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Designs for Learning Environments of the Future

International Perspectives from the Learning Sciences

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ISBN 978-0-387-88278-9 e-ISBN 978-0-387-88279-6
DOI 10.1007/978-0-387-88279-6
Springer New York Dordrecht Heidelberg London

Library of Congress Control Number: 2009942989

Printed on acid-free paper

Springer is part of Springer Science+Business Media (www.springer.com)

Preface

This volume began with a request to consider a follow-up to the *Innovations in Science and Mathematics Education: Advanced Designs for Technologies of Learning* book co-edited by Michael Jacobson with Robert Kozma nearly a decade ago. All of the chapters in that volume represented the work of US-based researchers, many of whom had been funded by the US National Science Foundation in the middle to late 1990s. In the intervening years, however, increasingly we see research into the design and use of technology-based learning innovations conducted by international teams of researchers, many of whom are now identified with the emerging field of the *learning sciences*.[1] Consequently, in planning for this new book, it was decided to request chapters from selected contributors to the earlier Jacobson and Kozma volume to illustrate more recent developments and research findings of relatively mature programs of research into innovative technology-enhanced learning environments, as well as to solicit chapters reflecting newer research activities in the field that also include international researchers.

It is important to realize, however, that the societal context in which research such as this is conducted has changed dramatically over the last decade. Whereas in the late 1990s, relatively few schools in countries such as the United States or in Europe (where computer scientists and engineers had developed the Internet and technologies associated with the World Wide Web) even had access to this globally distributed network infrastructure, let alone with significant numbers of computers with high resolution displays and processing capabilities. Today, countries such as South Korea have high speed Internet connectivity to all schools in the nation and nearly all developed countries have national plans for educational advancement that prominently feature discussions of using ICT ("information and communication technologies" that are essentially Internet connect multimedia computers) to help stimulate educational innovations. Further, there is increasing access in businesses, government, and homes to a variety of network-based information resources and Web-based tools, as well as sophisticated digital media such as networked 3D computer games and virtual worlds used daily by millions around the world.

[1]For an excellent collection of papers dealing with theory and research in the learning sciences with background information about the field, the *Cambridge Handbook of the Learning Sciences* edited by Keith Sawyer is highly recommended.

Approaching the second decade of the twenty-first century, it may be safely said that many of the "advanced technologies for learning" of the 1990s are now accessible in various forms by relatively large groups of teachers and students. It is less clear that many of the learner-centered pedagogical innovations such technologies may enable are as widely implemented as unfortunately didactic teaching approaches are still predominately used in the major educational systems around the world. A challenge we now face is not just developing interesting technologies for learning but also more systemically developing the pedagogical and situated contexts in which these learning experiences may occur, hence the major theme of this volume: *designing learning environments of the future*.

We recognize, of course, that one of the few certainties in life in the present century is rapid technological change. Still, we have solicited chapters to provide a representative (but not comprehensive) survey of a wide range of types of learning technologies that are currently being explored by leading research groups around the world, such as virtual worlds and environments, 2D and 3D modeling systems, intelligent pedagogical agents, and collaboration tools for synchronous and asynchronous learner interactions. More important, we believe, are that these various research projects explore important learning challenges, consider theoretical framings for their designs and learning research, and (in most chapters) discuss iterations on their respective designs for innovative learning environments. We hope these considerations of how research findings in these various projects may inform thinking about new designs for learning might serve as models for other researchers, learning designers, teachers, and policy makers who certainly will have to grapple with dynamic changes in the contexts of learning over the next few decades.

The chapter authors are all internationally recognized for their research into innovative approaches for designing and using technologies that support learner-centered pedagogies. This collection will be of interest to researchers and graduate students in the learning and cognitive sciences, educators in the physical and social sciences, as well as to learning technologists and educational software developers, educational policymakers, and curriculum designers. In addition, this volume will be of value to parents and the general public who are interested in the education of their children and of a citizenry in the twenty-first century by providing a glimpse into how learning environments of the present and future might be designed to enhance and motivate learning in a variety of important areas of science and mathematics.

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Chapter 1
Invention and Innovation in Designing Future Learning Environments

Michael J. Jacobson and Peter Reimann

The best way to predict the future is to design it.

As a central theme of this volume is the *future*, above we suggest a corollary to the famous Alan Kay observation that the best way to predict the future is to invent it, while also acknowledging his seminal technology contributions and his passionate vision for new ways of learning such resources enable. This theme of the future is endlessly fascinating and nearly always – as Kurt Vonnegut observed about life in *Slaughter House Five* – something that happens while making other plans.

A second theme – *design* – is one in "vogue" in the field of the learning sciences as there is design-based research, learner-centered design, learning by design, and so on. "Design" has connotations of someone creating an artifact that is generally new or innovative, which suggests a question: What is the relationship of design to innovation? John Seely Brown (1997), for example, wrote that in corporate research at Xerox Palo Alto Research Center (PARC), a view emerged that *innovations are inventions implemented*. A distinction is thus made between "inventions," that is, novel and initially unique artifacts and practices, and "innovations" that become more widely disseminated or appropriated by commercial environments – which, by extension, we suggest may also include communities of practice or social environments more generally. However, inventions are not "pushed" fully formed into an environment, as was Athena from the head of Zeus with armor, shield, and spear in hand. Rather, they are introduced into an environment and often foster changes in it that lead to iterative changes and developments of the original invention itself and the environment. Put another way, the transformation of inventions to innovations reflects *coevolutionary* processes of iterative changes of artifacts, practices, and the environment. J. S. Brown also notes that in the corporate world, it was often the case that considerably more resources were required for efforts involving innovations versus those necessary to create inventions initially.

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M.J. Jacobson and P. Reimann (eds.), *Designs for Learning Environments of the Future: International Perspectives from the Learning Sciences*, DOI 10.1007/978-0-387-88279-6_1,

By extension, we suggest that considerations of future learning environments may distinguish between the *design of "inventions"* (i.e., designing new pedagogies) and new types of learning environments, and the *design of "innovations"* (i.e., designing *implementations* of pedagogical and learning environment inventions). From this perspective, learning and technology research may focus on pedagogies and learning environments from the *invention* or the *innovation* perspective, or as a coevolutionary (and thus inherently longer term) trajectory from invention to innovation. For example, the history of the *SimCalc* Project exemplifies this last scenario. The initial design goals for *SimCalc* from the middle 1990s may be viewed as an advanced learning technology-based *invention* to help students learn core ideas about the mathematics of change and variation (i.e., calculus; see Roschelle, Kaput, & Stroup (2000)), whereas the research reported in this volume details research into *SimCalc* as it has been iteratively evolved and designed as an *innovation* being more widely utilized to help students understand challenging conceptual dimensions of algebra (see Roschelle, Knudsen, & Hegedus, this volume).

Whereas the notion of a learning environment has frequently been used to depict technical aspects, such as specific learning software, it has become accepted over the last decade that there is much more to the "environment" than the technology employed. The chapters in this book clearly incorporate this more holistic view that includes – in addition to the technology – tasks, assessment forms, and social (including organizational) aspects of educational settings such as classrooms. This widening of scope has resulted partly from research that has identified teaching practices and school leadership as two critical factors affecting the breadth and depth of uptake of learning technologies in schools, once issues of access to technology and teachers' basic technology skills have been addressed (Kozma, 2003; Law, Pelgrum, & Plomp, 2008). Teaching and leadership practices are, in turn, strongly affected by assessment regimens and accountability systems, and their objectives and rationales as expressed in educational policies.

Since the earlier volume was published (Jacobson & Kozma, 2000), a variety of learning technologies – often referred to as *information and communication technologies* (ICT) – have become ubiquitous in many educational sectors, at least in economically developed countries. As Kaput argued for in mathematics education, technology has become "infrastructural" (Kaput & Hegedus, 2007). In many classrooms, more or less advanced learning technologies are increasingly essential to the accomplishment of teaching and learning. However, as is the case for any infrastructure (such as roads or electricity), positive effects are neither immediate nor guaranteed; results depend on how the infrastructure is used. In the classroom, the key infrastructure users are the teachers because they not only use learning technologies themselves, but also they orchestrate the use for *other* users, the students. With respect to the technologies and pedagogical concepts included in this book, they all are infrastructural in the sense that they do not address a specific curricular area or focus on teaching a small set of skills, but they all create a space of possible designs. Some of them do so with a focus on representational designs, others are primarily concerned with designs for participation and ways of learning.

As we approach the second decade of the twenty-first century, many of the "advanced technologies for learning inventions" that were a focus of research in the 1990s – such as artificial intelligence, virtual reality, globally distributed hypermedia, network mediated communication, and so on – have now safely achieved the status of "invention." Thus a major challenge we now face is to engage in the even more challenging research concerned with the coevolution of *innovations* of learning environments and infrastructures and how these might enhance or even transfer learning in significant ways.

We make no pretenses for "predicting" how future environments for learning might look or be used. Rather, we have selected chapters for this volume that are representative of international learning sciences oriented research that are exploring a range of *designs for invention* and *designs for innovation*. We next provide an overview of the chapters, followed by a consideration of a set of thematic strands that emerged as we look across these chapters.

Chapter Overviews

In Chap. 2, Blikstein and Wilensky discuss the *MaterialSim* project in which engineering students program their own scientific models using the NetLogo agent-based modeling tool to generate microlevel visual representations of the atomic structure in various materials being studied. NetLogo also provides a multiagent modeling language to program rules defining the behaviors of agents in a system, which in the case of this research, consisted of the interactions of individual atoms. Of central importance in this chapter is the dramatic distinction between NetLogo-enabled visual and algorithmic representations versus the more typically used equation-based representations of the materials studied in these types of engineering courses, which based on classroom observations of a university level engineering materials science course consisted of 2.5 equations per minute in a typical lecture! An important argument advanced in this chapter is that the isomorphic visual and algorithmic representations of the relatively simple microlevel interactions of particular phenomena a computer-modeling tool like NetLogo affords may lead to dramatically enhanced learning compared to the highly abstracted mathematical representations typically used in traditional engineering education. Put another way, this research argues that *representations profoundly matter for learning*. Further, providing tools for learners to construct and shape these representations as part of modeling activities perhaps might matter even more.

The third chapter by Horwitz, Gobert, Buckley, and O'Dwyer presents research on "hypermodels," which builds on earlier work involving *GenScope* (Horwitz & Christie, 2000). *GenScope* was a "computer-based manipulative" representing genetics at different levels from microlevels of DNA and genes to macrolevel phenotypic and population expressions of organism traits. Learners may manipulate settings at the DNA and gene level in *GenScope* and then view how different traits would look on an organism. As is discussed in this chapter, however, just providing learners with a representationally rich, interactive, and open-ended (i.e., unstructured) environment such as *GenScope* did not necessarily lead to enhanced learning of genetics in many classrooms. In response to earlier mixed empirical findings, this research team worked on new ways to support or scaffold learners using an open-ended model or simulation tool using *hypermodels*. Briefly, a hypermodel provides a "pedagogical wrapper" around the core model or simulation engine that specifies particular sequences of learning activities involving the model or simulation engine for students as well as scaffolds for learning important conceptual aspects of the domain being represented. A centrally important aspect of this new research involves *model-based reasoning* (MBR), in which learners form, test, reinforce, revise, or reject mental models about the phenomena related to their interaction with hypermodels and other representations. This chapter reports on research involving the *BioLogica* hypermodel environment and its use to scaffold or structure genetics learning activities in classroom settings.

Ketelhut, Clarke, and Nelson, in Chap. 4, describe the main elements of three design cycles for the *River City* multiuser virtual environment (MUVE) that took place over 8 years. Conducted in the form of a design-based research project involving almost 6,000 students, the development of *River City* was driven by comparisons between "experimental" classes that used *River City* and conventional classes, all taught the same curriculum. One of pivotal design intentions was to let students themselves identify "factors" that might be causing diseases simulated in *River City* as part of science inquiry activities. The *River City* research team was able to explore important questions concerning the value of "immersive" science inquiry learning given their opportunity to experiment with thousands of students over a number of years. For instance, regarding the possible novelty affect of having students use a new approach such as a virtual world to learn, it was found that most students extended their engagement with the activities in *River City* beyond the first hours of using the system. It was also found that students who were academically low achieving profited from this kind of learning compared to traditional classroom instruction. In the last design cycle (2006–2008), a potential issue from the previous cycle – that of higher achieving students benefitting less compared to low-achievers – was addressed by incorporating a learning progression into the design of the environment in which some content was only accessible after certain prerequisite objectives had been achieved. Interestingly, the content then made available at this stage is not a higher "game level," as would be the case for a typical entertainment game, but rather was made available in a "reading room." This design approach thus raises interesting questions about the relation to – and possible synergies with – conventional text content and related learning activities and those activities with which students are engaged "in" a virtual world for learning.

In Chap. 5 – by Jacobson, Kim, Miao, Shen, and Chavez – discusses a number of design dimensions and research issues for learning in virtual worlds as part of the *Virtual Singapura* (VS) project. VS provides a virtual experience for students to engage in science inquiry skills, similar to *River City*, but the scenario is based