML plugin are required to operate our platform. (Because we are incorporating VRML models within specific frames of web pages, we require a VRML plugin instead of a VRML helper application or a standalone VRML browser.) The browser and plugin are included for free with a new computer or by free download. We are using both the Netscape and the Internet Explorer browsers for our project. In addition, we downloaded and have used several different VRML plugins. All of these browsers and plugins are satisfactory; a user should select one that is based on his or her own preference.

6.1 System Configuration

The system configuration is summarized below. (Several configurations have been tried, so several products are listed in some component categories.)

System Component	Brand or Chief Characteristic	Company
PC Computer	300 MHz (& others with higher speeds)	Dell
Operating System	Windows (95 & NT)	Microsoft
HTML Browser	Communicator 4.5 Internet Explorer 5.5	Netscape Microsoft
VRML Plugin	Cortona VRML Client 2.2 Contact 4.4 Cosmos Player 2.1	ParallelGraphics Blaxxun interactive, Inc. Computer Associates

6.2 Software Tool Requirements

We have not found a software tool that alone can enable us to develop all of the features and functionality we want for the platform and content. Instead we have acquired a number of tools to develop the components we want and to integrate those components together (with the appropriate tools).

The types of tool capabilities we need and the specific tools we are using for this project are listed below.

Tool Capability	Tool Name	Company
Web page development and modification (2D, i.e., HTML) Web administration & management	FrontPage 2000	Microsoft
VRML object creation	Internet Scene Builder (ISB)	ParallelGraphics
VRML behavior creation (of & between objects) VRML object assembly	Internet Scene Assembler (ISA)	ParallelGraphics
VRML file editor	VrmlPad	ParallelGraphics

7 PRELIMINARY RESULTS AND CONCLUSIONS

We have created a mockup of the platform we are envisioning to show several of the ideas and to demonstrate the approach that we describe in this paper. We plan to add sufficient breadth and depth to the platform and the content it contains by the end of this fiscal year (by October 1, 2001) to enable our approach to be evaluated.

The demonstration is packaged within a local web site. The site includes a presentation of the project, web pages that are repositories for information we are collecting for use in the project, and a preliminary version of the virtual, online museum for manufacturing knowledge.

The demonstration of the museum begins with a simple mockup of the MEL Shop Floor that can be explored in the conventional manner of exploring a VRML world—using a mouse within a standard VRML browser. The locations to explore on the shop floor are represented by cubes with text (in this preliminary version). Those are hotlinked to other VRML models that are manufacturing artifacts in the museum—for example, detailed models for machine tools and their behaviors; or detailed part models, where the part features can be separately accessed; or perhaps models of other virtual objects such as the concept planes described in this paper (but not yet implemented in the demonstration).

All artifacts (virtual objects representing real or abstract objects) in the museum are packaged in framed web pages that include a VRML object in at least one frame and textual and other types of information in the other frames that relate to the object or selected portions of it. The exact way to package this will be decided over time based on studying different approaches.

For example, the demonstration includes a web page where the user can view a part as a VRML model in one frame and select a part feature in that frame by clicking on it with the mouse. Information about that feature, for example, the portion of the STEP AP 224 text file that represents that feature, can then be displayed in a separate frame. Alternatively, the feature selected can be shown by itself as a VRML model in a separate frame and the user can explore information about that feature further by exploring in that separate frame. (That latter exploration has not yet been implemented. The intention is that the user will be able to manipulate individual part features and corresponding tolerance information that is represented graphically to provide an intuitive feel for different types of tolerances.)

Alternatively to navigating the virtual museum by following hotlinks on VRML objects, the user can follow HTML hyperlinks from one framed-web page to the next. This navigation is included for implementation purposes—i.e., web pages form stubs for development work still required which is a handy way to track the development effort.

In conclusion, the mockup represents a very preliminary demonstration that, within the context of information in the local web site, can provide a good description of the goals and approach for this project. In addition, the web site contains a growing repository of information that can be incorporated into the demonstration when applicable and can be available to provide input to standards organizations as well as to the learning-technologies industry.

Our plan is to publish the local web site on the MEL web and make it available to the public by the end of this fiscal year. Thereafter, the evolving compilation of information will be available to the learning-technologies industry and to any other interested parties. We hope to expand the web site to encourage industry interaction with us to assist in the information compiled.

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A RELEVANT ORGANIZATIONS[8]

In this Appendix we have listed a number of organizations (and major initiatives) that are significant to the learning-technologies industry.

Organization	Relevance to Project and/or Mission[9]	URL
Alliance of Remote Instructional Authoring and Distribution Networks for Europe (ARIADNE)	Development of tools and methodologies for producing, managing and reusing computer-based pedagogical elements	ariadne.unil.ch
Aviation Industry CBT Committee (AICC) (CBT is acronym for Computer-Based Training)	International association of technology-based training professionals. The AICC develops guidelines for aviation industry in the development, delivery, and evaluation of CBT and related training technologies	aicc.org
Computer Education Management Association (CedMA)	Enable new and existing learning content to be created as independent Learning Objects, such that they can be assembled in any combination to meet an individual's learning needs, resulting in increased personal productivity	cedma.org/guestlalo.html
Department of Defense (DoD)	Extremely interested in online training technologies to serve the training needs of its own civilian and military employees and is investing substantial funds in this area. Sponsor of ADL and SCORM	www.adlnet.org
Department of Education (DoEd)	Sponsors the project. Gateway to Educational Materials (GEM). This is a consortium effort to provide single access to educational materials available on various federal, state, university, non-profit, and commercial Internet sites.	geminfo.org
Dublin Core	The Dublin Core has become an important part of the emerging infrastructure of the Internet. Many communities are eager to adopt a common core of semantics for resource description, and the Dublin Core has attracted broad ranging international and interdisciplinary support for this purpose.	purl.oclc.org/dc
EDUCAUSE	EDUCAUSE is an international, nonprofit association whose mission is to help shape and enable transformational change in higher education through the introduction, use, and management of information resources and technologies in teaching, learning, scholarship, research, and institutional management.	www.educause.edu/
IMS Global Learning Consortium, Inc. (IMS)	Launched by NLII and is the lead organization for the Meta-Data effort in the learning-technologies industry	www.imsproject.org

[8] An excellent summary of standards efforts for the learning-technologies industry can be found in William Horton's web site at www.horton.com. (William Horton is the author of [WBT].)

[9] These are taken by quoting and/or paraphrasing information in the organization's web site.

IEEE Learning Technology Standards Committee (LTSC)	Develop technical Standards, Recommended Practices, and Guides for software components, tools, technologies and design methods that facilitate the development, deployment, maintenance and interoperation of computer implementations of education and training components and systems	manta.ieee.org/p1484
Information Technology for Learning, Education, and Training (ISO/IEC JTC1/SC36)	Subcommittee (SC) established by the International Organization of Standards (ISO) to develop standards in the area of information technologies that support automation for learners, learning institutions, and learning resources	jtc1sc36.org
National Learning Infrastructure Initiative (NLII)	Broad-based coalition of institutions and organizations sponsored by EDUCAUSE to create new collegiate learning environments that harness the power of information technology	www.educause.edu/nlii/
National Skill Standards Board (NSSB)	NSSB is building a voluntary national system of skill standards, assessments and certification that will enhance the ability of the United States workforce to compete effectively in a global economy	www.nssb.org
Presidential Task Force on Federal Training Technology	Established by Executive Order 13111. A coordinated Federal effort to provide flexible training opportunities to employees and to explore how Federal training programs, initiatives, and policies can better support lifelong learning through the use of learning technology	www.technology-taskforce.gov/new_force/eo.htm
Web3D Consortium	Leading organization for continued development of the VRML standard (as well as other multi-media standards for the web)	www.vrml.org

B CONTENT STANDARDS

This Appendix lists the standards that are relevant to the MEL domain base that we hope at some point to include in the platform. The sequential order they are listed in is approximately matched to the hierarchical decomposition of a control system architecture from top level to bottom as well as from a more general to more specific type of information. This is only a sub-list of the standards employed throughout the manufacturing domain space that includes these standards. However, understanding these and the knowledge they represent will provide a very solid knowledge base in manufacturing control system architectures, processes, and metrology.

(Note: the goal of this paper is to describe the knowledge navigation project and not to provide information for the standards listed herein and therefore don't provide references to those. However, it is anticipated that the web site that is eventually created as a result of this project will include references to access further information about the standards.)

Name	Acronym[10]	Official Designation	Comment
Process Specification Language	PSL	NY	Represents process information for applications. Goal is analogous to STEP which represents product information to facilitate exchange and sharing among applications.
A Language for Process Specification	ALPS	NA	Developed at NIST for use in the NIST Process Planning Testbed as a representation of a process plan.
Real-time Control System	RCS	NA	Developed at NIST for hierarchical, real-time control system applications.
Standard for the Exchange of Product Model Data	STEP	ISO 10303	Large complex standard, created as a hierarchical structure of parts, for the specification of a product model. Application protocols (APs) sit at the top of the hierarchy and specify information exchange requirements for particular manufacturing applications; some APs are generic, others are specific to particular industries and product families.
STEP Application Protocol for Mechanical Product Definition for Process Planning Using Machining Features	AP224	ISO 10303-224	Includes geometry, topology, features and tolerance information for a mechanical part.
Dimensioning and Tolerancing	Y14.5	ASME Y14.5M-1994	Defines the graphical call-out that appears on a part drawing to specify tolerances; defines how to interpret the tolerance. (revision of ANSI Y14.5M-1982)
STEP Application Protocol for Dimensional Inspection	AP219	NY	This standard is currently in development.

[10] Brief acronym that is commonly used for the standard.

Dimensional Measuring Interface Standard	DMIS	DMIS, ANSI/CAM-I 101-1995 version 3.0[11]	Programming and reporting language to provide a standard for the bidirectional communication of inspection data between computer systems and inspection equipment
Numerical Control Programming Language	RS274	EIA-274-D	Programming language for numerically controlled machine tools. The most recent standard version is RS274-D, 1979. Capabilities have been extended in The Next Generation Controller Part Programming Functional Specification (RS-274/NGC) by NCMS, 1994.

<u>Abbreviations Used in Above Table:</u>

ASME	The American Society of Mechanical Engineers
CAM-I	Consortium for Advanced Manufacturing International
EIA	Electronic Industries Association
ISO	International Organization of Standards
NCMS	National Center for Manufacturing Sciences
NA	Not applicable; this term is used here to indicate that the specification is not sanctioned by an official standards organization.
NY	Not yet (a standard). This designation is used for a specification that is on track to become an officially sanctioned standard.

[11] This is the most recent formal standard. Version 4.0 is in draft.