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Today's Web applications are already "aware" of the network of computers and data on the Internet, in the sense that they perceive, remember, and represent knowledge external to themselves. For example, search engines like Google prescan the Web and store a record of page contents. That image, not the real Internet, is then searched when a user makes a request. As an image, Google's internal representation of the Internet is similar to a memory formed from perception. But Web applications are generally not able to respond to the meaning and context of the information in their memories. As a result, most applications are insensitive and unresponsive to users' teaching and learning needs, and they are unable to decide when to abstract from interactions in order to synthesize new knowledge. As the Web becomes a distributed computing environment for eEducation applications that can dynamically share and update one another's information, however, future network-based learning and assessment applications have the potential to fill in these gaps.

This dynamic sharing or interoperability of programs across the Web has the potential to turn the Internet into a single computer. Future applications will move beyond today's access and sharing of textual information to full interoperability of algorithms and data using the Semantic Web (SW) architecture (Berners-Lee, Hendler, and Lassila 2001). In a way that is analogous to the mark-up of text for surface features such as bold and italics, the markup language of the SW encodes the meaning of data fields such as "author = Foreman" and "amount = owe – paid" as well as the contents of those fields. Emerging global agreements on terms, fields, and content types, arising naturally in the SW ecosystem of online interactions, will allow the new applications to work at a more complex level of machine inference than is possible today. This will lead to several advances in e-learning applications.

The article attempts to show how teaching, learning, and assessment might look with these advances fully elaborated in the future. As a forecast, this article is likely wrong about some details, but the basic picture is solid enough to demonstrate that a sea-change is about to happen in how we conceive of the Internet in eEducation—from the global reservoir of information to the global intelligence of multiple interacting knowledge communities. Keeping SW architecture in mind, we can envision a future with network-based resources, guidance, and assessment applications that will facilitate a significant increase in the number and speed of learners who travel full circle from consumers to creators of knowledge.

From Knowledge to Intelligence

The difference between knowledge and intelligence is knowing how and when to use information. An individual may know how to tie many good knots, but unless he can decide which one to tie and when, he lacks the intelligence that a specific circumstance may require. In this sense, today's Web has knowledge, but tomorrow's SW will have intelligence. The SW architecture will make it possible for one application to tell another not only exactly what the information is about, but also how to use the information it receives. This will provide the framework for the dynamic use of resources among applications. For example, such applications might take a "standing order" from a user about the kinds of resources most likely to help that user write an article that meets several criteria. Then, over several days, the application might present the user with options consisting of resource collections that fulfill the requirements to varying degrees.

The SW architecture enables this kind of dynamic responsiveness through the concept of the Resource Description Framework (RDF) triple structure, a data structure for describing or "marking up" Web page resources. Using RDF triples, an SW statement describing a Web resource has a subject, a predicate, and an object. The subject is the thing being described. The predicate expresses a trait or aspect of the subject, and the object is the value of that trait. In the statement "Vermont's postal code is VT," for example, the subject is "Vermont," the trait is the "postal code," and the object is the abbreviation "VT." A Web page rendered with RDF triples is a collection of such sentences—facts and relationships offered for processing. The triple structure in the markup language takes a step beyond a simple HTML display.

The RDF triple structure supports more complex Web interactions by providing a basic assertion model that allows application engines to store knowledge in relationship to a context for meaning, which is the foundation for making inferences. The predicate in particular expresses a directed relationship or simple rule between two entities, which provides an opening for building more complex rule-based statements, leading eventually to complex chains of rules or algorithms. When one RDF algorithm meets another (e.g., when one network-based application processes an incoming body of rules from another), the level of potential processing can cross from a one-way interpretive procedure to the possibility of mutual interacting and evolving systems—machines changing their stored memories and processes as a result of interactions among each other, their products, and their users.

As a result, future network-based eEducation applications reading RDF-encoded Web resources will be able to "parse" or break down statements and construct an appropriate computational response with the information. The SW application will ignore anything that it is not designed to process, but for things it recognizes, it will be able to use its embedded rules to interpret and compute with the results.

Teaching (Guidance, Resources, and Validation)

As the new network-based e-learning applications develop within the SW's technical specifications, they also will be guided by new conceptions of teaching that emerge through interactions among networks of humans and machines. Teaching, as this article defines it, entails:

guidance (getting to know and assisting the student in setting and monitoring goals for learning);
marshalling resources (providing learning opportunities, access to knowledge, and modeling); and
validating that learning has taken place (verifying that the learner changed, grew, and has new knowledge and skills).

Each of these roles requires that the teacher make inferences. By observing students' strengths, interests, and aspirations, the teacher infers what they need to learn. The teacher finds resources and constructs learning opportunities that introduce, exercise, and test new knowledge and skills. The teacher verifies that learning has taken place, accepting the learner's contribution to knowledge when appropriate. The "teacher" could be a community, an experience, an expert, or a machine that fulfills these functions for a learner.

SW applications, sometimes as an automated assistant to a human teacher, and at other times independently responding to a learner, will increasingly come to play each of the roles. SW applications can also facilitate a community, an experience, and the development or deployment of expertise. It is important to point this out so that we envision a broad, functionally defined set of processes that can potentially teach us.

SW applications can fulfill these functions, for example, by building an internal model or profile of the learner and then using it to search for resources and ways to assemble them for appropriate learning opportunities. The learner profile will develop gradually as a result of the learner's interaction with network resources, including existing texts and multimedia files as well as new documents and multimedia created through human-to-human and human-to-machine communications. Some network applications will "get to know" the learner through online surveys, and others will track what kinds of resources the learner uses. Based on the evolving profile, the software can recommend which resources are best for the learner to encounter next, in order to enhance learning or present interesting new resources for consideration and use.

Guided by learner profiles that have been shaped by human and machine communication and interaction, network-based SW applications will marshal new resources by searching globally distributed collections of resources that have been constructed by decentralized communities of experts and users. The collections, like the learner profiles, will evolve over time, reflecting the changing understandings of the social communities that create and extend knowledge. As people use resources, the use patterns will be saved, analyzed, and employed by SW software programs to select and arrange relevant new resources. Learners also will be able to offer what they have learned to expand the global knowledge base, and their offerings will increasingly be automated and automatic, resulting from collaborative online work as well as individual discoveries and creations.

An example is the EdReform portal network. Metatags, like dynamic card catalog listings of the resources, facilitate both import and export to external SW applications looking for resources. This enables support for a number of external applications where the EdReform collections provide ongoing responsive dissemination of resources (Gibson 2003; Sherry, Havelock, and Gibson 2004). Routing of resources can, for example, respond continuously to a learner's questions in an online course.

Since network-based applications can make inferences about new information resources, a new role for software, as an assistant in the assessment and validation of student work as evidence of learning, will emerge. This is possible because the SW architecture provides a mechanism for filtering, which is a basic component for making judgments (e.g., Does a student's work rate a high score? Is there enough evidence to say that the student meets a high standard?). With this capability, SW applications will evolve powerful new ways of applying network-enabled judgment in educational settings, including assessing what a learner knows and can do.

Learning (Cognition and Action)

As global network-based interoperability takes hold, SW applications will increasingly data-mine the learner's activity and then launch a variety of software programs that responsively search the global knowledge store. This activity will be represented in a profile that is constantly updated as the learner works in the SW application environment. The applications will assemble links to resources as well as locators for people, and will present the next best item for consideration, study, or enjoyment. Thus the thinking and actions of the learner captured in the learner profile will form a complex data set for analysis that will enable programs to find and assemble interactive, multimedia technology in response to a learner's strengths, interests, and aspirations. Three applications illustrate this process:

1. The EdReform portals demonstrate how a learner profile can be built and used to organize digital resources. A survey taken by the learner during registration is keyed to major concepts that have been used to catalog the resources (e.g., To what extent do you know how to "lead shared vision activities in an organization?") As a user responds to the survey (e.g., "I'm not very familiar with this idea"), a customized subcollection of portal resources is assembled that fits the profile of the answers to the survey. In addition, as the user selects and employs resources in the portal, a list of "most used" and "other resources you might want to view" is created and updated.
2. In software being developed by simSchool, the learner's actions will prompt the assembly of a collection of resources for further study as well as hints and suggestions for improving performance. These hints and other resources will be customized to fit the learner's skills and abilities, as made evident through his or her interaction with the portal.
3. The Educational Theory into Practice Software (ETIPS) site illustrates the principle of learner-centered profile analysis in another way. Experts have determined which resources within the collection are most highly relevant to solving various problems or challenges (referred to as "cases"). At the beginning of a case, the learner is prompted to decide which resources are needed and useful. The application then tracks and records the learner's actual use of each resource in terms of sequence and timing and compares the preliminary and concluding assessments.

Advanced learner profiles will evolve and differentiate as the learner grows. For example, one SW application might ascertain the learner's status on knowledge of science, another on the learner's goals for learning, and a third on interpersonal preferences. Automated advisors and human teachers will then be able to use SW helper applications to provide ongoing guidance to learners and enable a highly personalized learning experience.

The same capability will be used to mine the learner's products for new additions to knowledge. In this scenario, the profile of interest is that of the community of experts in a branch of knowledge. Future SW applications will be adept at helping humans apply filters for valid new content to enter the global storehouse, bringing the process full circle from inquiry to knowledge production and spanning appropriately from individuals to groups along the way.

Assessing (Evidence and Validation)

While we cannot see inside the learner's mind, we can data-mine the new Web-based environment for signs and artifacts of the learner's inquiry and expression. SW applications will lead to unobtrusive observations of learners who, rather than taking tests, are making decisions, constructing original work, and thinking aloud as they work in a naturally productive setting. Recent advances in the science of assessing thinking and learning (e.g., Pellegrino, Chudowsky, and Glaser 2001), when combined with the implications of SW applications in eEducation as outlined above, lead to the following ideas about the future of assessment:

Complex performances will be documented in network-based assessments by capturing the learner's actions, decisions, and work products over time.
With many instances of the learner interacting with applications in different times, places, and contexts, future network-based assessments will build a long-term record that documents how learners change over time.
Graphs and other visualizations of statistically analyzed changes in the learner's knowledge and skills will help teachers see the learner's conceptual growth or view the structural shape of the performance of a group of learners.
Analysis of expert/novice differences will allow for dynamic ongoing guidance to the learner.
The responsiveness of resources to learner profiles will assist in fostering metacognitive skills.
Dynamically generated metadata have the potential to identify the learner's problem-solving strategies.
These unobtrusive observation techniques, combined with libraries of evidence and tasks, will make possible timely feedback to learners and teachers and allow current needs to be matched with best "next step" materials, tasks, and challenges, including tasks that involve the transfer of learning to new contexts.

These same arguments can be applied as easily to a community of learners as to the individual. This leads to a vision of the future of eEducation in which knowledge growth through the accumulation of individual and group contributions will be facilitated and accelerated through SW applications.

The Question of Agency

Some might worry that the future could lead to the transfer of many customary teaching and learning decisions to SW applications and leave very little discretion to teachers and learners. Many customary decisions will indeed be transferred, but the result will free people to engage in higher levels of dialogue, guidance, decision-making, and support. The SW will be a greater amplifier of human creativity than today's Internet, not a machine to yoke human agency to an inexorable set of computations.

How can we be sure of this? While there are a few troublesome exceptions in the way that modern news and media are used when in the hands of the powerful, the general and unstoppable trend of technology and the Internet in particular has empowered of millions of people with greater freedom, access to information, mobility, and personal decision-making. The vision outlined here does not veer from or predict a reversal in that course of history. It accelerates and enhances it.

In simple pleasures—from locating the right image for tomorrow's lesson to finding the lowest priced fare to Italy to receiving an out-of-print book from someone's online garage sale—the personal dimension of today's Internet is evident. At the same time, global advances in research and knowledge, collaborative experiments and authorship, the safe transfer of highly sensitive information, exchanges of real value, and timely news about any place at any time all help illustrate the serious communal nature of today's network infrastructure. We can be assured that the SW future of learning will dramatically enhance both the individual and communal nature of learning, adding agency and capability and challenging us to see farther than we can today.

Conclusion

Ultimately a unique learner traverses the circle from discovering and using existing resources to expanding the world's knowledge base. With the SW architecture as a foundation, the network-based resources, guidance, and assessment applications of the future will facilitate and personalize this journey for each learner. As network-based applications emerge, students from the earliest age onward will be able to choose what to see and do while media unobtrusively record and facilitate accelerated learning. The future of learning with SW networks will balance the individual needs and interests of learners with the social and cultural goals of the knowledge community. The resulting multiplier effect will transform education as we know it.

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