A Model to Guide the Integration of the WWW as a Cognitive Tool in K-12 Education

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Abstract

The integration of World Wide Web (WWW) into K-12 education is progressing without adequate delineation of pedagogical models to guide this integration. Without clear specification of the goals, pedagogical dimensions, and expected outcomes of WWW integration (especially with respect to measurable outcomes), the WWW is likely to join the graveyard of previous technology innovations that have come and gone in K-12 schools. Carroll's (1963) Model of Classroom Learning identifies several of the critical factors that should inform the integration of the WWW as a "cognitive tool" into K-12 education, but it must be updated to reflect contemporary cognitive perspectives on learning. A proposed Model of WWW-Based Learning includes factors organized into three categories: inputs, processes, and outcomes. Inputs include individual differences, cultural habits of mind, and origin and strength of motivation. Processes include opportunities to construct knowledge, task ownership, sense of audience, quality and structure of Web resources, collaborative support, teacher support, and metacognitive support. Outcomes include knowledge and skills, mental models, and higher order thinking skills.

INTRODUCTION

In May 1998, researchers at the NEC Research Institute published a conservative estimate that at that time the World Wide Web (WWW) had at least 320 million pages (Lawrence & Giles, 1998). Although a large percentage of these pages may be inaccurate, misleading, biased, or even criminal, there are still millions of pages that K-12 students and their teachers can access to enhance teaching and learning. Unfortunately, while there is great fanfare in many quarters about the integration of the WWW into schools, there appears to be a lack of substantive thinking about the goals, pedagogical dimensions, and outcomes of using the web in K-12 education. This paper is intended to be a small step in specifying a more thoughtful approach.

Specifically, the purpose of this paper is to describe a model of the factors that enable the use of the WWW as a "cognitive tool" within K-12 learning environments. Cognitive tools refer to technologies that enhance our cognitive powers during thinking, problem-solving, and learning (Jonassen & Reeves, 1996). In this approach, web page authoring tools are given directly to learners to use for representing and expressing knowledge. Learners themselves function as designers, using software as tools for analyzing the world, accessing and interpreting information, organizing their personal knowledge, and representing what they know to others.

The model described below is based upon a model of school learning developed by Carroll 36 years ago. The updated model outlined in this paper can be used in the planning, development, and evaluation of Web-enhanced learning environments in K-12 education as well as to guide research into the effectiveness of the WWW as a cognitive tool.

THE CARROLL MODEL OF SCHOOL LEARNING

In 1963, John B. Carroll introduced a model of school learning which has influenced educational researchers and developers for more than three decades (cf., Bloom, 1977). In a 25-year retrospective look at his model, Carroll (1989) expressed surprise that his model had attracted as much attention as it had over the years, but also went on to state that "the model could still be used to solve current problems in education" (p. 26). Carroll's original model is a formal, quasi-mathematical one in which three of the five classes of variables that can explain variance in school achievement are expressed in terms of time. The structure of the Carroll Model is represented in Figure 1 and each of the six factors in the model are explained below.

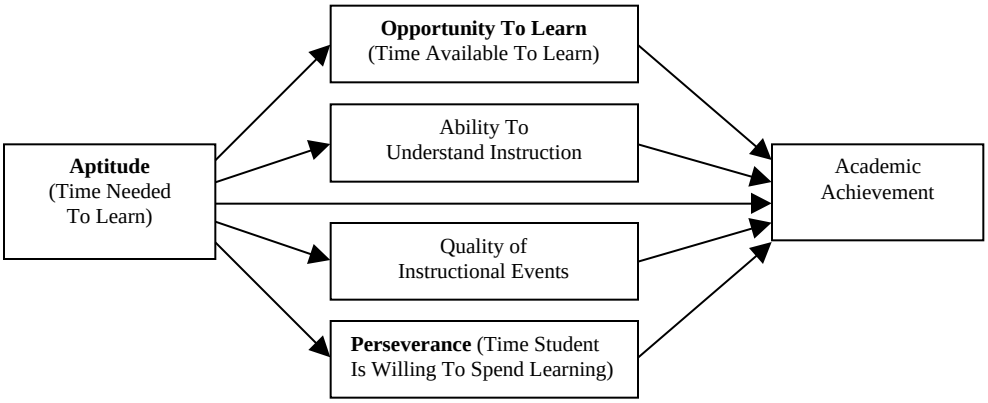

Figure 1: Carroll's (1963, 1989) "Model of School Learning."

Aptitude: An influential factor in Carroll's model is his interpretation of aptitude as "the amount of time a student needs to learn a given task, unit of instruction, or curriculum to an acceptable criterion of mastery under optimal conditions of instruction and student motivation" (Carroll, 1989, p. 26). Rather than viewing aptitude as a score on a standardized test, Carroll views most learners as capable of desirable levels of academic achievement provided enough time. This temporal interpretation of aptitude has influenced many, for example, Benjamin S. Bloom (1977) who is credited as the founder of the "Mastery Learning" instructional model.

Opportunity to Learn: The amount of time available for learning within a curriculum defines the "opportunity to learn" factor. Carroll points out that a weakness of many school schedules (e.g., 180 days a year divided into 60-minute classes devoted to different subjects) is that they provide less time than lower aptitude students need to achieve a given set of objectives. Content "covered" in a curriculum is another variable included in the "opportunity to learn" factor.

Ability to Understand Instruction: The ability to understand instruction factor includes language comprehension and learning skills, variables Carroll regarded as individual differences subject to development or enhancement. In Carroll's view, learners who develop better learning skills will be able to decrease the amount of time they require for learning, and in effect, increase their aptitude for learning.

Quality of Instruction: An often misinterpreted factor in Carroll's model of school learning is quality of instruction. Carroll emphasizes structural aspects of instruction such as knowledge of objectives, access to content, and carefully planned and clearly specified instructional events. Carroll (1989) clarifies that this does not mean that learning tasks must be broken down into small steps and subjected to drill and practice, defending his model as encompassing a wide range of instructional events, from direct tutorials to field trips.

Perseverance: The perseverance factor, often viewed as an operational definition of student motivation, also has a temporal interpretation. Perseverance is the amount of time a student is willing to spend on learning a given task or set of objectives. According to Carroll, if students have similar aptitudes, i.e., they need approximately the same amount of time to accomplish a certain learning task, then any of them who put forth more effort, i.e., spend more time, will attain higher achievement. Of course, if more time is not available for extra effort to be performed, then the perseverance factor will have little impact.

Academic Achievement: Carroll's model is focused on academic achievement of the kind usually measured by standardized achievement tests or by the grades achieved in academic courses. Typical achievement indicators predicted by the classes of variables in Carroll's model include course grades, grade-point-average (GPA), achievement test scores, and graduation rates.

THE WORLD WIDE WEB AS A COGNITIVE TOOL

More and more educators are turning to the WWW as a vehicle for implementing instructional improvements (Khan, 1997; Owston, 1997). Some of the common uses teachers are making of the Web include:

- enriching access to course materials,
- documenting course discussions,
- posting student writing, art, projects, etc. for critique,
- providing tutorials, simulations, and drills,
- facilitating group work,
- providing remedial support and/or enrichment, and
- enabling reflection and metacognition.

Despite these potentially powerful uses, there are serious misunderstandings and misgivings among educators about the potential of the WWW to support learning. As with previous innovations such as instructional television, many teachers and administrators assume that the WWW is a "magic box," and that simply putting content on the Web guarantees better learning. Windschitl (1998) describes the folly of these assumptions and calls for more systematic research into the effectiveness and impact of the WWW in education. Commercial ads for Web authoring tools encourage this assumption, proclaiming that once instructional materials are on the Web, students will learn automatically. Actually, the WWW does not guarantee learning any more than the presence of a library in a school guarantees learning. The Web is simply a resource which must be designed to support effective instructional dimensions.

The Web should be integrated into a learning environment only when its unique affordances are appropriate to the needs identified by teachers and students. Effective WWW-enhanced learning environments often require the integration of traditional media such as print materials and video, but some try to force these other media onto the Web. Different technologies should be employed for different purposes, and new technologies should not be used to deliver content better left in traditional forms. For example, the Web is an excellent vehicle for facilitating group work, but it is a lousy vehicle for reading.

A powerful use of the Web involves its application as a cognitive tool (Jonassen & Reeves, 1996). Cognitive tools have been around ever since primitive humans used piles of stones, marks on trees, and knots in vines to calculate sums or record events. In the broadest sense, cognitive tools are any technologies that enhance our thinking, problem-solving, and learning. Complex mathematical formulas and simple grocery lists are both cognitive tools in that each permits us to "off-load" memorization or other mental tasks onto something external to our minds.

Computer software programs are exceptionally powerful cognitive tools, but in many applications of computer software in education, content and interactions are encoded into pre-defined communications intended to transmit content to students with only superficial input from the learners themselves. By contrast, when computer programs are used as cognitive tools, students use software to analyze problems or tasks, organize unique knowledge representations, and share what they have learned with others. Although many types of software can be used as cognitive tools for learning (e.g., databases, spreadsheets, visualization tools, and multimedia authoring systems), this paper highlights the powers of web browsers and authoring tools when employed as intellectual partners in learning.

A MODEL OF WWW-BASED LEARNING

No model is a perfect reflection of reality, and some might argue that models like Carroll's are oversimplified and inadequate to capture the complexities involved in teaching and learning. However, if the impact of Carroll's model is any indication, people value even simple models because they help guide thinking about extremely complex phenomena such as teaching and learning. The model presented in Figure 2 is intended to capture many of the complexities of inputs, processes, and outcomes involved in education today. The factors in the model are described below, beginning with inputs, then the process factors that educators can manipulate to use the Web to support learning, and finally outcomes.

Aptitude and Individual Differences: Whereas Carroll (1963, 1989) defines aptitude in terms of the time a student requires to learn a task, the new model includes a richer analysis of the characteristics a student brings to a learning environment. The diversity reflected in most academic populations today demands a more complex portrayal. Certainly, aptitude in Carroll's sense is still relevant, but there are numerous other individual differences that should be considered when designing interactive learning environments (Jonassen & Grabowski, 1993). Locus of control, learning styles, anxiety, tolerance for ambiguity, prior experience, interests, attitudes, and disabilities are just a few of the individual difference variables that can be accommodated by improved instructional designs for Web-based learning environments.

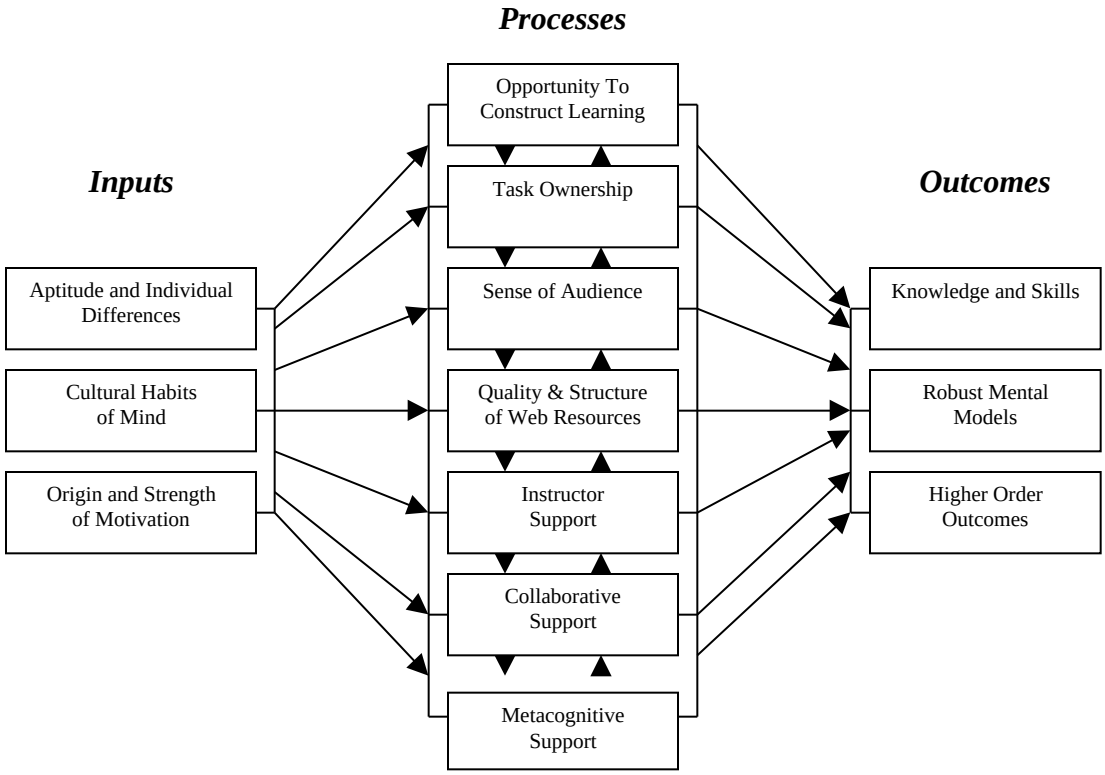

Figure 2: A model of WWW-based learning environment factors.

Cultural Habits of Mind: Some cultures emphasize rational problem-solving and critique whereas others place more value on normative communication and shared understanding. The importance of cultural influences on learning has been given increasing attention in education recently, although relatively few interactive learning environments have been designed to take advantage of cultural differences. Some might argue that cultural diversity is just a passing "fad," a by-product of the current attention to multiculturalism within North America and Europe. Another perspective is that sensitivity to cultural diversity and pluralism is a "meta-value" that should influence virtually every aspect of human activity, including the design and implementation of interactive learning environments. The role of cultural habits of mind in learning is an area in great need of disciplined research.

Origin of Motivation: Two primary forms of motivation are extrinsic (outside the learning environment, e.g., rewards if a child earns high grades) and intrinsic (integral to the learning environment, e.g., intellectual curiosity aroused by a problem). Every new educational technology promises to be intrinsically motivating, and the Web is no exception. Intrinsically motivating instruction is elusive regardless of the delivery system, but some proponents are convinced that the Web motivates learners automatically because it can integrate audio, graphics, text, animation, video, and a user-friendly interface. Others suggest that the learner control the Web provides enhances achievement motivation. The type of motivation affecting the learner is inevitably an important variable in explaining the effects of Web-based learning.

Opportunity to Construct Learning: Instructivists stress objectives sequenced into learning hierarchies that exist apart from the learner accompanied by direct instruction addressing each of the objectives in sequence. The WWW may be used for direct instruction, but its effectiveness is still unknown (Khan, 1997). Constructivists emphasize the primacy of the learner's intentions, experience, and cognitive strategies. The Web may prove to be a powerful vehicle for constructivist pedagogy if students use it to build and share unique knowledge representations. According to constructivists, learners construct different cognitive structures based upon their previous knowledge and interests. Rather than simply delivering instruction, constructivists create learning opportunities around tasks to be done or problems to be solved that have relevance for learners. In this approach, the WWW can serve as a "cognitive tool" for investigating and representing knowledge. The debate between instructivist and constructivist approaches to teaching and learning is far from over, but there is evidence that learners learn from opportunities to construct their own knowledge (Jonassen & Reeves, 1996).

Task Ownership: Brown, Collins, and Duguid (1989) emphasize the importance of task ownership in situated cognition, i.e., learning that is tied to the retrieval cues in the environments in which the learning will be used. Learning tasks may be primarily academic (writing an essay about the role of women during WWII) or primarily authentic (conducting research on the effects of pollutants on local stream quality). Academic tasks dominate the lives of students in schools, regardless of whether the Web is used or not, but the Web offers teachers and students unique opportunities to focus on authentic tasks. For example, in a high school chemistry course, a teacher might require learners to complete traditional academic exercises such as memorizing a table of elements. By contrast, the instructor might engage learners in practical activities such as analyzing the relationship between chemicals and allergies. Cognitive learning theory (Winn & Snyder, 1996) indicates that the ways in which knowledge and skills are initially learned affect the degree to which these abilities can be used in other contexts. By emphasizing authentic tasks that students "own" for themselves, Web-based instruction can be designed to enhance the transfer of knowledge and skills.

Sense of Audience: Surfing the WWW indicates that many people use the Web as a unique means of self-expression. The capacity to share knowledge with anyone anywhere in the world can be harnessed to give students a powerful sense of audience. Beichner (1994) described a project with seventh and eight grade students enrolled in a magnet middle school emphasizing the study of science. A primarily qualitative, observational investigation was conducted over a two-year period while the students worked cooperatively to create interactive displays for a touch-sensitive multimedia kiosk for the local zoo. Several categories emerged out of the qualitative analysis of the data which included extensive videotapes, interviews, observations, and student-created materials. The students' strong appreciation that they were preparing multimedia materials for a real audience emerged as the core category in the analysis. Related findings were:
1) students demonstrated great concern for accuracy in their displays,
2) students quickly assumed the major responsibility for content and editing decisions despite the fact that the original task of designing the displays had been structured for them by the teacher,
3) students accessed wide ranges of science materials to find the content they desired, and
4) their commitment to and enthusiasm for the project remained very high.

Although this project preceded the availability of the WWW in schools, similar outcomes can be expected when the web is used as a cognitive tool for knowledge representation.

Quality and Structure of Web Resources: The WWW is not a stable form of media in the sense that its features and functions are rapidly changing. Although "html," the hypertext language underlying the Web, was initially developed for the sharing of technical reports among scientists, it has evolved into a medium for many different forms of human interactions. Unfortunately, Web designs that support commerce (e.g., travel services) and communications (e.g., chat rooms) have progressed much further than designs and tools intended to support teaching and learning. Yet, despite a paucity of these tools, many educators are engaged in creating resources for education (Khan, 1997), and authoring systems for educational Web sites are making such innovations feasible for more and more teachers. Research and development to create more powerful Web resources for learning are greatly needed throughout education.

Collaborative Support: Collaborative learning refers to instructional strategies whereby learners work together in pairs, small groups, or even large groups to accomplish shared goals. Learners can benefit instructionally and socially when the WWW is used to structure and guide groupwork. Given an appropriate instructional design, two or more learners working together via the WWW may accomplish more than an isolated learner because the interactions among the learners may have more influence on their learning than the interactions between the learners and the Web-based content. The proliferation of Web-based tools for groupwork makes this one of the potentially most powerful factors in the model. Whereas early developers of interactive learning systems such as computer-based instruction were concerned with interactions between individual learners and machines, the WWW provides avenues for collaboration that may surpass the interactive powers of one individual with a computer.

Instructor Support: One of the lies about technology (in addition to the one that technology makes learning effortless) is that technology eliminates or reduces the roles of teachers. Web-based learning environments can be designed to support a range of roles for teachers from the traditional didactic role of "sage on the stage" to the facilitative role as "guide on the side." In 1968, Carroll wrote that "By far the largest amount of teaching activity in educational settings involves telling things to students..." (p. 4); little has changed since then. Meanwhile, researchers continue to focus on how the computer can be used to present information and judge learner input (neither of which computers do well) while asking learners to memorize information and later recall it on tests (which computers do with far greater speed and accuracy than humans). It is time to assign cognitive responsibility to each part of the learning system that does it best. The learner should be responsible for recognizing and judging patterns of information, organizing data, constructing alternative perspectives, and representing new knowledge in meaningful ways; the computer should perform calculations, store information, and retrieve it upon command; and the instructor should coach or collaborate in the knowledge construction process.

Metacognitive Support: Metacognition refers to a learner's awareness of objectives, ability to plan and evaluate learning strategies, and capacity to monitor progress and adjust learning behaviors to accommodate needs (Flavell, 1979). Metacognitive skills are the skills one has in learning to learn. "Metacognitive support" can be designed into Web-based learning

environments. For example, a Web site can be designed to challenge learners to solve complex problems such as troubleshooting electrical circuit boards. Metacognitive support integrated into such a site could provide learners with recapitulations of their troubleshooting strategies at any point in the problem-solving process. Much research and development remains before the WWW regularly includes sophisticated metacognitive support, but the potential is enormous.

Knowledge and Skills: Instead of the traditional achievement indicators in Carroll's model, a richer analysis of the outcomes of K-12 education is needed. The first outcome factor is labeled "knowledge and skills." Cognitive psychology has enriched our understanding of the mental states that result from learning to include constructs such as concepts, schema, rules, and skills (Winn & Snyder, 1996). Some variables in this factor can be measured with traditional tests, but others demand new approaches to measuring outcomes such as performance analysis and portfolio assessment.

Mental Models: It may seem strange to separate "mental models" from other types of knowledge and skills, but developing robust mental models is such an important educational outcome that it deserves special attention. Whether they go on to college or enter the workforce, our students must be able to activate appropriate mental models, use them to interpret new information, assimilate new information back into those models, reorganize the models in light of the newly interpreted information, and use the newly aggrandized mental models to explain, interpret, or infer new knowledge (Norman, 1983). Mental models are the mental structures we use to "understand systems and solve problems arising from the way systems work" (Winn & Snyder, 1996, p. 123). A benefit of mental models is that they can be "run" and "rehearsed." For example, students may develop rich mental models of evolution that allow the solution of complex problems in other fields.

Higher Order Outcomes: Although many educators are primarily concerned with the transmission of existing knowledge and skills in their fields, others also intend for students to develop higher order outcomes such as problem-solving abilities, creativity, curiosity, and the desire for lifelong learning. Higher order outcomes such as framing and resolving ill-defined problems, or exhibiting intellectual curiosity, are rarely directly observable. Although measures of variables such as curiosity have been developed, these types of outcomes must usually be inferred from students' performance on a range of alternative assessments.

RECOMMENDATIONS FOR DEVELOPMENT AND RESEARCH

The model of learning on the WWW described above has several uses. Consideration of the major input, process, and outcome factors in the model may encourage teachers and web developers to conceive new uses of the Web as a learning environment. Most innovations in education are adopted in ways that protect traditional teaching and learning practices. The challenge of developing "break the mold" applications of the WWW is great, but it is being accepted by creative educators around the globe. Hopefully, this model will inspire others to join in this quest.

The potential of the model to promote new research agendas is equally important. Much of the research in educational technology has been atheoretical, e.g., many studies have compared one educational technology with another in the absence of any theoretical framework for understanding how or why different technologies might provide different learning experiences and results for students. Analytical experiments unguided by sound, systemic theory yield research of little value. The WWW provides a unique vehicle for research on learning "with" technology that has a strong theoretical foundation (Jonassen & Reeves, 1996). Guided by robust learning theories and rich instructional models, new research agendas employing qualitative and developmental as well as experimental approaches are strongly encouraged.

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