Transforming Education for the 21st Century: New Pedagogies that Help All Students Attain Sophisticated Learning Outcomes

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The Friday Institute White Paper Series on Models for 21st Century Education

This study was commissioned by the William and Ida Friday Institute for Educational Innovation at North Carolina State University (http://www.fi.ncsu.edu/index.html) as part of a larger White Paper Series on transforming education to meet the demands of the 21st century global knowledge society. The goals of the Friday Institute are:

- To research, develop and disseminate K-20 educational solutions that meet 21st century demands.
- To generate and propagate effective technologies for teaching and learning.
- To strengthen educational capabilities of rural and underserved communities in North Carolina and beyond.

To achieve these objectives, the Friday Institute serves as an inter-sector organizational catalyst among business, government, and education for scalable, linked economic and educational development. This is an important institutional model of a new strategy for educational improvement to meet the challenges of a rapidly approaching future quite different than the immediate past.

In its activities, the Friday Institute must strike a multi-level chord of innovation whose notes include insights from the fields of economics, international policy, technology forecasting and assessment, workforce development, cognitive science, learning technologies, curriculum development, pedagogy, and educational assessment. The Friday Institute White Paper series commissions scholars in these and related fields whose ideas and methods are potentially transformative for teaching, learning, and schooling. The goal of the series is to infuse novel, powerful frameworks for innovation and action both into work at the Friday Institute and throughout the many types of stakeholders in 21st century schooling.

This initial paper is written not only to advocate an innovative strategy for helping all students attain sophisticated 21st Century understandings and performances, but also to sketch the overall dimensions and challenges the Friday Institute faces in achieving its mission.

Comment [cjd1]: We should discuss whether FI wishes to engage in forms of innovative outreach as each paper is completed, with news conferences, online discussions, face-to-face forums, virtual events…

Transforming Education for the 21st Century

As this study documents, the 21st century seems quite different than the 20th in the capabilities people need for work, citizenship, and self-actualization. In response, society's educational systems must transform their objectives, curricula, pedagogies, and assessments to help all students attain the sophisticated outcomes requisite for a prosperous, attractive lifestyle based on effective contributions in work and citizenship. This Friday Institute White Paper delineates a conceptual framework for understanding the challenges and opportunities involved in such a transformation of schooling and describes an innovative strategy by which new pedagogies based on emerging immersive media can aid all students in attaining sophisticated 21st century understandings and performances. As discussed later, this and similar initiatives towards transforming schooling for the 21st century can leverage large scale investments external to education in U. S. economic development for global competitiveness and federally funded "cyberinfrastructure" for advanced research.

At this point in history, what can scholars say to society and its educational systems about core "21st Century Skills" students must master? Clearly, this descriptor, used by many groups providing advice on the topic of schooling for the 21st century (ETS, 2002; NCREL/Metiri, 2003; Partnership for 21st Century Skills, 2006; Leitch Review of Skills, 2006; AACU, 2007), is an attention-getting misnomer; we can not reasonably predict the capabilities people will routinely use in 2095 any more than a comparable group of scholars in 1907 could have accurately forecast the competencies central to the workplace, citizenship and self-actualization in 1995. Thus, what we are really attempting to discern is the core capabilities people will need in the first part of the 21st century – say fifteen to thirty years hence – to qualify for an attractive, prosperous job and lifestyle. This paper focuses on the role of information and communications technologies (ICT) in determining those crucial capabilities.

Many frameworks for educational objectives in the 21^{st} century distinguish between *knowledge* and *skills* and list examples of each, using the overarching descriptor of "21^{st} Century Skills." However, a distinction between knowledge and skills is problematic. Research in cognitive science has established that knowledge and skills are richly intertwined, rather than knowledge as content on which skills act as a process (Scardamalia & Bereiter, 2006). For example, applying mathematics as a perspective on understanding the world requires recognizing situations in which mathematical models might apply. This is neither a process-free content nor a content-devoid process, but a complex knowledge-skill mixture, an "understanding." Categorizing what students need for the 21^{st} century as *understandings* based on interwoven content knowledge and process skills is a more accurate depiction of how the mind works than the separation between these that current frameworks typically impose, and how students actualize those understandings in practice are *performances*. So, this study uses the terms understandings and performances rather than knowledge or skills.

Using Futures Research to Incite Strategic Planning

The fundamental goal of futures research and strategic planning is to aid individuals and organizations in managing complexity and uncertainty in their external environments over time (Dede, 1990). Futures research is oriented to articulating the long-range external forces that affect individuals, organizations, and societies; strategic planning deals with internal institutional goal setting, resource allocation, and monitoring of progress across multi-year time horizons. "21^{st} Century Skills" is a conceptual construct developed through futures research and used by advocacy groups to incite effective strategic planning among stakeholders in education.

Ultimately, the single future that occurs is invented through the interaction of structural certainties (e.g., demographic forces), social-contractual assurances (such as cultural patterns), wild cards (e.g., natural disasters, terrorist acts), human choices, and indeterminacies. The predictions below about the workplace in 2022 are conservative in that the future is seen as largely determined by major trends in the present; in this respect, the vision presented is less sophisticated than a forecast. A prediction portrays the future as like a train track leading us to a predestined outcome for which we must prepare. In contrast, a forecast depicts the future as like a tree: one trunk (the past and present), with many branches (alternative futures). In this model of the future, individuals and institutions are like ants crawling up the trunk toward the branches, moving through the present to the future. Decisions made in the present strengthen and weaken various branches (fortify and undermine possibilities) because the choices not made are constrained as alternatives; by the time our present becomes our future, only one branch is left (the new trunk).

While more sophisticated than trend-based predictions as a basis for strategic planning, a forecast of civilization in 2022 is too complex both conceptually and politically to serve as a basis for conceptualizing 21st century understandings and performances. Using the predictions below is likely accurate enough to serve as a reasonable basis for educational decision making.

Three Observations about the Impacts of ICT on Society

The conceptualization of 21st century capabilities I advocate in this paper is based on three fundamental observations about the probable future impacts on society of ICT. The first observation is that the capabilities of computers and related technologies have repeatedly expanded since these devices were first developed in the 1940s: from numerical calculators to data processors, to productivity enhancers, to information managers, to communications channels, to pervasive media for individual and collective expression, experience, and interpretation. The kinds of personal expression enabled by sites such as MySpace and YouTube, the rich array of entertainment experiences available through massively multi-player Internet games such as World of Warcraft and America's Army, and the types of collective knowledge creation enabled by wikis and social tagging tools such as Edtags.org all illustrate this ongoing evolution of ICT. Many sectors of the economy are now in the process of developing and actualizing business strategies based on how people now use ICT as a means of individual and collective expression, experience, and interpretation.

Lagging behind other sectors of society, current approaches to using technology in schooling largely reflect applying ICT as a means of increasing the effectiveness of traditional instructional approaches: enhancing productivity through tools such as word processors, aiding communication by channels such as email and threaded asychronous discussions, and expanding access to information via Web-browsers and streaming video. All these have proven worthy in conventional schooling, as they have in workplace settings; however, none draw on the full power of ICT for individual and collective expression, experience, and interpretation – human capabilities emerging as core work and life skills for the first part of the 21st century.

The second observation about the impacts of ICT on society is that cognition is now distributed across human minds, tools/media, groups of people, and space/time (Salomon, 1993; Hutchins, 1995; Dede, in press - a). Further, the types of representations available in mediated interaction (e.g., immersive simulations, non-linear conceptual maps) are richer and more nuanced than those possible in face-to-face settings without ICT. For example, a class can discuss geography using Google Earth as a common referent in a more sophisticated way than through utilizing paper maps. Because of advanced computers and telecommunications, the process of individual and collective thought in civilization is increasingly dispersed symbolically, socially, and physically.

For better or for worse, entertainment and human interaction are delocalizing as well. People who share the same dwelling may have very different personal communities as their major sources of sociability, support, information, a sense of belonging, and social identity, as contrasted to the historic pattern of lifestyles centered on face-to-face groups interacting with local resources (Rheingold, 2002). Our great-grandparents would see our lifestyle as bizarre – "electronic nomads wandering among virtual campfires" (Mitchell, 2003) – yet in counterpoint many youth today see prior generations as hapless prisoners of geography, trapped in the limits of a single physical location. Given that distributed thought, action, and sociability show no signs of receding, formal education should prepare people to achieve their full potential as workers and citizens in this emerging, novel, intellectual and psychosocial context, avoiding its weaknesses and traps while maximizing its strengths and opportunities.

The third observation about the impacts of ICT on society is that the types of work done by people as opposed to the kinds of labor done by machines are continually shifting as computers and telecommunications expand their capabilities to accomplish human tasks. Economists Frank Levy and Richard Murnane (2004) have documented a very important aspect of what constitutes 21st century understandings and performances:

> Declining portions of the labor force are engaged in jobs that consist primarily of routine cognitive work and routine manual labor—the types of tasks that are easiest to program computers to do. Growing proportions of the nation's labor force are engaged in jobs that emphasize expert thinking or complex communication—tasks that computers cannot do. (pp. 53–54)

These economists go on to explain that "expert thinking [involves] effective pattern matching based on detailed knowledge; and metacognition, the set of skills used by the stumped expert to decide when to give up on one strategy and what to try next" (Levy & Murnane, 2004, p. 75). What a skilled auto mechanic does when all diagnostic systems show normal functioning, but the car is still malperforming is expert decision making: inventing new problem solving heuristics when all standard strategies have failed. "Complex communication requires the exchange of vast amounts of verbal and nonverbal information. The information flow is constantly adjusted as the communication evolves unpredictably" (Levy & Munane, 2004, p. 94). A skilled teacher is an expert in complex communication, able to improvise answers and facilitate dialogue in the unpredictable, chaotic flow of classroom discussion.

Education should prepare students for a world in which almost all types of routine cognitive tasks are done by computers and in which expert thinking and complex communications are the core intellectual capabilities by which people attain prosperity and economic security individually, as a region, and as a nation. These higher order performances are based on fundamental knowledge about how to do simpler types of work, so the shift needed is not to remove the learning of routine cognitive skills (such as basic arithmetic operations) from the curriculum. Rather, the fundamental change involves deemphasizing fluency in simple procedures as an end-goal of preparation for work and life (e.g., counting bills as a bank teller), instead using these routine skills as a substrate for mastering complex mental performances valued in the future workplace, such as advising clients about global investment strategies tailored to their individual situations.

Based on these three interrelated shifts (the evolution of ICT for expression, experience and interpretation; distributed thought, action, and sociability; the paramount importance of expert decision making and complex communications), this paper advocates that we as a field rethink our current conceptualization of 21^{st} century capabilities, framing the issue as preparing today's students for a societal context fifteen to thirty years hence. In this enterprise of predicting the mid-range future, I do not assume any major technological advances not yet achieved, such as a substantial leap forward in artificial intelligence. Instead, I build my analysis on the continued evolution of sophisticated ICT that are not creative or smart in comparison to humans, but are increasingly adept at accomplishing "routine" tasks.

How difficult in 2007 is developing predictions about the effects on civilization of ICT in 2022 and beyond, a period during which today's students are assuming roles of responsibility in society? The equivalent in recent history would be describing in 1992 the impact of computers and telecommunications in 2007. In the early 1990s – before the WorldwideWeb, universal email, digital telephony, massively multi-user virtual environments, and similar civilization-wide advances – scholars did accurately articulate many of the shifts in society we see today (Dede, 1992). However, very few people predicted some important changes, such as sociosemantic networking, and many “futurist” forecasts (e.g., widespread, sophisticated artificial intelligence) were unrealized.

Predictions about the Future Workplace Emerging From Early 21st Century Trends

Thus far, the 21st century has seen a dramatic shift in the economic model for industrialized countries (Dede, Korte, Nelson, Valdez, & Ward, 2005). Systems of economic development based on geography, trade rules, and tariffs; slow dissemination of scientific and technological discoveries; and long cycles of product life have given way to global trade, rapid product innovation, the lowering of trade barriers, rapid dissemination of scientific and technological discovery, and rapid global deployment and movement of capital and the means of production (Chang, 2003). In the early 21st century, income and wealth come from applying technology and new ideas to create new products and processes. Adding value to products and processes is the key to growing jobs and incomes in this new economic environment (Aubert & Reiffers, 2004).

Competitive advantage for a region, state, or nation is now built on the skills of its general workforce, as opposed to its geography, trade laws, research labs, and patents; and critical to that competitive advantage are the education and skills training adults acquire in primary and secondary schools (Organization for Economic Co-operation and Development, 2001). In this new economic environment—the New Economy—education plays a critical role in maintaining national prosperity and stimulating economic growth (Stevens & Weale, 2003). The level of workforce skills and the periodic need to update those skills are both steadily rising, with no end in sight (Temple, 2001).

The New Economy is driven by entrepreneurs, technology, and innovation. Novel ideas, discoveries, and technologies have produced whole new industries and products;

innovation is now the primary basis for income and wealth generation (Sianesi & Van Reenan, 2002). Globalization has forced business to drive rapid technological change into the very core of business operations and processes (Bhagwati, 2004). Early efforts to improve productivity in business were aimed at applying technology to administrative and processing applications, such as purchasing, accounting, and payroll. These applications of technology changed the speed of work, but not the fundamental nature of work. As the New Economy took hold, the complexity of business dramatically increased. Global markets, just-in-time manufacturing and product fulfillment, outsourcing, lean manufacturing, and other changes forced fundamental changes in the nature and complexity of work (Autor, Levy, & Murnane, 2003). ICT applied to the core functions of business resulted in huge gains in productivity and the ability to manage and solve complex problems (Brown & Duguid, 2000).

Another way in which ICT are changing the nature of the jobs for which schooling prepares its graduates is the increasing importance of "offshoring": geographic shifts of comparative advantage in various types of economic production (Blinder, 2006). For example, over the last couple centuries comparative advantage in textile manufacturing has geographically shifted from England to New England to the Carolinas to China and other low-wage countries; with each change, workers and employers in the region losing jobs were surprised and angered. In the 21st century, as ICT grow in power, geographic regions are exporting with comparative advantage not just manufactured goods, but also services, such as being a call-center operator (Friedman, op cit).

Whether or not employers can import a service from outside their local region is not determined by whether the job is high-skill, high-education (e.g., doctor) or low-skill, low education (such as a security guard). Rather, the determining factor is whether the service is deliverable electronically without substantial diminution in quality (for example, securities analysis), or not (e.g., taxi drivers, airline pilots). Blinder (op cit) terms these "impersonally delivered services" and "personally delivered services"; over time, advances in ICT will increase the proportion of jobs falling into the former category. Thus, for students to select a career and for countries to choose an economic development path that will lead to a prosperous, secure lifestyle is much more complex now than in prior generations because the division of labor and the location of work are both rapidly shifting.

Because the predictions above are based on economic trends in the initial years of the 21^{st} century, they likely underestimate the degree to which work skills and conditions will alter compared to the late 20^{th} Century. In particular, as discussed later, the impacts of emerging ICT on society (individual and collective expression, experience, and interpretation; distributed cognition and action; erosion of routine tasks in favor of expert decision making and complex communications skills) are probably understated. Forecasts of technology-based paradigm shifts tend to overestimate how quickly change will occur and to underestimate the impact of the alterations (Porter, Roper, Mason, Rossini, & Banks, 1991). This precept likely applies to our attempt to predict the 21^{st} century capabilities today's students will need in workplaces a generation from now.

What Employers Seek in 21^{st} Century Workers

Numerous reports on the global, knowledge-based economy and the "flat" world document that tomorrow's workers must be prepared to shift jobs and careers more frequently, to be flexible and adaptable in acquiring job skills, and to integrate and focus a changing mix of job-derived and education-based knowledge on business processes and problems (Friedman, 2005). The application of information technology to the very core of business operations has caused a profound change in the needed skills and talents of New Economy workers (OECD, 2004). Markets in the New Economy are rewarding those who have high educational achievement and technical skill (Task Force on the Future of American Innovation, 2005).

The worker of the 21st century must have science and mathematics skills, creativity, fluency in information and communication technologies, and the ability to solve complex problems (Business-Higher Education Forum, 2005). As the global economy continues to evolve, predictions are that workers will change jobs seven or eight times during their work life. To be competitive in this constant churn, workers will have to engage in lifelong learning to update their education and job skills (Card & Dinardo, 2002). Clearly, the future personal economic security and well-being of American workers is tied to educational achievement (Federal Reserve Bank of Dallas, 2004).

Yet much of U.S. education is still based on the premise that economic processes and institutions will mirror those in the 20th century. Students are prepared to be future employees of business organizations now rapidly becoming obsolete (Business Roundtable, 2005). Current trends suggest that more students will run their own businesses rather than work for others and as adults must constantly, quickly, and efficiently learn new skills and information to be effective entrepreneurs. In this respect, the workplace forecasts above likely overstate the importance of skills as employees and understate the creativity, flexibility, and strong sense of self-efficacy today's youth will need to assume roles of economic leadership, rather than serving as followers for a few "captains of industry."

Thus, a crucial challenge for U.S. education is to align curriculum and learning to a whole new economic model based on an emerging global, knowledge-based workplace (Dede, Korte, Nelson, Valdez, & Ward, 2005). To accomplish this we must transform children's learning processes in and out of school and engage student interest in gaining 21st century skills and knowledge. Linking economic development, educational evolution, workforce development, and strengthened social services is essential to meeting this challenge (National Academy of Science, 2006).

[Of course, education has many responsibilities other than aiding economic development, and this paper does not attempt to portray the full range of educational missions or the instructional strategies needed for success across this spectrum of goals. However, all those other responsibilities are possible only if education succeeds in providing the foundation for a prosperous national future. This does not mean that education for economic development is privileged more than other objectives. Nonetheless, those who want education to succeed in resolving major concerns (e.g., equity, moral citizenship, self-realization) need to incorporate perspectives about preparation for 21st century work into their planning.]

A Contextualized Conceptual Framework for 21st Century Skills

Before articulating 21st century understandings and performances that seem central in light of these workplace shifts, developing a contextualized conceptual framework for these core capabilities is necessary. Part of that framework requires stipulating the metrics by which we judge whether, to merit inclusion, a human performance is truly significant in its projected importance to attaining an attractive, prosperous job and lifestyle – and sufficiently different from "20th Century Skills" to merit special attention. Determining the *degree* to which the capability is valuable in work and citizenship is key to these metrics, as is distinguishing in *kind* between “perennial” and “contextual” performances.

For example, “collaboration” is a perennial capability, always valued as a trait in workplaces across the centuries; as such, the basic value of this interpersonal performance is not intrinsically special to our emerging economic context. Arguably, however, the *degree* of importance for collaborative capacity is growing in an era where work is increasingly done by teams of people with complementary expertise and roles, as opposed to individuals doing manual operations on an assembly line (Karoly, 2004). Thus, even though perennial in nature, collaboration is worthy of inclusion as a 21st century performance because, for the context in which today’s students will function as adults, the importance of cooperative interpersonal capabilities is substantially higher than in the prior industrial era.

In contrast, the ability to rapidly filter huge amounts of incoming data, extracting information valuable for decision making, is arguably a “contextual” capability. Due to the prevalence of ICT, for the first time in human history people are inundated by enormous amounts of data that they must access, manage, integrate, and evaluate. The ability to separate signal from noise in a potentially overwhelming flood of incoming data is arguably a 21st century performance not in degree – because this is novel in history as a valuable capability – but in *kind*. This distinction is important because, unlike perennial capabilities, new types of human performances are typically not part of the legacy curriculum inherited from 20th century educational systems.

A Framework of Omission as well as Commission

Another part of the contextualized conceptual framework for 21st century performances is more politically controversial, yet vital: What do we deemphasize in current instruction and assessment to make room for 21st century understandings? At present the dominant model for what the curriculum should contain is the federal No Child Left Behind (NCLB) Act, supported by both major political parties and the general public and based on "test-to-standard" strategies. Under NCLB, state content standards are developed by disciplinary experts, professional organizations, and various forms of interest groups; high-stakes tests document whether or not students are learning some subset of that content; and individual students, teachers, schools, and districts are rewarded or punished based solely on test performance. In practice, because states' high-stakes psychometric tests are typically based on multiple-choice and short-answer items that have no mechanism for assessing attainment of higher order understandings and performances (National Research Council, 2001), 21st century competences embedded in state curriculum standards are buried in a mass of lower-level material and generally ignored in day-to-day teaching. The curriculum is crowded with low-level facts and recipe-like procedures (e.g., In what year did Columbus discover America? What are the seven steps of historical inquiry?), as opposed to nuanced understandings and performances (i.e., What confluence of technological, economic, and political forces led to the age of exploration around the end of the 15th century? By what process of interpretating of historical data did you reach this conclusion?).

Even though the concept of standards, assessments, and accountability makes sense at a fundamental level, current policies for improving educational achievement based on this concept have many problems from the perspective of preparing today's children for tomorrow's world (Dede, 2005a). For example, current content standards are based on disciplinary "silos" that do not incorporate metrics of contextual value based on degree and kind. Physics experts indicate what pre-college students need to know if they eventually plan to be physicists, historians determine what pupils must master if they are to become professional historians, and so on. This has led to a huge tangle of content and skills that U.S. educators are mandated to cover in just 12 years—an impossible task! Further, much of what is taught within a subject is only useful to the small subset of students who plan to focus on that particular field in college; state curriculum standards in each discipline are typically neither interrelated nor prioritized to emphasize core understandings and performances all students will need to succeed in the 21st century (Aspen Institute, 2007). While attempts at integration and prioritization are made in national standards from professional organizations like the American Association for the Advancement of Science or the National Council for the Teaching of Mathematics, in practice this level of understandings and performances is ignored in classroom teaching because the high-stakes tests provide no vehicle for measuring student progress on them.

Because of the accountability systems built into this model of educational reform, teachers are using weak but rapid instructional methods, such as lecture and drill-and-practice, to race through the glut of recipes, facts, and test-taking skills they are expected to cover. Despite research indicating that guided inquiry, collaborative learning, mentoring, and apprenticeships are far more effective pedagogical strategies, introducing these into school settings is difficult given the crowded curriculum and the need to prepare students for high stakes tests. Simply delivering required information for students' passive absorption takes every second of instructional time. Teachers have no means by which to prioritize what understandings and performances to emphasize in terms of 21st century citizenship; workplace capabilities for the global, knowledge-based economy; and lifelong learning.

Among all these problems, the biggest single issue is that the first generation of high-stakes tests that our nation is using to determine students' educational outcomes has substantial flaws. These are summative, "drive-by" tests, which provide no diagnostic, just-in-time feedback that could help teachers aid struggling students. In addition, while some assessments emphasize on core ideas and measure at least a few higher-order thinking skills, many state legislatures have allocated such limited resources for test development that the resulting instruments often measure only a random assortment of low-level skills and content, rather than core, higher-order 21st century understandings and performances (Nicols, Glass, & Berliner, 2005). In addition, policies such as financial incentives for teachers and districts to raise test scores can exacerbate already troubling differences in educational outcomes, promoting the abandonment of the very at-risk students the NCLB legislation was intended to help (Confrey & Maker, 2005).

Yet this reform movement still has strong bipartisan support and widespread backing from the public. Under these circumstances, a contextualized framework must take on the political challenge of arguing what to deemphasize in the curriculum – and why – in order to make room for students to deeply master core 21st century understandings and performances. This is not a situation in we must eliminate an equivalent amount of current curriculum for each 21st century understanding added, because better pedagogical methods can lead to faster mastery and improved retention, enabling less reteaching and more coverage within the same timeframe (Van Lehn and the Pittsburgh Science of Learning Center, 2006). However, what education should emphasize as its core outcomes is politically controversial even if substantial sections of the 20th century legacy curriculum are not eliminated.

Downgrading the importance of some material in the current curriculum is much harder than adding content and skills because omission involves "unlearning." A major challenge in professional development is helping teachers, policy makers, and local communities *unlearn* the beliefs, values, assumptions, and cultures underlying schools' standard operating practices, such as forty-five minute class periods that allow insufficient time for all but superficial forms of active learning by students. Altering deeply ingrained and strongly reinforced rituals of schooling takes more than the superficial interchanges typical in "make and take" professional development or school board meetings. Intellectual, emotional, and social support is essential for "unlearning" and for transformational relearning that can lead to deeper behavioral changes to create next-generation educational practices. Educators, business executives, politicians, and the general public have much to unlearn if 21st century understandings are to assume a central place in schooling.

Crucial, Neglected 21st Century Understandings

If we use the conceptual framework delineated above to apply the three observations about impacts of sophisticated ICT on society (individual and collective expression, experience, and interpretation; distributed cognition and action; erosion of routine tasks in favor of expert decision making and complex communications capabilities) to predictions about the emerging global, knowledge-based economy, what insights emerge about 21st century understandings? In particular, which 21st century performances are most crucial to emphasize, from the perspective of both importance and relative neglect in the curriculum at present? In the current frameworks of the Partnership for 21st Century Skills (2006) and similar initiatives (ETS, 2002; NCREL/Metiri, 2003; Leitch Review of Skills, 2006; AACU, 2007), which core understandings are omitted or underemphasized? Which parts of contemporary instruction should we deemphasize to make room for deep mastery of 21st century performances? Conducting a comprehensive analysis of the entire school curriculum from this perspective is beyond the scope of this paper. What follows illustrates such an analysis on one aspect of the 21st century understandings and performances students should learn, including novel methods for teaching and assessing these competencies.

In current conceptual formulations and instructional practices a neglected cluster of 21st century performances relates to "collective problem resolution via mediated interaction." In 21st century work, knowledge is grounded in a setting and distributed across a community, rather than abstract and isolated within individuals. Problem *finding* (the front-end of the inquiry process: making observations and inferences, developing hypotheses, and conducting experiments to test alternative interpretations of the situation) is crucial to reaching a point where the work team can do problem solving. Individual and collective metacognitive strategies for making meaning out of complexity (such as making judgments about the value of alternative problem formulations) are vital.

Each person involved has strong strategies in effective pattern matching based on detailed knowledge and in judging when to give up on a particular problem solving strategy and what to try next. Individuals on the work team are adept at manipulating sophisticated ICT applications and representations utilized within the complementary perspectives they bring to bear (e.g., using a spreadsheet to examine financial hypotheticals). They also are skilled in expressing core insights from their knowledge to others who have different backgrounds and experiences. Richly interactive complex communication among team members is not limited to face-to-face dialogue, but frequently relies on mediated interaction across distance in which the team co-constructs and negotiates shared interpretive understandings and a problem resolution strategy.

For example, a school district might task a team of teachers, school administrators, parents, and local business executives to develop a plan for improving students' educational outcomes in mathematics. Potential factors leading to subpar educational performance include individual differences in native language, gender, culture, and socioeconomic status; teachers' experience and preparation in mathematical content, subject-specific pedagogy, classroom management, and student engagement; state and district policies related to educational reform, the curricular materials used in mathematics, and the capacity of the technology infrastructure at local schools, among others. Under these circumstances, individual and collective skills in problem finding, inquiry, metacognition, collaboration, expert decision making, complex communication, and use of ICT tools, communicative media, and representations are vital to the team's success.

Legacy Curricula as Arid Ground for Teaching 21st Century Understandings

The suite of interrelated 21st century understandings and performances described above is largely absent in current pedagogical practices. Conventional, 20th century K-12 instruction emphasizes manipulating pre-digested information to build fluency in routine problem solving, rather than filtering data derived from experiences in complex settings to develop skills in sophisticated problem finding. Knowledge is separated from skills and presented as revealed truth, not as an understanding that is discovered and constructed, resulting in learning about rather than learning to do. Also, problem solving skills are presented in an abstract form removed from their application to knowledge; this makes transfer to real world situations difficult. The ultimate objective of education is presented as learning a specific problem solving routine to match every work situation, rather than developing expert decision making and metacognitive strategies that indicate how to proceed when no standard approach seems applicable.

Little time is spent on building capabilities in group interpretation, negotiation of shared meaning, and co-construction of problem resolutions. The communication skills stressed are those of simple presentation, rather than the capacity to engage in richly structured interactions that articulate perspectives unfamiliar to the audience. As discussed earlier, ICT applications and representations are largely used to automate traditional methods of teaching and learning, rather to model complexity and express insights to others. Face-to-face communication is seen as the "gold standard," so students develop few capabilities in mediated dialogue and in shared design within a common virtual workspace.

The discussion above suggests the importance of embedding students' understandings in performances they can fluently accomplish. In the workplace, employees prove their worth through performances (e.g., collaboration), based on understandings but instantiated in sophisticated behaviors. In effective job settings, performances are part of an organizational culture that includes the provision of requisite tools, respect for all occupational roles, rewards for leadership and innovation; employees are part of a sociocultural, situated community of practice (Wenger, 1998). To prepare students for a prosperous and secure future, educators need to build not just understandings, but experiences in a community of practice that develops fluent, sophisticated behaviors – yet classrooms today typically lack this type of learning and teaching, in part because high-stakes tests do not assess these competencies.

Assessments and tests focus on measuring students' fluency in various abstract, routine skills, but typically do not assess their strategies for expert decision making when no standard approach seems applicable. Essays emphasize simple presentation rather than sophisticated forms of rhetorical interaction. Students' abilities to transfer their understandings to real world situations are not assessed, nor are capabilities related to various aspects of teamwork. The use of ICT applications and representations is generally banned from testing, rather than measuring students' capacities to use tools, applications, and media effectively. Abilities to effectively utilize various forms of mediated interaction are typically not assessed.

Beyond these deficiencies in conventional practices of instruction and assessment, current conceptual formulations of 21st century understandings tend to underemphasize the interrelated nature of the capabilities described above. In contrast to the analysis above, typical lists of "21st Century Skills" may mention each individual aspect described above somewhere, but the capabilities students need are typically not discussed in terms of degree and kind, not presented as understandings that interweave content knowledge and process skills, not clustered into related suites of performances, and not prioritized in terms of relative neglect in the typical curriculum at present. 21st century initiatives should demonstrate to other groups how to evolve "next generation" curriculum standards and assessments by modeling a sophisticated development process and contextual framework that includes advice about what to deemphasize in current instructional practice as part of the "road maps" presented about how to actualize these initiatives.

The Rich Interrelationships between 21st Century Understandings and ICT Tools

An easy way to understand the role of information technology in helping students learn a curriculum composed of understandings and performances, delivered via pedagogy, and evaluated through assessment is to see the tools, applications, media, and virtual environments used as instrumental (Dede, in press - b). Information and communication technologies (ICT) aid with representing content, engaging learners, modeling skills, and assessing students' progress in a manner parallel to how a carpenter would use a saw, hammer, screwdriver, and wrench to help construct an artifact. The two key points in this analogy are (1) the tools make the job easier and (2) the result is of higher quality than possible without the tools. 20th century containers (e.g., chalk and talk) are insufficient for representing 21st century understandings and intellectual/psychosocial performances.

Much of what distinguishes 21st century performances is that a person and a tool, application, medium, or environment work in concert to accomplish an objective unobtainable otherwise (e.g., remote collaboration via groupware among a problem finding team scattered across the globe). However, ICT are not mere mechanisms for attaining the desired behavior; through distributed cognition, the understandings they enable are intrinsic to the fluent performance (e.g., a group co-constructing a sophisticated conceptual framework using the representational tools available in a wiki). Frameworks that discuss new "literacies" that are based on the evolution of ICT help to illuminate this aspect of 21st century learning.

For example, Jenkins and his colleagues (2006) delineate a set of novel literacies based on new media (page 4):

> **Play** — the capacity to experiment with one's surroundings as a form of problem-solving

Performance — the ability to adopt alternative identities for the purpose of improvisation and discovery

Simulation — the ability to interpret and construct dynamic models of real-world processes

Appropriation — the ability to meaningfully sample and remix media content

Multitasking — the ability to scan one's environment and shift focus as needed to salient details.

Distributed Cognition — the ability to interact meaningfully with tools that expand mental capacities

Collective Intelligence — the ability to pool knowledge and compare notes with others toward a common goal

Judgment — the ability to evaluate the reliability and credibility of different information sources

Transmedia Navigation — the ability to follow the flow of stories and information across multiple modalities

Networking — the ability to search for, synthesize, and disseminate information

Negotiation — the ability to travel across diverse communities, discerning and respecting multiple perspectives, and grasping and following alternative norms

While these are presented as knowledge-independent skills rather than understandings, they illustrate how 21st century behaviors, such as collective problem-resolution via mediated interaction, are based on the capabilities of emerging interactive media.

Dede (2005b) describes the types of learning strengths, styles and preferences "neomillennial" students acquire from their use of immersive collaborative media, such as multiplayer online games:

- Fluency in multiple media, valuing each for the types of communication, activities, experiences, and expressions it empowers.
- Learning based on collectively seeking, sieving, and synthesizing experiences, rather than individually locating and absorbing information from some single best source.
- Active learning based on experience (real and simulated) that includes frequent opportunities for reflection.
- Expression through non-linear, associational webs of representations rather than linear "stories" (e.g., authoring a simulation and a webpage to express understanding, rather than a paper).

- Co-design of learning experiences personalized to individual needs and preferences.

As discussed later, using immersive collaborative simulations in classroom settings offers a powerful method for building on these learning strengths and preferences to nurture 21st century understandings and performances.

Leu and his colleagues (in press) describe four characteristics of the "new literacies" generated by ICT. First, emerging ICT tools, applications, media, and environments require novel skills, strategies, and dispositions for their effective use. Second, new literacies are central to full economic, civic, and personal participation in a globalized society. Third, new literacies constantly evolve as their defining ICT continuously are renewed through innovation. Fourth, new literacies are multiple, multimodel, and multifaceted. These characteristics are in accord with the media-based styles of learning presented above and with the 21st century performances this paper discusses.

Leu's third point raises important issues about stability: How durable are 21st century performances in their applicability to work, citizenship, and self-actualization? How quickly will additional, important 21st century understandings and behaviors emerge as ICT continue to evolve? Certainly, tools, applications, media and environments are changing rapidly, with no end in sight. Typically, despite predictions of paperless offices or the end of the book, this evolution involves adding additional literacies and understandings rather than new performances displacing previously useful behaviors. Examining predictions about the future of ICT helps to illuminate what these additional literacies may be and what knowledge and skills may become less useful over time, as well as showing how planned national investments in "cyberinfrastructure" can leverage transforming schooling for the 21st century.

Cyberinfrastructure as an Emerging Vehicle for 21st Century Learning and Teaching

In recent years, the National Science Foundation has championed a vision of the future of research that centers on "cyberinfrastructure": the integration of computing, data and networks, digitally-enabled sensors, observatories and experimental facilities, and an interoperable suite of software and middleware services and tools (National Science Foundation Cyberinfrastructure Council, 2006). Gains in computational speed, high-bandwidth networking, software development, databases, visualization tools, and collaboration platforms are reshaping the practices of scholarship and beginning to transform teaching (Dede, in press – a). Cyberinfrastructures developed for research purposes also create intriguing opportunities to transform work and education in ways that parallel the shifts advocated in this study.

During 2004-05, with NSF funding, four workshops attended by experts in education were convened by the Computing Research Association. The foci of these workshops were (Computing Research Association, 2005):

- Modeling, Simulation, and Gaming Technologies Applied to Education
- Cognitive Implications of Virtual or Web-enabled Environments
- How Emerging Technology and Cyberinfrastructure Might Revolutionize the Role of Assessment in Learning
- The Interplay between Communities of Learning or Practice and Cyberinfrastructure

Collectively, these groups envisioned a cyberinfrastructure that "provides: 1) unprecedented access to educational resources, mentors, experts, and online educational activities and virtual environments; 2) timely, accurate assessment of student learning; and 3) a platform for large-scale research on education and the sciences of learning… Moreover, the new educational cyberinfrastructure will make it possible to collect and analyze data continually from millions of educational activities nationwide over a period of years, enabling new advances in the sciences of learning and providing systematic ways of measuring progress at all levels" (CRA, op cit, pg. 1).

The NSF Cyberinfrastructure Council (2006) provides a scenario of how advanced visualization and simulation capabilities could advance education:

> Imagine an interdisciplinary course in the design and construction of large public works projects, attracting student-faculty teams from different engineering disciplines, urban planning, environmental science, and economics; and from around the globe. To develop their understanding, the students combine relatively small self-contained digital simulations that capture both simple behavior and geometry to model more complex scientific and engineering phenomena. Modules share inputs and outputs and otherwise interoperate. These "building blocks" maintain sensitivity across multiple scales of phenomena. For example, component models of transportation subsystems from one site combine with structural and geotechnical models from other collections to simulate dynamic loading within a complex bridge and tunnel environment. Computational models from faculty research efforts are used to generate numerical data sets for comparison with data from physical observations of real transportation systems obtained from various (international) locations via access to remote instrumentation. Furthermore, learners explore influences on air quality and tap into the expertise of practicing environmental scientists through either real-time or asynchronous communication. This networked learning environment increases the impact and accessibility of all resources by allowing students to search for and discover content, to assemble curricular and learning modules from component pieces in a flexible manner, and to communicate

> and collaborate with others, leading to a deep change in the relationship between students and knowledge. Indeed, students experience the profound changes in the practice of science and engineering and the nature of inquiry that cyberinfrastructure provokes (page 31).

One could create comparable vignettes to illustrate educational opportunities in constellations of fields across the sciences and social sciences.

The Computing Research Association report on educational visions for cyberinfrastructure also presents a vignette of a "serious game":

> Learners cooperate in designing and conducting a mission to Mars, in the context of a game-based simulation. In the course of the project they carry out a variety of STEM-related learning activities, spanning physics, chemistry, biology, engineering and mathematics. These become springboards for seeking other learning resources outside the game, and collaborating with other learners in online working groups. Learners access online science and engineering data sets and models in order to compare their predictions against results from space scientists. They receive guidance in inquiry skills, metacognitive learning skills, and collaboration skills. The game itself is constructed and adapted through the collaborative efforts of the participating learners. In his earth sciences course, John, for example, studies terrain data from Mars Rover missions and creates a model of the Martian terrain to be explored by others. Manuela, in her high-school engineering class, designs an autonomous rover vehicle to collect geologic samples and constructs a simulation of her rover design for use in the mission. She can then compare her model's performance in the simulation against records of actual Mars Rover missions. Sherry,

> the teacher, is assisted by virtual assistant teachers (intelligent tutors) embedded in the game that help her monitor learner progress and offer guidance and challenges. One of Sherry's virtual assistants reports that Manuela is having difficulty getting the controller of her virtual robot to work, and is not availing herself of online resources, so Sherry suggests that she discuss her design with an online community of robot enthusiasts. Data collected from learner performance within and surrounding the game provide the teacher with documentation and evidence of learning progress relating to curriculum standards and goals. In some contexts this may replace the need for standardized tests, but in others the teacher already has sufficient evidence to predict that the learners will meet the required standards (page 7).

These scenarios of educational cyberinfrastructure are "extreme" in the sense that every application of information and communications technologies (ICT) to learning is imagined as both effective and technologically/economically feasible. As such, these vignettes include a sophisticated set of competencies for the mid-range future.

These visions of cyberinfrastructure, set about fifteen years in the future, do not contain a discrepant set of 21st century understandings and performances from those discussed earlier in this paper. The human capabilities envisioned for the evolution of high-level scientific research certainly are likely to encompass performances as advanced as any other 21st century work setting. If these predictions about emergent cyberinfrastructure are accurate, the sophisticated understandings described above that underlie 21st century work and citizenship will remain reasonably stable for the next generation of students. Moreover, the U.S. is committed to spending billions of dollars to implement ubiquitous technologies for research and education that will provide an infrastructure to aid in preparing students for 21st century society.

Teaching 21st Century Skills in the Impoverished Setting of a Classroom

In classroom settings, sophisticated ICT capable of supporting the teaching of collective problem resolution via mediated interaction are now emerging. This is important, because until this point in history schools have lacked the capacity to inculcate 21st century understandings and performances best learned through situated participation in real-world communities of practice. Reports such as the National Research Council's *How People Learn* (Commission on Behavioral and Social Sciences and Education, 2000) cite situated theories of learning (mentoring and apprenticeships in communities of practice) as powerful in life, but very difficult to achieve in school settings. Emerging interactive media now have the capability to redress this deficit.

Emerging Media for Situated, Immersive, Collaborative Simulation

Three complementary technological interfaces are currently shaping how people learn, with multiple implications for K-12 education (Dede, 1995b):

- The familiar *"world- to- the- desktop"* interface provides access to distributed knowledge and expertise across space and time through networked media. Sitting at their laptop or workstation, students can access distant experts and archives, communicate with peers, and participate in mentoring relationships and virtual communities-of practice. This interface provides the models for learning that now underlie most tools, applications, and media in K-12 education.
- Emerging *multi-user virtual environment (MUVE)* interfaces offer students an engaging "Alice in Wonderland" experience in which their digital emissaries in a

graphical virtual context actively engage in experiences with the avatars of other participants and with computerized agents. MUVEs provide rich environments in which participants interact with digital objects and tools, such as historical photographs or virtual microscopes. Moreover, this interface facilitates novel forms of communication among avatars, using media such as text chat and virtual gestures. This type of "mediated immersion" (pervasive experiences within a digitally enhanced context), intermediate in complexity between the real world and paint-by-numbers exercises in K-12 classrooms, allows instructional designers to construct shared simulated experiences otherwise impossible in school settings. Researchers are exploring the affordances of such models for learning in K-12 education (Clarke et al, 2006; Barab et al, 2004).

- *Augmented reality (AR)* interfaces enable "ubiquitous computing" models. Students carrying mobile wireless devices through real world contexts engage with virtual information superimposed on physical landscapes (such as a tree describing its botanical characteristics or an historic photograph offering a contrast with the present scene). This type of mediated immersion infuses digital resources throughout the real world, augmenting students' experiences and interactions. Researchers are starting to study how these models for learning aid students' engagement and understanding (Klopfer et al, 2004; Klopfer & Squire, in press).

MUVEs empower creating contexts inaccessible in the real world, while AR enables the infusion of virtual contexts within physical locations.

In both MUVEs and AR, knowledge is grounded in a setting and distributed across a community, rather than isolated within individuals. Contrary to conventional K-12 instruction where knowledge is decontextualized and explicit, in MUVEs and AR the learning is situated and tacit: Problem finding is central to problem solving. This parallels the nature of 21st century work, as well as the learning styles and strengths of today's digital-age students. These immersive interfaces for collaboration and simulation can aid students in learning collective problem resolution via mediated interaction as a key cluster of 21st century understandings and performances.

The Power of Situated Learning for Inculcating 21st Century Performances

Situated learning requires authentic contexts, activities, and assessment coupled with guidance from expert modeling, mentoring, and "legitimate peripheral participation" (Wenger, 1998). As an example of legitimate peripheral participation, graduate students work within the laboratories of expert researchers, who model the practice of scholarship. These students interact with experts in research as well as with other members of the research team who understand the complex processes of scholarship to varying degrees. While in these laboratories, students gradually move from novice researchers to more advanced roles, with the skills and expectations for them evolving.

Potentially quite powerful, situated learning is much less used for instruction than because classrooms are by design isolated from the real world to encourage reflection and to provide custodial care. However, as discussed below, emerging media such as multi-user virtual environments (MUVE) and augmented realities (AR) can draw on the power of situated learning even in school settings by enabling immersive, collaborative simulations with problems and contexts similar to the real world. In particular, these emerging interactive media provide the capability to create problem-solving communities in which participants can master 21st century understandings and performances such as collective problem resolution via mediated interaction.

Situated learning is important in part because of the crucial issue of transfer. Transfer is defined as the application of knowledge learned in one situation to another situation and is demonstrated if instruction on a learning task leads to improved performance on a transfer task, typically a skilled performance in a real-world setting (Mestre, 2002). One of the major criticisms of instruction today is the low rate of transfer generated by conventional instruction. Even students who excel in schooling or training settings often are unable to apply what they have learned to similar real-world contexts. Situated learning addresses this challenge by making the setting in which learning takes place similar to the real-world context for performance in work or personal life. Learning in well-designed digital contexts can lead to the replication in the real world of behaviors successful in simulated environments (Schwartz, Bransford, & Sears, 2005).

Moreover, the evolution of an individual's or group's identity is an important type of learning for which simulated experiences situated in virtual environments or augmented realities are well suited (Murray, 1997). Reflecting on and refining an individual identity is often a significant issue for students of all ages, and learning to evolve group and organizational identity is a crucial skill in enabling innovation and in adapting to shifting contexts. The social sciences see both the self and the organization as often fragmented, with complementary parts, rather than centralized and unitary (Turkle, 1995). Identity "play" through trying on various representations of the self and the group in virtual environments provides a means for different sides of a person or team to find common ground and the opportunity for synthesis and evolution.

Immersion is important in this process of identity exploration because virtual identity is unconstrained by physical attributes such as gender, race, and disabilities. Virtual environments based on games such as Lineage (Steinkuehler, 2006) and simulations such as Whyville (Neulight et al, in press) illustrate how participants take advantage of fluidity in the identities they present. Simulations in virtual environments and augmented realities increase the value of these explorations by providing realistic feedback on how the real world responds to various patterns of individual and group behavior.

But what is so special about the situated learning now enabled in classrooms by emerging media? After all, outside of school contexts students have opportunities for situated learning without using technology. One attribute that makes mediated immersion different and powerful is the ability to access information resources and psychosocial community distributed across distance and time, broadening and deepening experience. A second important attribute is the ability to create interactions and activities in mediated experience not possible in the real world, such as teleporting within a virtual environment, enabling a distant person to see a real-time image of your local environment, or interacting with a (simulated) chemical spill in a busy public setting. Both of these attributes are actualized in the MUVE and AR interfaces.

How Immersive Presence Enhances Learning

Immersion is the subjective impression that one is participating in a comprehensive, realistic experience (Heeter, 1992; Witmer & Singer, 1998). Immersion in a mediated, simulated experience (such as a virtual environment or an augmented reality) involves the willing suspension of disbelief (Dede, 2005b). As an example, when watching a Harry Potter movie on an IMAX screen, the plot and characters coupled with visual and auditory input produce a sense of psychological immersion: the audience does not focus on the sensations of sitting in a theatre seat but instead on being present in a wizarding "world," observing a fascinating series of events. The example is weak, however, because the experience is passive, as opposed to the stronger immersion induced when participants shape an experience rather than just observe it.

The design of mediated-immersion simulated learning experiences depends on actional, symbolic, and sensory factors (Dede, Salzman, Loftin, & Ash, 1999). Inducing actional immersion involves empowering the participant in an experience to initiate actions that have novel, intriguing consequences. For example, when a baby is learning to walk, the degree of concentration this activity creates in the child is extraordinary. Discovering new capabilities to shape one's environment is highly motivating and sharply focuses attention.

Inducing a participant's symbolic immersion involves triggering powerful semantic associations via the content of an experience. As an illustration, reading a horror novel at midnight in a strange house builds a mounting sense of terror, even though one's physical context is unchanging and rationally safe. Invoking intellectual, emotional, and normative archetypes deepens the experience by imposing an overlay of associative mental models.

Beyond actional and symbolic immersion, advances in interface technology are now creating virtual environments and augmented realities that induce a psychological sense of sensory and physical immersion. Sensory immersion is relatively easy to foster in augmented realities, which are set in physical environments. Psychological immersion is achievable in MUVEs by design strategies that combine actional, symbolic, and sensory factors in manipulating an avatar to further the suspension of disbelief that the participant represented by the avatar is "inside" a virtual environment: the equivalent of diving rather than riding in a glass-bottomed boat.

Learning 21st Century Performances in the River City MUVE

With funding from the National Science Foundation, for seven years my colleagues and I have used design-based research methods to study an educational MUVE called River City. In the River City MUVE, a participant takes on the identity of an avatar, a virtual persona in the world (see figure 1) and communicates with other participants' avatars via text chat and virtual gestures (Clarke, 2006). In this graphical virtual context, participants also interact with digital artifacts, such as viewing pictures or manipulating tools (e.g., an online microscope), as well as with computer-based agents (see figure 2).

Figure1: Avatars

Figure 2: Talking to Computer-Based Agents

The River City curriculum is a middle school science unit designed around national content standards and assessments in biology, ecology, epidemiology, and scientific inquiry (http://muve.gse.harvard.edu/rivercityproject/). In the River City MUVE curriculum, students work in teams of three to collaboratively solve the problem of why the residents of River City are falling ill. Students travel back in time—into a series of virtual worlds—to the period in history that scientists were just discovering bacteria.

The curriculum is historically accurate and contains pictures from the Smithsonian Institute that help to portray accurate picture of what the time period was like. The River City virtual “world” is an industrial 18th century city with a river running through it (see Figure 3). Different forms of terrain influence water runoff in the various neighborhoods (wealthy area, middle class area and tenements). The city has a hospital, hotel, and university. The students populate the city, along with computer-based agents (residents of River City, see figure 2) and digital artifacts that can include audio or video clips (such as audio clues of sick residents coughing or mosquitoes buzzing). Content in the right-hand interface-window shifts based on what the participant encounters or activates (Figure 4).

Figure 3: Map of River City

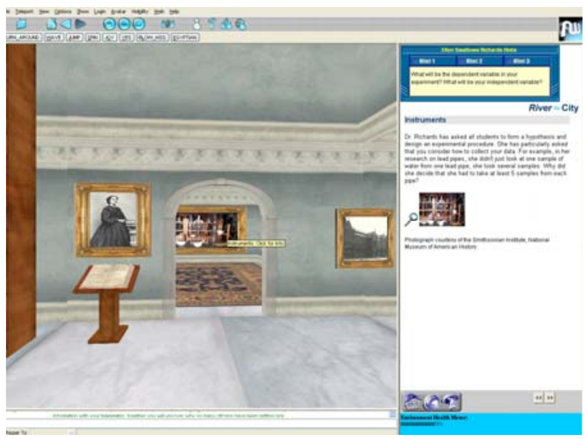
Figure 4: View of 3-D environment and web-based content on right side of screen.

Inquiry and River City

Students learn to become scientists by engaging in the inquiry practices of scientists. The National Research Council defines science inquiry as a multifaceted activity that involves students actively making observations, posing questions, planning and conducting experiments, and communicating results (NRC, 1996). In River City, students engage in all aspects of inquiry as defined by the NRC. These aspects are listed in table 1 below.

Table 1: How River City Objectives Map onto Inquiry (as defined by the NRC, 1996).

Making Observations	Throughout the curriculum students are asked to make observations and draw inferences about what they see and hear as they move around the world.
Posing Questions	Students not only ask questions of the residents of River City and elicit information that often offers a clue about the problems. They also record their own questions and reflect on them as they gather data and make observations and inferences.
Planning Experiments	Students are guided through a generalized process of the scientific method, where they learn how to turn their questions into hypothesis and design a procedure.
Conducting Experiments	Students conduct their experiment in River City. They visit a 'control world' (controlled part of their experiment and gather data) then they visit the 'experimental world' (where their independent variable has been changed and collect the same data). They then compare the data gathered in the two worlds and write up their results using graphs and charts. (This is explained in more detail below).
Communicating Results	Students then write up their results in a report to the Mayor of River City. They also participate in a research conference where they present and share their findings with their classmates. (These are explained in more detail below).

Engaging in inquiry also involves students learning how to collect data and test their hypotheses and use the tools of scientists, such as an online microscope. For example, they can use the virtual microscope to take water samples (see figures 5 and 6 below) from one of the water sampling stations in the city. Multiple sources of data collection include:

- Conversations with the residents of River City (students click on residents and choose from drop down menu of conversation options)
- Tacit Clues (visual and auditory)
  - Appearance of river, trees
  - Weather (changes in seasons influence the illnesses)
  - Sounds: mosquito buzzing, coughing, water flowing
- Hospital Admissions chart (students can click on and read the chart that lists symptoms and demographic info of patients)

- Environmental Health meter (students can click on this tool and take readings of a locations “health”)
- Clues associated with Pictures (students can click on pictures from Smithsonian Institute Collection and read clues)
- Sampling stations using online microscopes:
    - Water Purity (see figures 5 and 6 below)
    - Mosquito nets

Figure 5: Taking a water sample with the virtual microscope.

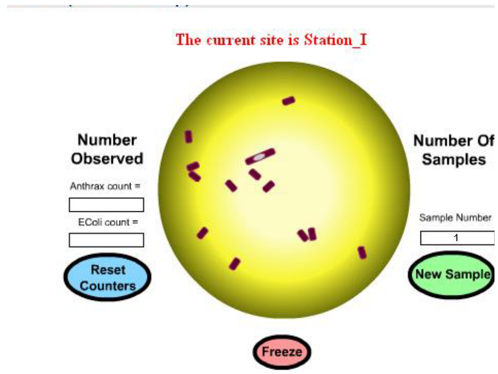

Figure 6: Close up of Microscope. Students click “Freeze” and count the number of EColi and Anthrax in the water.

Advancing Through the Curriculum: Collecting Data; Conducting an Experiment

As students move through the curriculum, they advance through four different worlds chronologically that represent different seasons in River City: October 1878, January 1879, April 1879, and July 1879. This allows participants to collect data on change over time in River City. After collecting data across these 4 seasons, students have produced enough observations and inferences to develop a hypothesis and to design their experiment. They spend two class periods designing their experiment in face-to-face groups. The curriculum walks them through turning the problem about the illness into a researchable question, then identifying independent and dependent variables. They then develop a hypothesis and write up a procedure. Next, after designing their procedure, they go back into River City two more times to test their experiment. They first visit the control world, Fall 1879 (controlled portion of their experiment), and then the following class they visit the experimental world (changing their independent variable and contrasting data from that world to the control world).

The experimental world is identical to the control world except for the one variable that students want to change in their experiment (their independent variable). The MUVE is based on an underlying simulation that allows one aspect of the world to change. For example, if students think the illness they identified is spreading because of the mosquitoes breeding by the bog, they can choose to drain the bog. Thus, when they enter the experimental world the bog is no longer there—it has been drained. Students must then gather the same data they gathered the day before in the control world in order to see how draining the bog affects the illness. Students collect data in both the control and experimental worlds by visiting the same places and talking to the same people. They then analyze data from their experiment by comparing their findings in each world. They write up their findings, draw conclusions, and make recommendations for stopping the illness from spreading.

Essentially, students use their 21st century knowledge and skills to identify a problem and then develop and test a hypothesis based on one of the three disease strands infecting the city (i.e., insect-born, air-born, and water-born). The three disease strands are embedded in the environment as mentioned above, with historically accurate social and environmental content. After testing their hypotheses, students analyze their data and then write up their research in the form of a report to the mayor of River City. The report, based on the concept of a lab report, describes their experiment, research findings, conclusions, and recommendations for how the mayor can stop the spread of illness in River City. We have found that these reports to be accurate representations of students' inquiry learning (Ketelhut, Dede, Clarke, Nelson, & Bowman, in press). Teams of students then present their research and findings to the entire class. The purpose of this final sharing day is to see how each teams' research was a small piece of the larger picture and to connect it to the real practice of scientists.

Students participate in the curriculum along a trajectory from novice (scientist-in-training) to expert (research scientist), as they learn to develop questions, generate hypotheses, collect and analyze data, and make conclusions and recommendations. Over time, they actively disentangle multi-causal problems embedded within a complex environment. We have developed both psychometric and performance-based summative assessments of student learning and have embedded formative diagnostic evaluations of student progress in the virtual world. We also are studying whether using datamining analytics on the extensive logfiles we collect of students' utterances and actions in the MUVE may yield novel insights about learning and teaching.

This extended example illustrates how situated, immersive, collaborative simulations based on MUVEs can aid students in learning 21st century understandings and performances, such as collective problem resolution via mediated interaction, while in classroom settings. The next section briefly describes how augmented realities can serve a similar pedagogical role using an alternative interface with different strengths and limits.

Learning 21st Century Performances in the Alien Contact! Augmented Reality

In the past year, via funding from the U.S. Department of Education, researchers at the Harvard Graduate School of Education have developed an augmented reality simulation designed to teach math and science literacy skills to middle school students, with help from colleagues at the University of Wisconsin at Madison and the Teacher Education Program at MIT (http://isites.harvard.edu/icb/icb.do?keyword=harp). This immersive collaborative simuilation is played on a Dell Axim X51 handheld computer and uses Global Positioning System (GPS) technology (see figures 1 & 2) to correlate the students' real world location to their virtual location in the simulation's digital world.

Figure 1: Dell Axim X51

Figure 2: Holux GPS Receiver

As the students move around a physical location, such as their school playground or sports fields, a map on their handheld displays digital objects and virtual people who exist in an augmented reality world superimposed on real space (see figures 3, 4, & 5).

Figure 3: Dell Axim & GPS Receiver

Figure 4: Students Exploring School Grounds

This capability parallels the new means of information gathering, communication, and expression made possible by emerging interactive media (such as Web-enabled, GPS-equipped cell phones with text messaging, video, and camera features).

Figure 4: Handheld Display of Digital Objects on School Grounds

In the Alien Contact! curriculum to teach math and literacy, middle school students are presented with the following scenario: Aliens have landed on Earth and seem to be preparing for a number of possible actions, including peaceful contact, invasion, plundering, or simply returning to their home planet. Working in teams of four, the students must explore an AR world located immediately outside of their school, interviewing virtual characters, collecting digital items, and solving mathematics and literacy puzzles to determine why the aliens have landed.

Each team has four roles: Chemist, Linguist, Computer Expert, and FBI Agent. Depending upon his or her role, each student will see different pieces of evidence. In order to successfully navigate the augmented reality environment and solve various puzzles, the students must share information and collaborate within and among the teams. As students collect this data, they will discover different possibilities for why the aliens may have landed; students are asked to form and defend a hypothesis based upon the data collected. At the end of the unit, the students orally present their findings as a team to the class and support these with data collected in the field. In addition, each student writes a persuasive essay detailing why they think the aliens have landed.

Alien Contact! is based on Massachusetts state curriculum standards and fosters multiple higher-order thinking skills. In particular, we focused on 21st century understandings and performances related to collective problem resolution via mediated interaction. In designing this unit, we targeted concepts in math and literacy typically difficult for middle school students to master. Using the spring 2005 8th Grade Massachusetts high-stakes test as a reference to determine areas of need, we centered the curriculum on aspects of mathematical ratio, proportion, and indirect measurement, in combination with how English vocabulary has been influenced by Latin and Greek languages. In addition, other math and literacy standards are embedded within the unit, such as reading graphs and group presentations.

The simulation content and structure are designed to allow for multiple entry points on which teachers may build in future iterations. This design allows teachers the flexibility to emphasize 1) different academic standards; 2) different content areas (math, ELA, science, social studies/history); and 3) different current events (energy crisis, oil shortage, global nuclear threat, cultural differences). In addition, the simulation space is designed with multiple potential layers of complexity. For example, during the simulation the students are asked to solve mathematical puzzles to get 4-digit codes that unlock virtual buildings containing evidence. The sequence of the resulting codes represents a Fibonacci sequence, i.e., 1, 1, 2, 3, 5, 8, 13, 21, 34.

This design rationale is three-fold: 1) build in multiple entry points for teachers; 2) build in mathematical and linguistic patterns that, when recognized, reveal the ubiquity and mystery of mathematics and language; and 3) build in multiple layers of complexity that will engage and challenge students regardless of ability and will provide teachers opportunities for differentiation. We are trying to engage students in mathematics and literacy by capitalizing on some inherent math and literacy properties that are potentially fascinating (e.g., Fibonacci sequence, golden ratio, ancient languages and cultures) if embedded within an interesting backstory and instantiated through active, collaborative learning. As with the MUVE, we have developed both psychometric and performance-based summative assessments of student learning and also plan to collect and analyze logfile data. This research gives us the opportunity to contrast two different immersive interfaces (AR and MUVE) that provide the capacity to teach sophisticated 21st century understandings and performances.

Implications for the Friday Institute

This paper advances a complex conceptual framework for understanding the challenges and opportunities involved in transforming schooling for the 21st century and describes an innovative strategy by which new pedagogies based on emerging immersive media can aid all students in attaining sophisticated understandings and performances. Its rationale draws on changes in the global and U.S. economies; the impacts of advanced ICT on work, citizenship and everyday life; and shifts in the outcomes society needs from educational systems. A contextualized conceptual framework for 21st century understandings and performances is proposed that includes an appeal to deemphasize aspects of the 20th century legacy curriculum. A process is modeled for selecting an interrelated set of neglected 21st century understandings and performances, analyzing their relative importance as educational outcomes, and developing innovative, technology-based pedagogies and curricula to aid students in learning these. While complex, this type of design-based educational research is central to preparing both students and the United States for a prosperous, stable, attractive future.

The vision of the William and Ida Friday Institute for Educational Innovation at North Carolina State University (http://www.fi.ncsu.edu/index.html) is "to transform education to meet the demands of the 21st century global knowledge society." Its goals are:

- To research, develop and disseminate K-20 educational solutions that meet 21st century demands.
- To generate and propagate effective technologies for teaching and learning.
- To strengthen educational capabilities of rural and underserved communities in North Carolina and beyond.

As such, the ideas in this paper are central to its mission.

One may ask how attaining sophisticated 21st century understandings and performances relates to the third goal of equity for underserved educational populations. After all, aren't the understandings and performances described in this paper quite sophisticated, and is not equity about helping struggling students disadvantaged in learning to master even basic knowledge and skills? But this paper is written from the premise that all students can attain advanced educational outcomes if they are taught in a manner that unlocks their trapped intelligence and engagement by building on their interests and learning styles outside of school settings. Our research in MUVEs and AR is establishing that even the bottom third of students who struggle with remedial curricula can learn sophisticated 21st century understandings and performances when taught using 21st century pedagogies and 21st century learning technologies. In contrast, "dumbing down" an already inadequate school curriculum and intensively implementing instructional approaches that have already failed with these pupils is a guarantee of continuing to throw away huge amounts of human talent at a time when our nation desperately needs this intellectual capacity and social justice demands that we seek alternative, more effective educational strategies.

A generation ago, Bill Friday was among the visionary leaders in North Carolina who created the Research Triangle as a regional engine of economic development and advanced education. Now, the Institute that bears his name seeks to invent a new type of economic and educational model that can address a new century's regional and national needs in a global knowledge-based economy infused with an emerging cyberinfrastructure. North Carolina is a state that has committed to a variety of initiatives related to education for the 21st century: formal affiliation with the Partnership for 21st Century Skills, investments in virtual schooling, sophisticated state content standards in key areas such as science (http://www.ncpublicschools.org/curriculum/science/). While many challenges confront the Friday Institute, the commitment of North Carolina, the proximity to the Research Triangle, and the sponsorship of the company SAS (a leader in data analytics that may serve as the basis for next generation educational assessments) all provide a strong foundation for actualizing the recommendations in this White Paper.

Conclusion

This paper presents an optimistic viewpoint about improving education at a time when a dark future for our country seems more likely. The advanced technologies this paper describes are double-edged swords. One can easily imagine MUVEs used to create fabulous virtual worlds in which people invest substantial time and resources living alternate lives while the real world rots around them. As readily, one can imagine a cyberinfrastructure embedded with ubiquitous sensors used not to implement augmented realities for learning, but instead to document each action of every person, to be judged by some central authority in terms of whether their behaviors are proper in light of some ideology deemed both moral and essential for "national security."

As always, the most powerful remedies we have for dark futures are initiatives that emphasize education and equity. In *A Christmas Carol*, Dicken's ghost of the present shows Scrooge images of ignorance and want, the twin evils that can bring down even the most advanced civilization. We still have time to change our course towards educational innovations that overcome modern-day versions of Victorian ignorance and want, but the window of opportunity is shrinking quickly. Hopefully we will have the wisdom and the courage to act together, to exhibit as a society our capacity for collective problem resolution via mediated interaction.

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