



INSTITUTE FOR DEFENSE ANALYSES

**Opportunities for New “Smart” Learning  
Environments Enabled by Next  
Generation Web Capabilities**

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J. D. Fletcher

January 2004

Approved for public release;  
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IDA Document D-2952

Log: H 04-000071

**This work was conducted under contracts DASW01 98 C 0067/  
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IDA Document D-2952

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## **PREFACE**

This study was conducted for the Office of the Under Secretary of Defense (Personnel and Readiness) (OUSD(P&R)) under the “Advanced Distributed Learning Common Framework” task. Technical cognizance for this task was assigned to Dr. Robert Wisher.

# CONTENTS

## **OPPORTUNITIES FOR NEW “SMART” LEARNING ENVIRONMENTS ENABLED BY NEXT-GENERATION WEB CAPABILITIES**

EXECUTIVE SUMMARY .....	ES-1
A. Introduction .....	1
B. Some Questions .....	1
1. Are Technology-based Learning Environments Worthwhile? .....	1
2. What Do We Mean by ITSs and What Do They Add? .....	3
3. What Emerging Standards, Infrastructure, and Learning Objects Are Needed For These Systems? .....	4
4. How Might the Web and Web Services Impact This Evolution? .....	8
5. Where Might These Capabilities Take Us? .....	11
References .....	Ref-1
Glossary .....	GL-1

## EXECUTIVE SUMMARY

This document briefly reports on an effort to identify some directions that the Advanced Distributed Learning (ADL) technologies, particularly those designated as Intelligent Tutoring Systems (ITSs), may take as their capabilities and the capabilities of the World Wide Web evolve. Findings of this effort are that

- Tutorial, one-on-one instruction appears to be substantially superior to classroom, one-on-many instruction. Interactive instructional technology based on computer technology may make tutorial instruction economically practical.
- Findings from many studies across different subject matters suggest a “rule of thirds,” indicating that interactive instructional technology can reduce the cost of instruction by about one-third and also either reduce the time of instruction by about one-third or increase learning by about one-third.
- ITSs are distinguished from other applications of interactive instructional technology by their capabilities to permit mixed initiative dialogue in which either the technology or the student can initiate questions and to generate instructional material, strategies, and interactions on demand in real time.
  - Both ITS capabilities require the availability of sharable instructional objects. Specification and development of the objects are goals of the ADL initiative, which is intended to make high-quality education, training, and performance aiding available anytime and anywhere. These sharable instructional objects, along with their packaging, aggregation, and sequencing, are being specified by the ADL Sharable Content Object Reference Model (SCORM), which will provide a foundation for affordable, adaptive, and intelligent learning systems.
- One way—perhaps the only way—for education, training, and performance materials to be made available anytime and anywhere is to take advantage of the World Wide Web and its services.
- Development of semantic capabilities and services will dramatically increase the capabilities of the Web, Web services, and Web applications, such as ADL, to achieve their goals. Web-based semantic capabilities will allow automated development of more comprehensive and accurate models of subject matter, more substantive models of learners and their evolving levels of mastery, and, through enhanced discovery and resolution, more precise identification of instructional objects needed to produce desired levels of human competence.

- Discovery and resolution services will be vastly improved through the use of Universal Resource Names (URNs), which will serve as persistent, location-independent, resource identifiers. These URNs will be made possible by applications of the Handle System developed at the Corporation for National Research Initiatives (CNRI).

Developments such as these will allow instructional programs to assemble continuously and unobtrusively models of each learner's state, style of learning, and progress toward objectives and, in turn, will provide the precise, on-demand tailoring of instructional interactions characteristic of one-on-one tutoring. Such a capability may produce a third revolution in anytime, anywhere learning equivalent to the development of written language and, later, of books printed from movable type.

# **OPPORTUNITIES FOR NEW “SMART” LEARNING ENVIRONMENTS ENABLED BY NEXT-GENERATION WEB CAPABILITIES**

## **A. INTRODUCTION**

How might the emerging standards and infrastructure for Web-based learning objects enable, or even encourage, the development of sophisticated learning environments that evolve into intelligent tutoring systems (ITSs)? This question, which roughly identifies the topic of this document, raises plenty of questions of its own.

## **B. SOME QUESTIONS**

Let us suppose that these learning objects do enable the development of ITSs. Are technology-based learning environments worthwhile? What do we mean by ITSs and What do they add? What emerging standards, infrastructure, and learning objects are needed for these systems? How might the Web and Web services impact this evolution? Where might these capabilities take us?

### **1. Are Technology-based Learning Environments Worthwhile?**

As discussed in more detail by Fletcher (2002), the case for using technology to create these learning environments can be roughly summarized as follows:

- Tailoring instruction (education and training) to the needs of individual students has been found to be an instructional imperative and an economic impossibility. Research has determined that students tutored one-on-one score about 2 standard deviations higher on end-of-course achievement tests than students taught in one-on-many classrooms (Bloom, 1984). However, and except for a few critical skills (e.g., airplane piloting, surgery), we cannot afford the one instructor for each student that such tutoring requires.
- Technology-based instruction can, in many cases, make this instructional imperative affordable. Under any appreciable student load, providing instruction with technology is less expensive than hiring a tutor for each student.
- Technology-based instruction has been found to be more effective than current classroom instructional approaches in many settings and across many subject



matters. A review of 233 evaluations of typical technology-based instruction found an average improvement of 0.39 standard deviations over classroom instruction, which is roughly equivalent to raising the performance of 50th percentile students to that of 65th percentile students. Review of 44 similar evaluations of interactive multimedia instruction found an average improvement of 0.50 standard deviations, roughly raising the performance of 50th percentile students to that of 69th percentile students. ITSs have produced improvements of 1.05 standard deviations, roughly raising the performance of 50th percentile students to that of about 85th percentile students.

- Technology-based instruction is generally less costly than current instructional approaches, especially when many students or expensive devices are involved. In 16 studies where achievement under technology-based training was at least equal (and mostly superior) to that of classroom instruction, the cost ratios of the former to the latter were found to be 0.43 for initial investment, 0.16 for operating and support, and 0.35 overall.
- Technology-based instruction has been found to decrease the time needed to reach targeted instructional objectives. A review of 40 studies found that savings in the time needed to achieve given instructional objectives averaged about 30 percent. The Department of Defense (DoD) could save hundreds of millions of dollars in specialized skill training if training time could be reduced by 30 percent. Time savings may even more important in K–16 civilian education, where opportunities for students to expand their capabilities and develop their potential as rapidly as possible lay the foundation for fully realized, satisfying lives as well as global competitiveness and economic health.
- Technology-based instruction has been found to be a cost-effective alternative for achieving instructional goals. Compared with reducing class size, providing professional tutors, using peer tutors, or increasing the length of the school day, the costs to provide technology-based instruction for 15 minutes each day were found to be the least expensive means for raising comprehensive mathematics scores on a standardized test.
- Technology-based instruction will become increasingly affordable and instructionally effective with the development and use of standardized, reusable instructional objects. Early results have already indicated significant savings (Dodds, 2002).
- The knowledge structures underlying technology-based instruction can be readily (i.e., inexpensively) used to provide interactive performance aiding that both lowers training costs and enhances job performance (Fletcher and Johnston, 2002).

Overall, a rule of “thirds” emerges from assessments of technology-based instruction. Use of these technologies reduces the cost of instruction by about one-third, and it either reduces time of instruction by about one-third or it increases the amount of skills and knowledge acquired by about one-third.

Technology-based instruction can be used either by individuals or groups of individuals working in collaboration. It can be used in residential classrooms, remote classrooms, or any remote (distributed) location (e.g., the workplace, home, or elsewhere). It can be available anytime, anywhere.

## **2. What Do We Mean by ITSs and What Do They Add?**

The features that garden-variety technology-based instruction provide are notable. It can

- Accommodate individual students’ rate of progress, allowing as much or as little time needed by each student to reach instructional objectives
- Tailor the content and the sequence of instructional content to each student’s needs
- Make the instruction as easy or difficult, specific or abstract, and applied or theoretical, as necessary
- Adjust to the student’s most efficient learning styles (collaborative or individual, verbal or visual, and so forth). These capabilities have been available and used in technology-based instruction from its inception in the 1950s (Fletcher and Rockway, 1986).

The term “intelligent” in an ITS refers as much to intentions as to results, but it is more than a marketing term. It refers to specific capabilities that have been the goals of ITS development since these systems were first attempted in the 1960s (Carbonell, 1970; Brown, Burton, and DeKleer, 1982). Two defining capabilities of ITSs are that they

1. Allow either the system or the student to ask open-ended questions and initiate instructional, “mixed-initiative” dialogue as needed or desired
2. Generate instructional material and interactions on demand rather than requiring developers to foresee and pre-store all such materials and interactions needed to meet all possible eventualities.

Mixed-initiative dialogue requires a language that is shared by the system and by the student/user for information retrieval, decision-aiding, and instruction. Natural language (NL) has been a frequent choice for this capability (e.g., Brown, Burton, and DeKleer, 1982;

Graesser, Person, and Magliano, 1995), but the language of mathematics, mathematical logic, electronics, and other well-structured communication systems has also been used (Suppes, 1981; Sleeman and Brown, 1982; Psotka, Massey, and Mutter, 1988).

The generative capability requires the system to devise the interactions with students on demand—not draw from predicted and pre-stored formats. This capability involves not only generating problems tailored to each student’s needs, but also providing coaching, hints, critiques of completed solutions, appropriate and effective teaching strategies, and, overall, the interactions and presentations needed for one-on-one tutorial instruction. These interactions must be generated from information primitives using an “instructional grammar” that is analogous to the deep-structure grammar of linguistics.

Motivations for these two capabilities can be found in basic research on human learning, memory, perception, and cognition. Findings from this research have led us to view all cognitive processes as constructive and regenerative (Neisser, 1967). These findings have also extended general theories of perception and learning from the fairly strict logical positivism of behavioral psychology, which emphasized directly observable actions, to a consideration of the internal, cognitive processes that are assumed to mediate and enable human learning. The hallmark of these conceptions of cognition is that seeing, hearing, and remembering are all acts of *construction*, making more or less use of the limited stimulus information provided by human perceptual capabilities.

The generative capability sought by ITS developers is not something merely nice to have, but it is essential if we are to advance beyond the constraints of prescribed, pre-branched, programmed learning and the ad-hoc principles commonly used to design technology-based instruction. We need this capability if we are to deal successfully with the immensity, extent, and variability of human cognition.

### **3. What Emerging Standards, Infrastructure, and Learning Objects Are Needed For These Systems?**

Specification for learning objects has become an essential component of the Advanced Distributed Learning (ADL) initiative. This initiative is the most recent and visible effort in a long campaign to adopt the benefits of technology-based instruction and performance aiding in routine practice. It is intended to accelerate large-scale development of dynamic and cost-effective learning software and to stimulate a vigorous market for learning software. Its goal is to ensure access to high-quality “learning” (education, training, and

performance aiding) that is tailored to individual needs and capabilities and available at any-time and anyplace (Dodds, 2002).

The ADL initiative is preparing for a future in which communication networks and personal delivery devices are pervasive, inexpensive, and effectively transparent to users through ease of use, expanded bandwidth, and portability. It will establish knowledge libraries, or repositories, where learning “objects” can be accumulated and cataloged for broad distribution and use. These objects, because of their enhanced accessibility, will be ready for assembly on demand and in real time into instructional and performance-aiding materials that are tailored to the capabilities, intentions, and learning state of each individual or group of individuals needing them (Dodds, 2002).

ADL and ITSs, therefore, have several key goals in common:

- Both are generative in that they seek to prepare and present interactions on demand, in real time.
- Both are intended to provide instructional interactions that are tailored in content, sequence, difficulty, style, and so forth to users’ intentions, backgrounds, and needs.
- Both have a stake in research intended to accomplish such individualization.
- Both can be used equally well in instruction and performance aiding.
- Both are intended to accommodate mixed-initiative dialogue in which either the technology or the user initiates or responds to open-ended inquiry and discussion.
- Both require a supply of sharable instructional objects that are readily available for the generation of instruction or performance-aiding presentations.

To date, most of the ADL effort has been devoted to the specification of instructional objects that will populate learning libraries and other Web-available repositories. These objects are separated from context-specific run-time constraints and proprietary systems so that they can be incorporated into other applications. They have common interfaces and data exchange formats. They are *accessible* so that they can be indexed and readily found or “discovered”; *interoperable* so that they operate across a wide variety of hardware, operating systems, and Web browsers; *durable* so that they do not require modification as versions of the underlying software systems change; and *reusable* so that they can be adapted and used by many different development tools. The ADL initiative has coordinated groups of industry, academic, and government stakeholders working together to

specify objects that meet these criteria. These specifications have produced evolving, cumulative versions of the Sharable Content Object Reference Model (SCORM) (Dodds, 2002).

As presently defined, SCORM objects can be entire courses, lessons within courses, or modules within lessons. Their granularity or size remains an issue. ADL development is presently focused on packaging these objects for what has been called the “educational object economy” (Spohrer, Sumner, and Shum, 1998). One idea behind such an economy is that the emphasis in preparing materials for technology-based instruction (or decision-aiding) will shift from the current concern with preparing content components, or instructional objects, to one of integrating already available content into meaningful and relevant presentations.

Technicians, software engineers, instruction designers, and cognitive researchers from all sectors of the economy in the Americas, Europe, and Asia have joined in this quest. The task of specifying and developing these objects has become a global effort. The primary contribution of ADL has been to orchestrate this effort and document the results.

### **Toward More Adaptive, Intelligent Learning Systems**

Until recently, most mainstream learning systems have relied on predetermined and often fixed-path delivery of content. Such systems lack agility in adapting to learners’ mastery states and are thereby limited in their ability to tailor learning experiences to individual learners. An adaptive, “intelligent” learning system needs an accurate model of the learner, a model of the knowledge domain, and a capability that can evaluate the differences between the two models and identify or devise (on-demand and in real time) instructional strategies that will achieve desired instructional outcomes.

SCORM presently provides a rules-based “learning strategy” that enables sharable content objects (SCOs) to set the state of globally accessible records. These records can store the learner’s degree of mastery in the form of a score or a pass/fail state or can store the progress of the learner in terms of completion. A “hook” was included in the records that permits them to reference externally defined competencies. As the learner is sequenced through the SCOs, the learning system constructs a representation of the learner’s mastery and progress. The objective records can be viewed as a simple model of the learner’s state (Gibbons and Fairweather, 1998). How far can SCORM’s sequencing, navigation, and assessment capabilities can be pushed in the direction of generative intelligent learning systems? This remains an empirical issue that is currently being settled in applications of increasingly sophisticated learning systems observing SCORM specifications.

Another emerging specification called the *IMS Reusable Definition of Competency or Educational Objective* (IMS Global Learning Consortium, Inc., 2002) defines a means of building a taxonomy of competency definitions that meet specific objectives. This taxonomy can be organized hierarchically to represent dependencies, supporting skills, or prerequisites. Each competency definition has a text description of the competency and a unique identifier that can be referenced externally. The organization of a competency definition could represent specific skills or knowledge to be acquired for a specific task or subject domain (e.g., as one might find in Quantitative Domain Mapping). Since objectives records in SCORM can reference the competency model identifiers, the means to compare the state of the learner and the desired competencies now exist. This capability provides a system-based means to perform knowledge and skills gap analyses that will lead to more sophisticated and adaptive strategies that use such information (Wiley, 2000).

As learning system specifications become more robust, they will also become more adaptive. Improved assessment methods and results that will continuously and unobtrusively extract information from instructional interactions and better represent the state of the learner are emerging (e.g., Conati, et al. 1997; Corbett, Koedinger, and Anderson, 1997). The strategies developed by learning systems will be informed further by learner profile information, which can “pre-load” the learner model with mastery information from outside of the system. This process will improve the processes used by technology-based instructional systems to bypass relevant content of pre-mastered material (e.g., holders of certificates in particular subjects) and concentrate on relevant material yet to be learned.

The emerging specifications have provided a means of modeling and tracking the learner and referencing external models of knowledge and competency. The specifications now allow conditional rules that can tailor what the learner experiences to his/her mastery and progress (e.g., Dodds, 2002). Future services and processes will extend these basic capabilities in more sophisticated and nuanced ways.

Basically, what we seek is an engineering of instruction in which all learners reliably achieve outcomes such as the retention of skills and knowledge, the transfer of learning to new but similar applications, the motivation to continue study, the speed and accuracy of response, and so forth. Such an engineering of instruction would adjust and modulate the learning experience for each individual. It would identify the learner’s characteristics, level of knowledge, and style of learning; devise learning strategies as described earlier and later provide these learning strategies on-demand and in real time for each successive interaction with the learner; locate objects that are appropriate to the outcome being sought; and specify

the instructional strategy that was identified or devised. This is a significant challenge for the developers of instructional objects and for Web-based services, but current work suggests that they can meet it successfully.

#### **4. How Might the Web and Web Services Impact This Evolution?**

One way the current and near-term capabilities of learning systems might evolve is through the Semantic Web, which will provide powerful new technologies for both knowledge representation and the ontologies needed to connect them (Heflin, 2003). These technologies will provide ways not only to relate, but also to reason about information from widely different domains.

The Semantic Web is intended to imbue information available on the Web with sufficient meaning to improve substantially the cooperation between computers and human beings. It requires abstract representation of information on the Web using a Resource Description Framework and other specifications that have not yet been developed. Dealing with the semantic content of Web pages and information will improve the process of discovery needed to access relevant information and objects from the Web. Through an ontology that consists of a taxonomy and a set of inference rules that formally define operations and relations among terms, identifying and exposing semantic linkages between highly disparate bodies of information will be possible.

If the Semantic Web is successful, it will integrate real-world knowledge and skills acquired through simulation, education, training, performance aiding, and experience. It will provide a foundation for building more comprehensive and substantive models of subject matter domains and learners' levels of mastery than we now have and will combine them with more precise discovery of the instructional objects needed to produce desired human competencies. Learners and practitioners will be presented with a constellation of related activities (e.g., learning, doing, trying, referencing). This integration, combined with the already available functionalities of ITSs, provides the basis for a next-generation meta-architecture and learning environments based on instructional objects.

Core components of the Semantic Web will be built on top of existing and emerging Web standards. These standards provide the means to express the complex relationships and inference rules processed by Web services to perform specific tasks, such as profiling learners; representing their skills, knowledge, and abilities; linking these representations to instructional objects; and managing their progress toward objectives and competencies. Web services will serve as reusable, black-box applications that generate other Web-based

applications from objects. They will use open Internet standards, such as Hyper-Text Transfer Protocol (HTTP), eXtensible Markup Language (XML), Universal Description Discovery, and Integration (UDDI), and Simple Object Access Protocol (SOAP) to exchange information between applications as needed. The services will be language, platform, and object model independent. They will enable different applications, which run on different operating systems and are developed with different object models using different programming languages, to cooperate and become easily used Web applications. Taking advantage of existing infrastructure and applications, they will provide flexible, standards-based capabilities for binding applications together over the Internet.

### **Content Object Discovery and Retrieval**

Searching and discovering contextually relevant instructional content have become major topics. The success of Google and other Web search engines have whetted everyone's appetite for "just when you want it" search and retrieval and has demonstrated the value and utility of content discovery. Presently, Google may be the most important, effective, and widely used source of Web-based education. However, Google's method of locating content only by text crawling and indexing and by retrieving anything that is available and remotely relevant has limited its use as a discovery system for just-in-time, focused content assembly. Its operation could be improved substantially if it were to "cooperate" with content and retrieve only what is intentionally prepared and published for discovery.

A series of Internet specifications, which have been in development for some time, appear to be maturing and might form a framework on which sophisticated search, authentication, accreditation, and resolution services might be built. These services will provide a comprehensive means for instructional programs to locate and access appropriate content. At least two capabilities are needed to build such services:

1. **Content object identification and resolution.** Content object identification (to select candidate objects) and resolution (to narrow the selection to objects that are precisely relevant) are being addressed through the use of Universal Resource Names (URNs), which are intended to serve as persistent, location-independent, resource identifiers. The Corporation for National Research Initiatives (CNRI) has created a URN implementation called "The Handle System" (Kahn and Wilensky, 1995; CNRI, 2003), which allows digital objects to obtain a unique identifier and link each object to its location—wherever that might be—through the use of a Handle Resolution Service (similar to domain names resolving to Internet protocol addresses through the Domain Name System). CNRI hosts a global root server that can be queried during resolution



requests. The Handle System addresses a key repository problem: the unique identification of objects along with their present location and descriptive metadata.

2. **Discovery indexing with search criteria.** Discovery indexing presents another challenge. How does a user locate relevant content in the first place? One approach may be to use the Handle System to set up a registry and index of content repositories so that a repository can be located and searched. To do so, some form of external search must be enabled against some defined search criteria. The Global Information Locator Service (GILS) specification, which is based on an International Standards Organization (ISO) search standard (ISO 23950),<sup>1</sup> addresses how repositories might identify (discover) content within a repository collection.

The Common Indexing Protocol (CIP), developed by the Internet Engineering Task Force (IETF) (<http://www.ietf.org/>), allows the owner of content to create its index metadata while also allowing this indexing information to be shared among different servers, thereby enabling the development of new search and discovery services. New learning and performance aiding specifications are emerging. These specifications permit the identification of skills, competencies, and knowledge so that logical relations among them can be made and then represented in taxonomies that are relevant to specific but quite different communities of practices. One example of these specifications is the Reusable Definition of Competency or Educational Objective specification from the IMS Global Learning Consortium, Inc., (<http://www.imsglobal.org/>), which is now being advanced to the Institute of Electrical and Electronic Engineers (IEEE) as a candidate standard.

These specifications show great promise for the design and deployment of Internet and Web services that will enable accurate, precisely focused, and contextually correct discovery and retrieval of learning content objects on a highly scalable basis—an ability still not yet available. They will allow instructional programs to assemble continuously and unobtrusively the models of each learner’s state of knowledge, style of learning, and progress toward instructional objectives. In turn, these models will provide each student the

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<sup>1</sup> ISO 23950: *Information retrieval (Z39.50)—Application Service Definition and Protocol Specification*. It is the international standard for information search, equivalent to the U.S. standard designated American National Standards Institute/National Information Standards Organization (ANSI/NISO) Z39.50. ISO 23950 was developed primarily in the library and information services communities, though now it is broadly applied worldwide on the Internet and other networks. It supports full-text search but also supports large, complex information collections. While ISO 23950 leverages common practice, it does not enforce any particular format. It does not specify how network servers manage records or how clients use records. It only specifies how to express a search and return results.

precise tailoring of instructional interactions that is a characteristic and unique strength of one-on-one tutoring. The next several years are likely to see a great deal of emphasis on developing the specifications and services needed to make this possible.

## **5. Where Might These Capabilities Take Us?**

The emphasis on instructional technology causes us to reflect upon revolutions in instruction. The first revolutions in instruction may have occurred with the development of written language about 7,000 years ago. This allowed the content of advanced ideas and teaching to transcend time and place. The second revolution in instruction began with the technology of books. Books made the content of high-quality instruction available anywhere and anytime in an inexpensive medium that was accessible to many more people. A third revolution in instruction appears to be accompanying the introduction of computer technology. The capability of this technology for real-time adjustment of instructional content, sequence, scope, difficulty, and style to meet the needs of individuals suggests a third pervasive and significant revolution in instruction. It makes both the content *and* the interactions of high-quality instruction widely and inexpensively accessible—again, anytime and anywhere.

Building on this possibility, ADL, SCORM, intelligent tutoring, and the Semantic Web will provide a foundation for generative education, training, and performance aiding available anytime and anywhere. These developments will capitalize on the growth of electronic commerce and the global information grid. They will build on this worldwide, almost irresistible activity, accelerate it, and apply it to a full spectrum of education, training, and performance aiding needs.

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## **GLOSSARY**

ADL	Advanced Distributed Learning
ANSI	American National Standards Institute
CIP	Common Indexing Protocol
CNRI	Corporation for National Research Initiatives
DoD	Department of Defense
GILS	Global Information Locator Service
HTTP	Hyper-Text Transfer Protocol
IEEE	Institute of Electrical and Electronic Engineers
IETF	Internet Engineering Task Force
ISO	International Standards Organization
ITS	intelligent tutoring system
NISO	National Information Standards Organization
NL	natural language
OUSD(P&R)	Office of the Under Secretary of Defense (Personnel and Readiness)
SCO	sharable content object
SCORM	Sharable Content Object Reference Model
SOAP	Simple Object Access Protocol
UDDI	Universal Description Discovery, and Integration
URN	Universal Resource Name
XML	eXtensible Markup Language

# REPORT DOCUMENTATION PAGE

Form Approved  
OMB No. 0704-0188

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1. REPORT DATE January 2004		2. REPORT TYPE Draft Final		3. DATES COVERED (From-To) May 2003-July 2003	
4. TITLE AND SUBTITLE  Opportunities for New "Smart" Learning Environments Enabled by Next Generation Web Capabilities				5a. CONTRACT NUMBER DAS W01 98 C 0067/DASW01-04-C-0003	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S)  Philip Dodds, J.D. Fletcher				5d. PROJECT NUMBER	
				5e. TASK NUMBER BE-2-1624	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)  Institute for Defense Analyses 4850 Mark Center Drive Alexandria, VA 22311-1882				8. PERFORMING ORGANIZATION REPORT NUMBER  IDA Document D-2952	
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) OUSD(P&R) Readiness and Training Pentagon, Room 2C757 Washington, DC 20301				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION / AVAILABILITY STATEMENT  Approved for public release; distribution unlimited. (1 July 2004)					
13. SUPPLEMENTARY NOTES					
14. ABSTRACT Empirical evaluations suggest that use of interactive technologies can reduce the costs of instruction by about 1/3 and either increase achievement by about 1/3 while holding time constant or reduce time by about 1/3 needed to achieve targeted instructional objectives. These technologies can be delivered over the Web, which can also support systems that generate instruction on demand. Development of either generative instruction or pre-specified interactions will benefit from a ready supply of instructional objects such as those specified by the Sharable Content Object Reference Model (SCORM), which is now receiving wide, international acceptance. SCORM will be further enhanced by the development of the Semantic Web, which will allow more extensive links between available representations of knowledge and enhance the discovery of learning objects for use in instruction.					
15. SUBJECT TERMS technology-based instruction, Advanced Distributed Learning (ADL), education, training, Sharable Content Objects (SCO), reusable content, instructional courseware, intelligent tutoring systems, semantic web, web-based instruction, Sharable Content Object Reference Model (SCORM)					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT  SAR	18. NUMBER OF PAGES  20	19a. NAME OF RESPONSIBLE PERSON Dr. Robert Wisher
a. REPORT Uncl.	b. ABSTRACT Uncl.	c. THIS PAGE Uncl.			19b. TELEPHONE NUMBER (include area code) 703-697-4992