

New Technology-based Models for Postsecondary Learning: Conceptual Frameworks and Research Agendas

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Reconceptualizing Postsecondary Learning

Advances in technology and in knowledge about expertise, learning, and assessment have the potential to reshape the many forms of education and training past matriculation from high school. In the next decade, higher education, military and workplace training, and professional development must all transform to exploit the opportunities of a new era, leveraging emerging technology-based models that can make learning more efficient and possibly improve student support, all at lower cost for a broader range of learners.

Potential risks must be managed, including those arising from the disruption of established delivery economics in our current learning institutions, the variable quality of learning outcomes these new models offer today, and the technical and conceptual challenges of better understanding how to design, develop, and implement innovative capabilities in ways that reliably deliver on their promise. This workshop developed a framework for understanding this sea change and sketched steps towards a research agenda for realizing its benefits while avoiding pitfalls.

Many forms of postsecondary learning will be influenced by these developments. These sectors are shown in Figure 1.

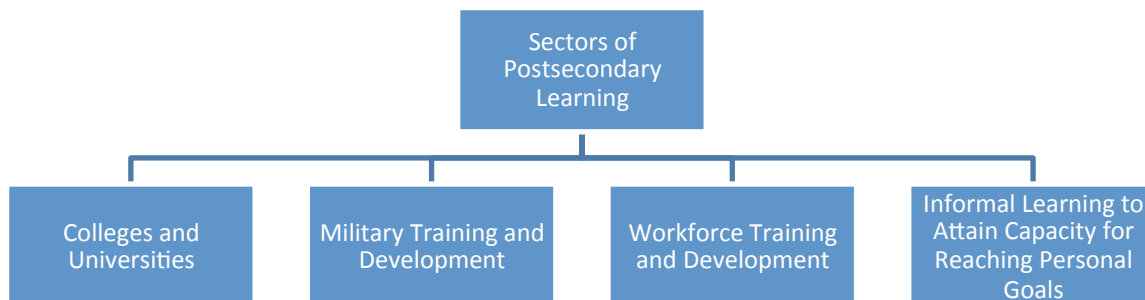


Figure 1. Forms of Postsecondary Learning

New media, insights from research, and alterations in organizational structures are changing longstanding assumptions that have shaped postsecondary learning. Shifts now occurring include:

Instructional objectives

- *Moving from thinking about expertise as something an expert “knows” and can articulate, to a complex mix of tacit (i.e., non-conscious) and conscious competencies:* This evolution has major consequences both in how we identify critical competencies that experts exhibit, and in how we design instruction to reach those competencies. Simply asking experts to “teach” whatever comes to mind, whether in an online format available to millions or in their own classrooms, is not enough to efficiently bring many students to expert performance levels.
- *Moving from knowledge and skills localized in a student’s mind to distributed understandings and performances:* Our understanding of expertise has expanded from something “stored in the head” and documented by its retrieval in sequestered testing to instead include a collection of elements accessible via technologies (such as mobile devices, search engines, and augmented reality) that enable finding necessary information rather than remembering it. Mastery involves decisions about when to make use of such resources as well as when these

are not sufficient. Understanding how to apply distributed knowledge and skills in real world and novel contexts therefore requires demonstrations via sophisticated, authentic performances adapting to complex situations, rather than traditional rote recall of a small amount of what experts comprehend and do in routine situations.

- *Moving from a focus on memorizing and applying facts, simple concepts, and straightforward procedures to “higher level” conceptual and analytical capabilities deployed adaptively in diverse contexts:* By increasing the accessibility and affordability of experiences with higher level problem-solving, complex decision making, and learner-based experimentation and exploration, technology-based instruction and practice substantially increases opportunities for learners to focus their attention on the conceptual and analytical capabilities that underlie the deep understanding, retention, and transfer of learning needed to deal with life-long, real-world applications. These capabilities are key to the development of expertise and promotion of innovation that, in turn, lead to an expanding economy prepared to meet the many rapidly evolving science and technology challenges of the future.
- *Recognizing how, beyond the conceptual and procedural aspects of learner competencies that are often described as “cognitive,” complementary aspects of learner competencies, so-called “non-cognitive factors,” are instrumental to successful postsecondary learning, work, and citizenship.* Extensive research from social and developmental psychology has documented how learner orientations, such as persistence/grit, engagement, “mindset” about intelligence (as either improvable through effort or as a non-malleable personal attribute), stereotype threat, and related constructs are consequential for learning.

Instructional Processes

- *Moving from time-based models of schooling to competency-based learning:* In conventional course-based education and training in the United States, learners are processed through an assembly-line system that involves one-size-fits-all instructional treatment, with occasional summative tests utilized to determine each student’s fitness to move on to the next stage of the process. Calendar time in teaching is held constant; student learning is allowed to vary somewhat, but the necessary focus is on each student achieving a set of pre-specified instructional objectives—crossing a minimum threshold of learning. This approach served course-based, classroom education and training well in the 20th century. However, research on learning makes it clear that learners critically differ from one another in terms of their unique, historically constructed long-term memories and their personal goals and motivation, with the consequence that the “same” processes are experienced differently by individual learners. As it is often characterized, the ‘taught curriculum’ is different than the ‘learned curriculum.’ Lock-step classroom instruction for courses cannot take account of the vast divergences in prior learning, individual differences, and time needed to acquire competencies. These differences have been long recognized by teachers, students, and researchers. Increasingly, technologies for learning enable adaptive learning experiences that are responsive to the uniqueness of each student as an individual, providing the opportunities to achieve targeted competencies, as well to surge ahead and be “all the student can be” in the calendar time available. Competency-based, personalized instruction made affordable and accessible through technology can enable all learners to succeed, in many cases more quickly and at lower cost, by providing whatever amount of support is needed to attain mastery—anyplace, anytime—with immediate certification or credentialing when this occurs.
- *Moving from a few providers to many sources of accredited learning:* The disintermediation and distribution of learning, made possible through technology, has vastly increased the range of providers, innovative business models, and new marketplaces for services. This is leading to substantial shifts in the attitudes of both students and employers towards institutional credentialing. This disintermediation, with its increased agility for adapting not only to

learners, but also to the needs of the workforce, leads to even more focus on exactly what competencies truly predict success in a domain after leaving a learning environment—and what performance demonstrations provide evidence of successful education and training.

- *Moving from “digital deserts” to “digital oceans” of data (Behrens et al., 2011): moving from educational improvement based on occasional evaluations to continuous analytics providing feedback across multiple providers.* Aggregated data streams from participants in learning activities provide mechanisms for continuous improvement and research via diagnostic analytics at large scale. This requires, however, that we develop assessments of behavior and success at scale that are reliable and valid for each individual, adding up to usable evidence for future learner success in their domains of interest. This advance also creates pressure to have more generalized guidelines for what constitutes a “good enough” pilot or trial (especially at scale, not just in laboratory settings), as well as “good enough” measures for predictive variables.
- *Moving away from a conception of technologies in education and training to be principally those designed explicitly as “educational technologies”:* Beyond learning management systems, courseware, tutors, and the like, researchers are increasingly recognizing that the full spectrum of information and communication technologies are used by learners and instructors as ‘bricoleurs’ – who are improvising what they need from the broad palette of tools ‘ready to hand’ in their everyday experiences, whether social networks, cloud computing tools, mobile apps, physical meet-ups, or other emerging resources.

A framework for understanding these shifts is “connected learning.” Online learning or e-learning may be terms that unnecessarily limit what is possible with information technology. Both have roots in original conceptions of distance education, where the objective was to port classroom-style learning to off-campus students through an alternative delivery mechanism, whether via the postal service, cable television networks, or the Internet. When the metaphor is changed from “the information age” to connected “learning in a networked world” (NSF Cyberlearning Report, 2008) one should ask “what does ‘e-learning’ look like when it shifts from moving information to being about connections?” Connected learning may be a more useful construct for today’s environment. A working definition of connected learning is (Ito, M., et al., 2013, pg. 4):

...broadened access to learning that is socially embedded, interest-driven, and oriented toward educational, economic, or political opportunity. Connected learning is realized when a young person is able to pursue a personal interest or passion with the support of friends and caring adults, and is in turn able to link this learning and interest to academic achievement, career success or civic engagement. This model is based on evidence that the most resilient, adaptive, and effective learning involves individual interest as well as social support to overcome adversity and provide recognition.

To explore connected learning, educators must continue their work linking schooling to interdisciplinary problems and collaboration beyond classrooms and campuses. While there is research that applies to connected learning, further exploration is needed on large-scale collaborative and connected environments. These environments should transcend K-12 and higher education to include the workplace and citizens. There is merit to continuing the exploration of how to engage learners as “prosumers” in generative scholarship, where they help build the knowledge of the field and use the tools of the profession to draw their own conclusions. Of course, learning encompasses more than content—it involves learner empathy, support, motivation, persistence and more. When learning is connected it forms pathways; one activity feeds forward to another. Learners are not often engaged in unrelated activities—

they eventuate from their identity and intentionality as they pursue their interests. Nor are they in the dark about the progress they have made, the improvements they need or what comes next. With connected learning, the focus is on continuing pathways, not gates or gate keeping. The point is to connect-the-dots and to connect learning with life.

This report emphasizes strategies for investing in research that can help realize the many potential benefits from these changes. It does not attempt to predict the outcome of these and related transformational shifts, which are without historical precedent. As discussed later, follow-on workshops are needed to discuss questions such as: How might technology-based education and training evolve, and what developments could accelerate improvements and mitigate possible problematic scenarios? How can these shifts be used to create more personalized learning experiences, while preserving and perhaps enhancing the role of interaction, collaboration, and communication of group interactions—both face to face and remotely? What are the implications of this evolution for all instructional institutions and, particularly in this report, for the structures, staffing, credentialing and financing of all forms of postsecondary learning? How might this evolution affect the research and the instructional missions of higher education? What shifts in roles and professional opportunities might faculty and other types of instructors experience as new models and sources of learning take hold in their professional practices?

This report is also designed to aid various groups in understanding the opportunities and challenges that are emerging:

- *Leaders of higher education and other postsecondary learning institutions* who are making decisions about research and development investments and about the future of their institution, including adjustments in organizational frameworks and human/technical infrastructures.
- *Faculty members and other instructors* who are proposing research on new models of teaching/learning, creating new types of learning environments, or pondering how to productively adapt to changes that may occur in their professional roles.
- *Providers of technical infrastructure* (IT researchers, developers, providers, entrepreneurs, CIOs) *and of human infrastructure* (researchers on learning, professional developers, Chief Learning Officers (CLOs), college and career guidance counselors) who are seeking ways to foster and build new capacities and to improve organizational innovation, productivity, and competency.
- *Research funders and policy leaders* who are planning their investments, prioritizing and establishing research programs, assessing their returns, and creating policy climates favorable to innovation.
- *Decision makers in business and in finance* who are seeking to understand new markets, opportunities, and threats.

The report provides “lenses” through which each of these constituencies can focus on findings most relevant to their role.

Why educational leaders should read this report

Most forms of postsecondary learning are experiencing disruptive change. The external environment is now seriously questioning the costs, accountabilities, and resulting value of much of the higher-education enterprise. Workplace training is given lip service, but similar questions arise when budgets are

scrutinized. In both cases, the rise of “post-traditional learners,” those who are older, first-generation, attend part-time, or are unprepared for college and other forms of postsecondary learning, is catalyzing change, as are new institutional models that promise to meet their needs.

In particular, the advent of massive open online courses (MOOCs), discussed in this report, has inverted the funnel of all postsecondary learning institutions: Rather than needing to pass through a narrowing admissions filter to gain access to educational opportunities, potential learners worldwide can now freely access high quality, interactive certification granting programs, so that only their ability to master the material in a timely fashion limits their experience. The computational infrastructure that supports massive distribution of postsecondary learning world-wide, the assessment tools that enable hundreds of thousands of participants to be measured and to receive immediate, individualized diagnostic feedback, the social media environments that enable group discussion on massive scales, and the growing suite of simulation and interaction tools are combining to create a new, ubiquitous infrastructure. Whether used for global, distributed learning, or applied to augment residential-based experiences, these new models of instruction are dramatically changing the face of postsecondary learning. This infrastructure challenges the roles of synchronous classroom experiences and the value of campus life in learning; offer new options for assessment and personalized exploration; provide opportunities to rapidly and dramatically change how we teach, based on data analytics at massive scales; and is disrupting traditional financial models for both education and training.

Leaders in education and training are faced with important decisions in the near future. Rather than ignoring technology, which may eventually overwhelm their current institutional practices (with the framing of ‘tsunami’ often offered), they must ask: How can technology enable an evolution to more efficient and effective pedagogies? What tools and techniques—whether technology, cognition, analytics, simulation, or collaboration—ensure that learning is grounded in the most sophisticated strategies available? How will technology enable decision makers to achieve more readily and with higher instructional effectiveness the economies now sought through the use of large classroom lectures? How might the certifications offered by online technology be authenticated and validated? How might technology help ensure the fiscal viability of instruction in highly specialized areas of learning sought by limited numbers of students?

The challenges involved transcend the impact of technology on pedagogy, faculty time, or the quality of institutional learning experience. New business models are emerging with selected functions being “out-sourced” to external providers or “in-sourced” as for-profit ventures partner with traditional institutions to create programs financed through a share of future tuition. And, as new models promise lower costs, institutions are being challenged to return more of the “profit” from lower division or online courses to students or the taxpayers. Ultimately, the changes impact more than individual institutions; they will likely reshape the entire ecology of postsecondary learning. Like any ecological disruptions, not all species will survive, as new niches in the ecosystem are filled by species better suited to new conditions.

This report begins a conversation on the questions that need to be asked about the best uses and contributions of learning technologies, and how those technologies may impact the business and financial model of an institution, its pedagogical and curricular infrastructure, and its professional development

strategies. The research challenges and opportunities articulated in this report give a clearer picture of the decision environment and future possibilities for all institutions of postsecondary learning.

Why faculty members and instructors should read this report

New technology-based models of learning have provided faculty with a variety of educational tools, but have also generated a host of concerns. Both the popular and academic press have speculated wildly about how massive online open courses (MOOCs), in particular, will impact the organization and economic base of higher education, the structure of the curriculum, the professional identity of the faculty, and what universities will continue to exist. As noted above, while the exact shape and character of the academy in a post-MOOC world is impossible to predict, it is unlikely, as both history and current events indicate, that post-secondary education will not be changed in significant ways. Those effects are likely to be more nuanced and more complex than predicted by either promoters or critics of MOOCs, which are an early, naive form of the models that will eventually emerge. Thus, it is incumbent upon faculty and instructors to educate themselves about research on how expertise and learning actually work (as opposed to informal ideas most faculty members have used to frame their instruction so far), the opportunities educational technologies afford, how those technologies can help improve economics of delivery and the likelihood of student success, and what collateral changes may occur in their wake.

These models may enable post-secondary education and training institutions to provide their students with more of the benefits now found primarily in graduate study, such as guided problem solving and connected, personalized work with experts and distinguished faculty who explore and learn in the company of their students. Faculty and trainers may find it useful to explore the tools, techniques, and processes of guiding experiences in authentic, “situated,” real-world environments. Much of the low-level drudgery of teaching may be assumed by technology, such as tailoring standardized learning environments to student needs and particular instructional objectives, and providing frequent diagnostic assessments of student progress. Technology may also help fill the gap between the quasi-conscious, almost reflexive techniques used by experts in problem solving, experimentation, and exploration and the basic enabling steps needed by their students to achieve equivalent levels of competence.

With that said, large gaps exist in our understanding of educational practices with these technologies. This report can begin a conversation with faculty and instructors on questions about the best uses and impacts of educational technology, especially in terms of student success, and about strategies for proceeding with research that will answer those questions. Action-based research can give faculty and instructors a clearer picture of the future of postsecondary education and training, the institutions that provide it, and how to undertake the critical task of preparing learners for their personal future and that of their nation and global society.

Why providers of IT technology infrastructure should read this report

Providers of IT technology infrastructure (aka “cyberinfrastructure”) services should read this report because the services they provide constitute an essential platform for what is envisioned. Cyberinfrastructure includes technology together with the human and organizational resources to create and deliver services. Cyberinfrastructure enables the creation of learning ecosystems that can radically relax constraints of geography, time, and access— including access to new resources for learning. Much

of the disruption and opportunity premised in this report is a consequence of the continual expansion in both scale and function of cyberinfrastructure.

Understanding and realizing the potentials highlighted here will require participatory design and cooperation among the providers of technology, learning and technology researchers, administrative leaders, and instructors and learners. All these types of providers need to better understand the mechanisms of new technology-based models for enhancing learning and teaching, and the user community needs to better understand the potential of these emerging technologies to enhance how learning and aid instruction. A “waterfall” model for cyberinfrastructure provisioning will simply not work. Both the nature of cyberinfrastructure provisioning and the pedagogies enabled by that cyberinfrastructure are in rapid flux. Although many education organizations provide these services locally, this scenario is being augmented and may be overtaken by remote cloud services together with personally owned, sensor-enabled, mobile Internet access devices.

At the same time that the potential for meaningful use of cyberinfrastructure to support education has never been greater, and the possible modes for providing services are increasing, most educational institutions are under unprecedented financial stress and growing public concern about higher education affordability and even relevance. In response to this, the providers of cyberinfrastructure services for educational organizations must rationalize and reduce the cost of providing the current generation of services, while at the same time providing leadership for evolving to the next, probably cloud-based generation of services that actually aligns with how learning works, not merely is “able to be sold.” To realize the full potential of this shift, providers must be significant consumers of research on how learning works, as well as participants in strategic planning processes for the future of postsecondary education organizations. Providers must also be able to convince executives with budgetary control of the necessity for wise investments to explore and adopt the new services critical to thriving in their mission; these must incorporate both tacit and conscious mastery components. As a minimum, educational organizations may retain the savings from rationalization to reinvest in the next generation of services. It is not easy to decide exactly what these investments should be: we should adopt an attitude of exploration and experimentation, with a lean startup model of fast trials and failures in order to rapidly learn and improve, while at the same time not disrupting the current critical services.

This report provides some of the necessary vision and contributes to increasing the urgency for strategic planning and action (e.g., financial investment, policy shifts, organizational changes) necessary to move towards a bright future. If this report leads to increased emphasis by NSF and other funding agencies on the future of higher education and postsecondary learning as an object of research—not just an agent for research—that too will eventually benefit the providers of technology for this sector.

Why research funders and policy leaders should read this report

This report describes the development of 21st century workforce skills and how disruptive technologies can address those skills. The report discusses some of the research necessary into how to study learning and disruptive technologies, including the development of the new fields of learning analytics and educational data mining that enable research on large repositories of student learning data through the lens of what's known about learning and mastery. With the advent of disruptive technologies in education and training, multiple policy and research issues arise. Some of these are related to the changes in postsecondary instruction and certifications that are enabled by these technologies, while

others are research issues linked to realizing the full potential of new tools and media. The missions of public and private organizations that are involved in postsecondary learning will need to incorporate the new understanding of expertise as a mix of tacit and conscious capabilities, recent research on how media and the structure of learning experiences can help or hinder learning, and new related capabilities of technology — or those organizations risk becoming irrelevant.

In particular, policy issues revolve around the incorporation of disruptive technologies in the higher education ecology. Several recent reports address issues such as the certification of expertise (ED, 2010, NRC, 2011a); the efficacy of existing technologies (ED, 2010, NSF, 2008, NRC, 2011b); recommendations to local, state, and national organizations (ED 2010, NSF, 2008, PCAST, 2010); and the changing nature of colleges and universities in the light of disruptive technologies that can increase access to postsecondary learning while decreasing costs (Bowen, 2012; DeMillo, 2011). To inform policy makers in their decision-making, this report synthesizes insights from many of these studies.

Research issues revolve around the development of disruptive technologies and how people learn with these new tools and media. Both private foundations (Gates and MacArthur, for example) and public funding agencies (e.g., NSF, the U.S. Department of Education, various Defense organizations) have been funding research in these areas as part of their mission. For example, the overall mission of the National Science Foundation from its initiating Act includes “[promoting] the progress of science, to advance the national health, prosperity, and welfare, to secure the national defense, and for other purposes.” A general strategy supporting this mission from NSF’s current strategic plan is to “prepare and engage a diverse science, technology, engineering, and mathematics (STEM) workforce motivated to participate at the frontiers,” and a specific strategy is to “support the development of innovative learning systems.” Thus, NSF’s current strategic plan addresses both issues of postsecondary learning and a strategy to develop innovative learning systems, which increasingly are potentially disruptive technologies. Another example is the Department of Education’s mission “to promote student achievement and preparation for global competitiveness by fostering educational excellence and ensuring equal access,” along with one of its strategies, which is to “increase college access, quality, and completion by improving higher education and lifelong learning opportunities for youth and adults.” Also, the Institute of Education Sciences is specifically charged with generating and synthesizing rigorous empirical data about how learning works and how various combinations of pedagogical interventions, teacher training, and technology do (or don’t) lead to objective learning improvement. The study of how people learn with disruptive technologies and the development of those technologies is central to all these agencies’ missions.

Why decision makers in business, industry, and defense should read this report

Employers continue to be frustrated at scale by the outputs of increasingly expensive traditional learning environments – not from the highest ranked institutions, whose admissions selectivity ensures a relatively small number of highly capable students emerge with sufficient skills and enthusiasm to be helpful, but instead from the large majority of institutions that trains most people who need to perform valuable work in expert ways. With the baby-boom generation on the verge of retiring, the post-secondary institutional incapacity both to capture the tacit and conscious decisions and skills of that cohort and to transmit them rapidly and effectively to new generations of contributors is enormously frustrating – and undercuts the value of their enterprise.

With the right research underpinnings, new technologies and practices can potentially accelerate the identification and mastery of a more complete palette of decisions and skills that current experts deploy, even without conscious awareness. Enabling the emerging workforce to build on this foundational knowledge would be enormously valuable – not just to the employers, but also to civilization.

To say that technology has affected every operational facet of postsecondary learning as an industry may seem obvious and self-evident, but the rate at which technologies are integrated into daily operations continues to vary among institutions and sectors. One significant benefit of technology is that it enables post-secondary education and training institutions to respond with substantially increased agility to the needs of Defense as well as national and local business and industry. How NSF and other funders develop and advance the capabilities of technology applied in education and training will have a substantial effect on the nation’s workforce, including how well the needs of business and industry are satisfied.

As leaders in business, industry, and Defense know, using technology to address an organization’s problems (including issues other than education) can make good strategies more affordable, reliable, available, data-rich, and customizable. However, technological capabilities are equally capable of supporting ineffective approaches—automating a bad process with technology will not solve the fundamental problem of adding value to users, even though new tools and media readily make such “improvements” widely available. For example, one could argue that the first “flipped” classrooms should have emerged with the advent of book printing technology; textbooks potentially moved lecture-based material to students’ own time, freeing up classroom for more inspired conversations and coaching. Clearly, that “technology shift” didn’t fully work out—we must take care in adopting the latest round of well-intentioned technological enhancements for classroom lectures to take into account what’s known about what works (and doesn’t) for learning.

Business, industry, and Defense leaders bring an appetite to invest and innovate in postsecondary learning. However, the history of applying technology to education shows many cul-de-sacs. Developing the right strategies for how new technology-based post-secondary models can help rather than hinder student success—and ultimately enable employer success with thoroughly prepared graduates who’ve mastered both tacit and conscious components of employers’ experts—is critical. A single poor learning experience can now reach millions of learners, just as can a terrific solution. Solid research from the NSF and elsewhere showing “what works” for student success, together with tested guidelines and parameters that can be turned into “learning engineering” principles by those working and investing at scale, are invaluable. Systematic and effective processes for performing such “what works” analyses are in hand (NRC, 2005; O’Neil, 2005; Clark and Mayer, 2011; US DoEd, 2013) and ready to be applied more extensively to strategies for technology-based education and training.

From a practical standpoint, Lowendahl (2012) has noted that post-secondary institutions are well along the way toward automating analog business processes. All postsecondary institutions are finding they must be mindful about new organizational capabilities based on digital advances, in part because they are under pressure (sometimes without regard to evidence of effectiveness) to fundamentally change their ways of doing business by means of what Lowendahl calls “digitalization.” Digitalization refers to the point at which technologies take on tasks, operations and activities that could not be done if technologies were not included in the mix. Digitalization means moving past retrofitting old operational practices and instead evolving to technology deployment as an essential, mission-critical ingredient for

transformative success. Digitalization trends popularly include “technologies” such as adaptive learning, affective computing, big data and MOOCs, but none of these labels have been broken apart to tie “what works” within them to either student or employer success, regardless of the attractive economics of delivery. Extreme collaboration (the intersection/amalgamation of social media, mobility, the cloud and massive information) represents another emerging arena of inquiry.

Gartner’s *Hype Cycle for Education*, featured in Lowendahl’s analysis, offers an (annual) look at technology triggers catalyzing interest in investment among providers of technology content and services for the educational vertical market. The 2012 Hype Cycle features digitalization among its new entries, with an eye on adaptive learning, big data, and MOOCs. These join previous technologies, including affective learning, gamification, and virtual environments/virtual worlds, tracked through Gartner’s “boom, bust and renewal” model of innovation adoption. Similar to the New Media Consortium and EDUCAUSE Horizons Report (2013), in that the predictions around time to technology adoption lie at the heart of both, Gartner’s projections take direct account of financial markets in ways that the Horizon Report typically does not. Nevertheless, both reports underscore that future practice-based research on teaching and learning excellence involves keeping an eye on emerging technology triggers and investing in those that are most likely to have commercial success. However, information is lacking on what exactly does lead to teaching and learning excellence—and student learning success near- and long-term.

Lowendahl’s analysis reminds us that, in a challenging financial climate, it can be difficult to favor economies of scale that imply flexibility, not standardization, especially at a time where existing technical solutions take time, are costly to change, and lack serious evidence of impact on learner (or employer) success. Nevertheless, institutional leaders also understand that competitive advantage implies that “one size does not fit all.” Institutional leaders must make technology choices that harness and integrate the innovative power—and individual limits—of faculty and students, while also being attentive to the needs of operational stakeholders – the end beneficiaries of the learning process. In higher education and elsewhere, this challenge for institutional leaders often results in organizations betting on more than one horse, dabbling in multiple technologies while waiting for the dust to settle, bolting from one approach to another without actually measuring impacts for learning, and thereby failing to achieve the scalable improvements that come from investing deeply in a technology and squeezing every drop of utility from selected investments, careful measurements, and good piloting.

This report suggests a range of opportunities and problems on which NSF and other funders could work over years to come, providing a better framework of evidence about what works (and doesn’t) for learning (U.S. Department of Education, 2013), to let those working at scale (including publishers and other businesses supplying services) know where the best “learning engineering” investments should go to lift student outcomes, and to help organizations lower the cost and time for delivery without harming student near- and long-term success.

Overall, this report provides the five “lenses” above to enable people who hold a particular type of role/responsibility to understand the implications for their decision making concerning new technology-enabled models for teaching and learning. Of course, dialogue among these different types of stakeholders is central to realizing the potential power of these advances, and this report may aid in facilitating that intercommunication.

A Framework for Understanding Postsecondary Learning

Workshop participants developed a framework for interrelating various dimensions of postsecondary learning. Figure 2 provides an overview that guides the structure of this report.

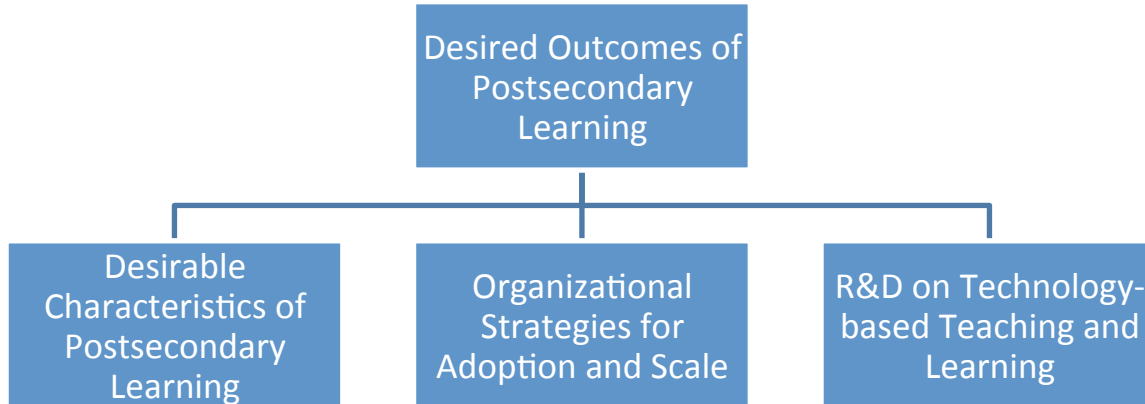


Figure 2. Framework for Postsecondary Learning

Desired Outcomes of Postsecondary Learning

The various types of outcomes students, employers, and society seek from postsecondary learning are displayed in Figure 3.

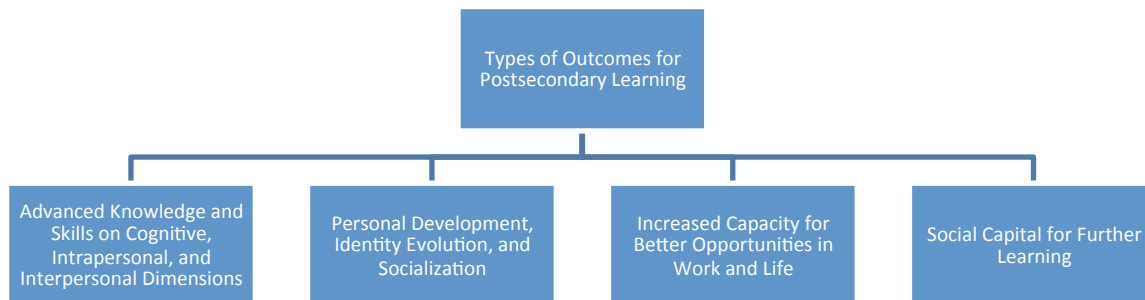


Figure 3. Types of outcomes sought from postsecondary learning

Advanced knowledge and skills manifested as understandings and performances. As described in the National Research Council 2012 report, *Education for Life and Work*, cognitive, intrapersonal, and interpersonal dimensions of advanced knowledge and skills are developed in tandem, shown in Table 1:

Table 1: Dimensions of Advanced Knowledge and Skills (read in columns, not across rows)

<i>Cognitive Outcomes</i>	<i>Intrapersonal Outcomes</i>	<i>Interpersonal Outcomes</i>
Cognitive processes and strategies	Intellectual Openness	Teamwork and Collaboration
Knowledge	Work Ethic and Conscientiousness	Leadership
Creativity	Positive Core Self-Evaluation	Communication
Critical Thinking	Metacognition	Responsibility
Information Literacy	Flexibility	Conflict Resolution
Reasoning	Initiative	
Innovation	Appreciation of Diversity	

Mastery involves understanding how to apply advanced knowledge and skills in real world contexts—for which all three dimensions are important—and demonstrating proficiency via effective, authentic performances. What makes mastery even more complex is how that much of the decision-making and task completion associated with a complex performance becomes tacit through repeated practice. Thus, what underlies proficiency is largely hidden from view, making it a complex task to describe it fully and accurately for training/learning.

Overarching research issues related to this type of outcome include:

- *Operational definitions.* For all three domains of competency, how do we operationally define the “constructs” (and subconstructs) for purposes of systematic design of learning environments as well as measurement and assessment of the outcomes? How do we most efficiently articulate the tacit (non-conscious) and conscious components of high-performing experts? Across domains, how do we identify such experts and expertise?
- *Evocation and validation of competencies.* How do we craft efficient ways to evoke and scaffold the various competencies, individually and collectively, and how do we test and validate them?
- *Learning maps and pathways.* For complex performance expertise as above, how can we efficiently and objectively determine and describe dependent sequences of objectives to get there—and, for alternative sequences, under what conditions are each applicable? How do we standardize, store, and communicate these dependent sequences of objectives for use by multiple stakeholders/learning environments? How can we classify and make explicit relationships between and among knowledge components (e.g., different tasks/decisions themselves, and the supporting facts, concepts, processes, or principles that feed them)? How can we usefully demonstrate how similar concepts appear and reappear in various disciplines, domains, and contexts (a multiple-instances practice that we know strengthens transfer and retention), while balancing the real-world, domain-specific practice needed for human minds to apply these within their domains?

- *Systematic, comprehensive assessment.* How do we craft a systematic approach to the development of comprehensive and authentic assessments (using frameworks like Evidence-Centered Design)? How do we apply this approach to the development of performance tasks and assessment rubrics that ask learners to demonstrate their competence in ways that truly tie to longer-term student success? How do we store and communicate these data, and connect back to the constructs?
- *Instructional design principles.* How do we build a sufficient body of evidence to support better common principles about how text, graphics, and media help, vs. hinder, learning of different kinds? How do we identify guidelines for learning activities that work better for different types of knowledge components? How do we incorporate what's known about meta-cognition and motivation as guidelines or principles to enhance learning environments? How do we “take into account” how learners differ from each other (both diagnostically and in instructional design)? How should we match specific individuals on specific occasions with specific instructional approaches to produce the outcomes suggested by Table 1?
- *Access to relevant research.* How do we curate relevant research results for related objectives and practices together, so that those most interested in certain objectives or practices can automatically hear about relevant results?

Support for personal development, identity evolution, and socialization. In the rapidly changing 21st century, many forms of postsecondary learning include opportunities: (a) to enhance personal characteristics, such as leadership and collaboration; (b) to evolve identity in assuming or shifting occupational roles; and (c) to be socialized into the norms and cultures of workplaces, fields, and multinational contexts.

Overarching research issues related to this type of outcome include:

- *Identity development.* What types of identity development, including disciplinary identity, can be supported through immersive experience in various salient situations as an avatar or in interacting with computer-based agents? What kind of identity development can be supported by interacting with others whose worldviews differ, including attitudes, beliefs, and norms in communication? What are the most promising ways to involve domain practitioners in such experiences?
- *Development of empathy and social perspective taking.* How could immersive experiences be used to develop empathy—and potentially improve teaching? Almost any workplace setting now involves working with a wide varying array of colleagues and stakeholders. Even within the specific work of a college or university, an instructor could participate in an interactive online world as a first-generation college-attending child of immigrants and experience his/her actions of learning, peer interaction, distractions from study, and lack of supports. Collaborative distributed teams across cultures are commonplace in large multi-national corporations, and work within these and other institutions could benefit from social learning technologies.
- *Implications of identity development for learning.* Do immersive experiences improve learning to perform tasks and to make decisions in the domain, either directly, or mediated through improved motivation to start, put in effort, and persist on these skills?
- *Intercultural competencies.* Do interactions on MOOC discussion boards, for example, promote cross-cultural understanding? What are promising technology-based mechanisms to support cross-cultural teams across distance? How can we learn more about cross-cultural teams from the data that might be generated from these collaborations? Does

language learning in immersive environments that convey a sense of the culture aid multicultural understanding as well as linguistic fluency? How do we efficiently identify and connect the best approaches in domains along these lines with practice tasks in these environments?

- *Cost/utility.* How should we balance the cost for an individual or an organization to invest in postsecondary learning with the improvements it may return in quality of life? What measures should we apply to both sides of the balance? Are there analogies to be drawn with cost/utility analyses in other fields?

Increasing capacity for better opportunities in work and life. Effective educational models are emerging that blend academic instruction with workplace experience, including remote internships and immersive simulated apprenticeships. These models are enabling seamless transitions between education and employment, ongoing occupational support and development, and informal life-wide and lifelong learning.

- *Bringing work experiences directly into learning environments.* With the potentially wide variety of students at work and their varying goals (e.g., advancing in a current career vs. changing to a new one or deciding on the first one), what are the best ways to bring individual work-experiences to bear on new learning, either to benefit the individual or the group? What is the cost-effectiveness of specific approaches such as problem-based learning, virtual environments, augmented reality, or game-based learning in immersing learners in likely work experiences?
- *Selecting the level of fidelity for learning and experience environments.* Given that creating and/or delivering realism in authentic, simulated environments does not typically come for free, how should we select levels of realism for a simulated environment? What are the cost-effective, cost-validity, and cost/utility trade-offs that allow us to optimally match learners to specific experiences? What collection of parameters and the values we assign will allow us to do this matching in a satisfactory and sufficiently valid manner?
- *Accelerating expertise.* How should we transfer the acceleration of expertise demonstrated across a number of projects, such as those found in Department of Defense training research, to civilian learning environments? What models for policy, process, and funding would best affect this transfer? How should we establish the return on investment in these capabilities?
- *Lateral transferring of competencies.* Given the rapid evolution of technology, what models for policy, process, and funding should be established to determine what occupational competencies, cognitive and/or procedural, lend themselves best to decisions about selecting, training, and transferring individuals from overstaffed occupational specialties to understaffed occupational specialties? What return on investment models should then guide and inform the value of these transfers?
- *Intelligent tutoring for teams.* Because most work in most sectors of the economy is performed by teams of individuals, the question arises of how best we can apply the techniques and capabilities of generative or ‘intelligent’ tutoring to the preparation of teams and/or of individuals for work in teams? How might we apply the mental modeling used in intelligent tutoring systems to the shared mental models of team members? How can we apply the ‘transactive’ models of individual team members in intelligent training for teams?
- *Education and training for ‘cognitive readiness.’* What, if any, among the proposed components of cognitive readiness (e.g., adaptability, creativity, meta-cognition, critical

thinking, resilience, interpersonal skills) are generalizable, measurable, and subject to improvement through education and training? What is the return on investment in developing skills that meet these three criteria? How should we develop education and training experiences that establish or enhance these qualities?

- *Agility in training and education.* How can we enhance the agility of our education and training institutions to respond to the perennially evolving and changing demands of the workplace and the economy? What policies, processes, and funding programs should be put in place to promote this agility?
- *Guidance.* What programs for pre-service, in-service, and end-of-service occupational guidance actually pay off? How can we best identify ‘likely’ high-fliers before we actually begin investing in their education and training? Are there more sensitive assessments, especially perceptual and cognitive assessments, for specific, occupationally relevant talents, than those we now have in place? How should we adaptively link the guidance we provide to mid-career individuals about the perennially evolving requirements of the workplace?
- *Remote internships vs. physical presence.* Even with so much work being virtual, how much physical presence is needed to gain the benefits from an internship (identity, feedback, modeling, relationships, etc.)?
- *Connections to on-going evolution of real-world competencies.* What are the best methods to align educational program outcomes with the identification and accelerating evolution of workplace competencies, both tacit and conscious?

Social capital for further learning. A desirable outcome of postsecondary learning is the development of social capital (e.g., networks of people who provide mentoring) that contributes to furthering learning and its associated productivities beyond the initial educational experience, as well as to supporting all of the outcomes described above. The questions below illustrate research issues related to this topic.

- What can an analysis of the discussion boards associated with online learning experiences (particularly MOOCs, modules, programs) tell us about bridging bonding capital (connecting with “like” students) and about expanding perspective capital (connection with “unlike” students)?
- What factors influence whether students who participated in a discussion board on one online experience continue to communicate after this experience is completed?
- What are the predominant roles (beyond ‘help giver’ and ‘help seeker’) of those who post on discussion boards associated with online experiences? Can we see any correlations between those who post more regularly and their persistence and achievement in the online experience? If so, can encouraging more regular contributions lead to greater learning and course completion?
- What are the characteristics (of outcomes, of the kind of practice being used, of the individual students) that predict whether various forms of peer-to-peer work will be productive for individual participants, vs. non-productive?

Any particular institution providing postsecondary learning might seek to offer some of these four types of outcomes (advanced knowledge and skills, support for personal development, increased capacity for work and life opportunities, social capital for further learning); collectively, the aggregate system of postsecondary learning should provide access to all these outcomes.

Desirable Characteristics of Postsecondary Learning

Postsecondary learning organizations working to achieve these outcomes, individually and collectively, should strive to:

Serve a wide range of learners. As massively open online courses (MOOCs) are demonstrating, new models of technology-based teaching and learning can reach learners worldwide by using a variety of delivery options and by relaxing traditional constraints on fees and enrollment.

Key questions related to this characteristic include:

- How can one best measure learning effectiveness using online provision of lecture material? Using automated assessment tools? Using peer assessment? Using social media as a group dialogue mechanism? What are the most appropriate ways of measuring the effectiveness of technology-enhanced models that go beyond the assumptions of a face-to-face world?
- How can one best utilize information about learner interactions, especially at large scales, to refine understanding of the learning experience? How can one use such analytics to fine tune learning experiences for specific learners, by leveraging knowledge of standard paths of interaction with the material to tailor specific interactions?
- What is the educational background and experience of students who enroll in MOOCs or other technology-mediated postsecondary learning experiences (e.g., highest level of schooling they have attained, domain-specific work experience or other exposure)? Can we see any correlations between these characteristics and students who persist in the course, or who benefit from different approaches? In their level of achievement?
- What are the demographic characteristics (e.g., age, gender, race/ethnicity, mobility, socio-economic status) of post-secondary students enrolled in MOOCs or other technology-enhanced learning environments, and can we see correlations between these demographic characteristics and students who persist in the course? Are those indicators as effective as considering characteristics of prior knowledge, prior domain experience, and level of prior academic achievement? Which recommendations for learning environment characteristics for a learner depend on which features of the student?
- What motivates students to enroll in a MOOC (e.g., professional development? intellectual curiosity? connection to a worldwide community of learners? free?) and in relation to what alternatives? Can we see any correlations between these motivations and students who persist in the course? In their level of achievement?

Good return on investment by learners and by society. An important goal for postsecondary education is providing quality learning opportunities with high rates of retention and success in building knowledge and skills valued by learners, useful for society, and providing economic return. The new technology-based learning experiences described in this report show promise of offering these benefits at lower costs than traditional approaches to instruction and training, in a manner efficient for learners in terms of time and access.

Key questions related to this characteristic include:

- What models should we use to measure outcomes? For example, what models and measures indicate “college completion” for different types of learners and institutions? And are those preferable to other models of “career success,” including detailed

competency certification? How do we handle measuring the impact of domain-specific courses (e.g., organic chemistry) on careers that are not within that domain (e.g., medicine, the pharmaceutical industry)?

- With an abundance of learning environments becoming available, how can we improve our advice to learners on “what comes next” for them? What efforts are required to develop learning maps and associated learning pathways across the domains of proficiency that are part of the postsecondary landscape? How do we expose learners to potential career options their own experience and families might never highlight, being clear what it’s truly “like” to be a professional in such a field in an immersive, participatory way vs. just providing overview information?
- Is there a mechanism to achieve balance between efficiency (e.g., short time to degree completion or credentialing) and exploration? Which students would benefit from more exploration, and how do we achieve this without disrupting the “deeper divers” looking for the extended practice that leads to expert skills for careers? Is there a way to allow degree or career exploration without the “cost” of extending the degree program?
- What impacts do new residency models have on student success? On efficiency? These models redefine the undergraduate experience to include broader ranges of on-campus, off-campus and virtual learning experiences.
- What are the most appropriate ways of measuring the effectiveness of technology-enhanced models that go beyond the assumptions of a face-to-face world? (This applies to learning environments, courses, and institutional models, etc.) Which students with which goals should be evaluated against which measures of “success,” from “liking” the course, to specific performance objectives, to actual on-the-job performance evaluations?
- How do new curricular models, such as competency-based instruction, compare with traditional open-ended and time-based models in promoting higher-order outcomes like lifelong learning, critical thinking, and problem solving skills? What would be valid and reliable evidence across these capabilities—or is it sufficient to look within each? Do the new models display the same or different efficiencies compared to traditional models? Can we identify which learners need which types of experiences?
- Are new models scalable with inter-institutional collaboration, or will the scaling of innovation depend on regulation?

Self-improving via research and continual feedback. New technologies provide mechanisms to collect and analyze massive amounts of detailed data about every aspect of the learning experience, as well as to collect ongoing diagnostic assessments of a learner’s engagement and understanding that could be used formatively to guide subsequent instruction and learning. This can improve both efficiency and effectiveness for each individual’s learning, as well as allowing overall, evidence-based evolution of learning experiences, in part through such mechanisms as A/B experiments that enable refining instruction in terms of what works when for whom.

Key questions related to this characteristic include:

- What are efficient measures of outcomes and study characteristics (e.g., implementation fidelity, participant characteristics) to use for this purpose? For example, are learning, efficiency, effort invested (by providers and students), and learner/faculty/ provider characteristics useful?

- How do we document/disseminate these, and provide (with data privacy provisions in place) open researcher access to large, useful datasets of these, tagged with uses/sources?
- How do we practically evaluate validity and reliability of these measures in the field—and provide evolving guidance about them to practitioners?
- Which of these measures are sensitive enough and rapid enough that they are useful for continuous improvement efforts?
- What are scalable, repeatable sources of practical ideas for improvement that can scale?
 - How do we encourage many ideas from a wide range of stakeholders (internal: students, faculty, technologists, other staff; external: domain professionals, researchers, employers, funders, vendors/providers, wider community)?
 - How do we improve the quality of ideas submitted (e.g. via training, tools, examples)?
 - How do we collect and categorize these ideas efficiently (e.g., tags)?
- What are systematic, rapid, transparent ways to prioritize a large number of ideas for testing and ultimate implementation?
 - What are the right criteria to employ (e.g., prior evidence, prior use, cost/effort data)? How are these to be captured and presented?
 - What are systematic workflow methods to regularly re-prioritize and maintain a pipeline?
 - How can we simplify data access processes for researchers while maintaining safeguards on student privacy?
- What are systematic, rapid, efficient methods to execute many “good enough” pilots at scale?
 - What kinds of pre-determined documentation can be created and kept at scale for many to use (e.g., nearly-approved IRB templates, permissions language for learner and staff, rights documentation methods)?
 - What taxonomy of standardized studies, together with standard reporting and analytics, can be created to guide/streamline comparisons of multiple approaches?
 - What sorts of automated study-running tools (e.g., semi-automated randomization by learner, faculty, intervention) can make each study more efficient/less costly to do?
 - What are efficient ways to inform/train relevant participants of their role in a study—and ways to document and improve fidelity of implementation?
 - What types of workflow to speed up and systematize studies can be created and used in multiple circumstances? As an example, one can test an idea that parallels medical/IES models for a set of studies, starting with crowd sourcing capabilities (such as Mechanical Turk) to pilot for implementation and initial promise at small scale, followed by a small scale RCT within the targeted learning environment, followed by a larger scale RCT—and then comparing that (efficiency, costs, “burdens” on participants) to a Google-Amazon model for immediate, highly instrumented, large-scale RCTs that can be quickly stopped?
 - What workflow tools can systematize and speed up repeated series of related pilots?

Overall, any particular institution providing postsecondary learning might have some of these characteristics (serving a wide range of learners, good return on investment, self-improving); collectively, the aggregate system of postsecondary learning should have all of these characteristics.

Strategies for Adoption and Scale

The speed and scope with which potential benefits of these innovations in postsecondary learning are realized will depend on the sophistication of the strategies used for adoption and scaling. The challenges associated with spreading and deepening transformational educational innovations have received increasing attention from researchers. Dede's framework articulating strategies to design innovations for scale is a resource (Clarke & Dede, 2009), as is the work of Rogers and numerous scholars on knowledge diffusion (Dearing, 2009).

Build and use authentic assessments based on outcome objectives. Developers of postsecondary learning environments should clearly define the nature of the competencies students will develop over time with instructional guidance and how this knowledge links to expert performance, as well as the forms of evidence necessary to monitor student progress and outcomes. Such work, much of which is exemplified by redesign projects in the STEM disciplines, involves applying ideas such as “backwards design” (Wiggins & McTighe, 2005) and constructive alignment (Biggs & Tang, 2007) for course and curriculum design, and “evidence centered design” (Mislevy & Haertel, 2006) for associated assessment development.

Select initial innovations carefully so that strong models of learning are implemented well. Too often, educational innovations are dismissed as ineffective because early implementations were suboptimally conducted and were based on marginal models of teaching and learning (such as passively viewing video-lectures). To minimize this problem, initial efforts using a technology-based innovation should be based on strong models of (inter-) active learning, involve effective instructors willing to reconfigure their teaching to new forms of delivery, use implementation fidelity measures to compare what was intended to be experienced with what was actually experienced, and utilize thorough planning for broad implementation rather than rushing to be first-to-market.

Emphasize convivial tools and user-friendly interfaces. In the digital market, the devices and software that succeed are based on transparent interfaces requiring little cognitive overhead on the part of users. Design for simplicity and transparency is central in developing technology-based learning experiences that can scale to broad audiences with differing levels of digital sophistication.

Study the design and adoption strategies for effective educational media that have scaled. The programming languages Scratch and Lego-Logo are now ubiquitous in learning about computer science, but required decades of design-based research to develop to their current level of scalability. Lessons learned from these and other educational media that have achieved widespread acceptance and impact can inform the next generation of technology-based educational innovations.

Accomplish tasks instructors and institutions are happy to relinquish. Uptake of technology-based models in postsecondary learning will occur most rapidly for innovations that accomplish tasks which instructors and institutions now find onerous. For example, effective technology-based strategies for remedial learning that aid struggling students in succeeding with mainstream curricular offerings (such as remedial mathematics) are likely to be quickly adopted and scaled.

Use organizational development strategies for changing the culture. Many postsecondary educational institutions have common challenges in culture (e.g., a “not invented here” attitude about curriculum,

instructors who are phobic about or dismissive of technology-based instruction, or a belief that online learning is necessarily impersonal). Increasing effective adoption and scale requires professional and organizational development initiatives to alter these misconceptions and change the institutional culture.

R&D Needed on New Technology-based Models for Postsecondary Learning

Coordinated research and development investments are needed to realize the value of new technology-based models for postsecondary learning. For example, postsecondary learning providers need to conceptualize what is designed and provisioned as “learning resources” at multiple levels of granularity, both smaller than courses (units or modules of variable size), and larger than courses (integrated curriculum maps encompassing a full complement of courses). We also need to provide multiple frames for education, including simulations, games, and virtual worlds. In colleges and universities, we need to think beyond content-based courses that are the staple of the academy’s offerings and develop a new “language” for online learning that ties to specialized or common competencies needed in a wide array of successful work outside academia. One central aspect of the longer-term vision for new technology-based models is the ‘remix’ potentials of course components created in many different universities for which para-data (e.g., usage, appraisals) are available, so that a comprehensive learning map for the knowledge and skills a learner wishes to master can be created. These maps can guide students towards the competencies and credentials that comprise the expertise and education they seek, precisely because they are demonstrated to be at the core of what experts in their chosen field of work actually decide and do, both tacitly and consciously.

Various types of research investments are needed to realize the promise of new technology-based models for postsecondary learning. Figure 4 categorizes the types of R&D needed.

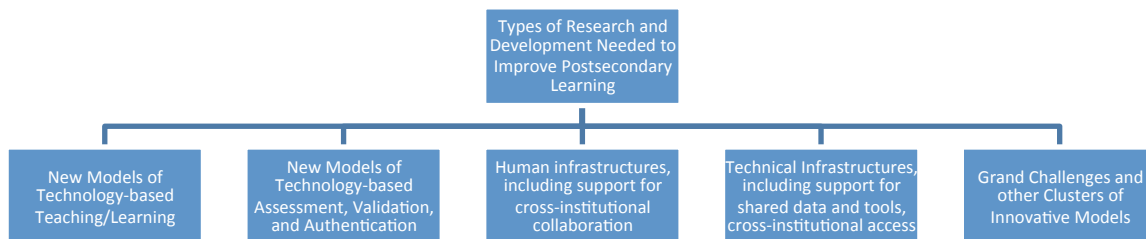


Figure 4. Types of Research and Development Needed

Five types of research and development are needed to realize the potential of technology-based innovations in postsecondary learning. Both the research illustration on teaching/learning discussed next and the five types of research topics briefly summarized in the Appendix are based on a three to seven year timeframe.

New models of technology-based teaching and learning

Below is a detailed example of research needed to realize one type of technology-based teaching/learning model. The Appendix briefly summarizes examples of other research topics across the five categories above.

Type of pedagogy. Immersive virtual simulations of internships and apprenticeships

Description of teaching and learning model.

Susan entered the Portal for the initial session of her learning experience about the methods of ecosystems science. The learning objectives for this experience are to diagnose the problems of various simulated environments using the knowledge and methods of ecosystems science, based on a cognitive task analysis of the expert processes of ecosystem scientists. 8000 students are taking this learning experience over the next month, which is based on parts of a college course about this topic that is reviewed every year against what objectively high-quality experts in this field decide and do. Susan has completed a questionnaire that generated her learning profile, done her readings and video preparations, and passed the initial assessment.

Susan was pre-assigned three virtual teammates with complementary knowledge and skills and similar schedules for access. Each of the four has their own, individualized, practice experience as well to ensure they get the basic knowledge components mastered, but the four must coordinate their involvement so as to work as a stable team throughout their various learning sessions on specific projects. The primary method of learning is immersion in virtual worlds that simulate ecosystems problems. As a secondary method of learning, Susan and her teammates have access to a few sessions of edited video clips from the college course, with a virtual study group of sixteen composed of four teams who each experienced different simulated ecosystems.

After initial skill-building based on diagnostics of what students have already mastered, the curriculum is inquiry-based, with project environments and questions moving from relatively straightforward to increasingly complex as teams demonstrate progress: students investigate research questions by exploring immersive digital ecosystems, with each team member having a role based on a different area of expertise (e.g., botanist, microscopic specialist). In these ecosystems, the team interacts with Animated Pedagogical Agents who use Transformed Social Interactions (discussed further below). The team works collaboratively to analyze their combined data and understand the ecosystem interrelationships, rotating roles (which may require some individual practice and feedback during the transition) as they move through different simulated ecosystems. As a summative assessment, each module culminates with the team creating a causal model of the ecosystem, supported by data and theory; automated pattern-matching algorithms score this.

Immersive virtual environments enable productively transcending real-world limits on social interaction. As one example of how Transformed Social Interaction (TSI) is used, since eye gaze influences persuasion, in these virtual ecosystems digital mentors maintain eye contact with every digital apprentice at the same time. This is possible because every student sees the virtual world from his or her own computer display, and these versions of reality need not be congruent. Another TSI feature used is “identity capture”—the digital mentor’s face is morphed to unobtrusively make that person similar to each student, because students whose teachers resemble them pay more attention compared to control conditions. Likewise, students who interact with virtual agents that look just like them and who model behaviors for the students to master have improved learning outcomes; this feature is used as well.

The unobtrusive, real-time assessments used to provide formative feedback include (Dede, 2012):

- *Capturing exploratory paths.* The paths that a student takes in exploring a virtual world to determine the contextual situation, identify anomalies, and collect data related to a hypothesis for the causes of an anomaly are an important predictor of the student’s understandings about scientific inquiry.
- *Analyzing usage of guidance systems.* Gathering data on students’ use of an interwoven individualized guidance system, both before and during projects, which messages they viewed, where they were in the immersive simulation when they viewed them, and what actions they took subsequent to viewing a given guidance message provides diagnostic insights that can aid instruction.
- *Interacting with animated pedagogical agents (APAs).* APAs are lifelike autonomous characters [that] co-habit learning environments with students to create rich, face-to-face learning interactions. The trajectory over time of questions students ask of an APA is diagnostic—typically learners will ask for information they do not know but see as having value. This can help us comprehend a student’s thought processes and methods of knowledge acquisition, and should allow further personalization of learning topics an individual student might need to master. Also, APAs scattered through an immersive authentic simulation can collect diagnostic information in various ways, such as the APA requesting a student to summarize what he or she has found so far.
- *Documenting progress and transfer in similar settings.* Shifting a student to a similar, but not identical environment in which he or she must identify a problem (earlier in the curriculum) or resolve a problem (later in the curriculum) can provide insights into a student’s progress and aid transfer. Further, centering these benchmarking assessments on learners’ common misconceptions, then immediately conveying the results to students, can prompt “aha” moments that help to synthesize new levels of understanding.
- *Attaining “powers” through accomplishments.* Like leveling up in games, students can attain new powers through reaching a threshold of experiences and accomplishments. These new capabilities document team achievements, promote engagement, facilitate learning, and offer additional opportunities for interwoven assessment.

All of these types of assessment are based on authentic actions in rich simulated contexts.

The designers — to improve the learning experience — continuously conduct A/B experiments. These include varying the complexity of the simulated environments, trying different forms of unobtrusive assessments, and varying the amount of transformed social interaction and APAs utilized.

Table 2: Illustrative enabling technologies for immersive virtual simulations

Innovation	Learning Method	Examples
Immersive authentic simulations via virtual worlds	Active learning via virtual apprenticeships	Limited illustrations now; http://ecomuve.gse.harvard.edu
Animated pedagogical agents (APAs) are lifelike autonomous characters manipulated by the computer	Provide engaging diagnostic and mentoring interactions with learners	Limited illustrations now; Bowman, C. D. D. (2011). Student use of animated pedagogical agents in a middle school science inquiry program. <i>British Journal of Educational Technology</i> , 43(3). Retrieved from http://onlinelibrary.wiley.com/doi/10.1111/j.1467-8535.2011.01198.x/pdf
Transformed social interactions (TSI) based on immersive interfaces	Transcending real-world limits on social interaction without user awareness	Limited illustrations now; Blascovich, J., & Bailenson, J. (2012). <i>Infinite reality: The hidden blueprint of our lives</i> . New York, NY: William Morrow.

Illustrative research questions:

- What is the best way to weave individualized competency instruction (guidance and availability) with team projects? Does it depend on the domain? How to trade off pre-screening for pre-requisites vs. making requisite skill and fluency training available to individuals on the fly?
- To what extent do various forms of TSI improve retention? increase learning outcomes?
- To what extent do APAs improve learning outcomes?
- What, if anything, is added by the forms of unobtrusive embedded assessment?
 - Capturing exploratory paths
 - Analyzing usage of guidance systems
 - Interacting with animated pedagogical agents
 - Attaining “powers” through accomplishments
 - Documenting progress and transfer in similar settings

Ways that this innovation empowers aspects of the framework:

- Lower cost
- Broader initial access and potential for success
- Good return on investment
- Increased capacity for better opportunities in life
- Advanced knowledge and skills
- Authentic assessment

- Aids faculty and organizations linking education to work

This example illustrates a detailed description of an important field for research. The Appendix briefly summarizes more examples of needed research in five areas: new models of technology-based teaching and learning; assessment, validation, and authentication; human infrastructures; technical infrastructures; and Grand Challenges.

All the national reports about education cited in the Appendix call for substantially greater investments in research on learning technologies. The 2010 National Education Technology Plan discusses the type of research investment needed to realize the potential of digital tools and media for learning. The Plan proposes a national center that would (U.S. Department of Education, 2010, pp. 76-77):

...identify key emerging trends and priorities and recruit and bring together the best minds and organizations to collaborate on high-risk/high-gain education R&D projects. It should aim for radical, orders-of-magnitude improvements by envisioning the impact of innovations and then working backward to identify the fundamental breakthroughs required to make them possible. Through the funding of rapid and iterative cycles of design and trial implementation in educational settings, the national center can demonstrate the feasibility and early-stage potential of innovative tools, content, and pedagogies that leverage knowledge, information, and technology advances at the cutting edge.

The center should also ensure that teams working on each individual project share developments, progress, best practices, and outcomes with each other to take advantage of key findings and economies of scale and to ensure integration and interoperability between projects when desirable. The national center will need to work closely with representatives of private industry to develop clear memoranda of understanding concerning the terms for precompetitive fundamental research. The national research center can focus on grand challenge problems in education research and development...

Both more investment in research on learning technologies and an increased emphasis on Grand Challenge funding, as well as integrated, large-scale research that lays the foundations for Grand Challenges, are essential to realizing the visions described in this report. Small-scale, bottom-up research driven by peer review rather than an overarching goal is important, but insufficient in both scope and focus to attain the widespread implementation of new technology-based models for postsecondary learning.

Heuristics for Establishing Priorities among these Innovations

Illustrative heuristics for prioritizing among these innovations are presented below. As discussed earlier, which heuristics are most appropriate to use depends on one's professional role (e.g., leader, investor, developer).

- What research will produce the most central “gating” findings, which if established would open up important new developments to improve postsecondary education (e.g., supports that would enable universal course completion)?
- What research advances would have the biggest uptake by postsecondary educators (e.g., successful remedial STEM education)? What would have the biggest support from industrial stakeholders? What

frameworks for new public-private partnerships would enable these dual energies to be synergistically combined?

- How big is the footprint (e.g., number or proportion of students that are affected) of an R&D effort? For example, innovations in large introductory college courses have a large impact in terms of both number of learners and effect on subsequent career path.
- Does the effort potentially illuminate important research questions that are fundamental about learning (e.g., revisiting aptitude-treatment interaction (ATI) with data science analytics as a new methodology for making progress)?
- How urgent is the outcome: Are findings from a particularly type of research needed quickly, or is later soon enough? For example, delays in addressing STEM workforce preparation have grave consequences in lost human capital.
- How much does the research expand access? As illustrations, principles and tools in designing for accessibility, such as Universal Design for Learning are important for ethical, legal and universal access reasons.
- What are the highest leverage research activities to solve the important problems of the field? As illustrations, “leverage” can involve decreased time (or cost) for same level of learning, or higher levels of capability for the same time spent, or can mean avoiding losses in human capital when students drop out of postsecondary education.
- Is some research more likely to attract entrepreneurs, thus having the possibility of scaling more rapidly? What new communicative mechanisms between the academy and the world of VC funding, educational technology incubators and “edupreneurs,” and established education technology companies can create greater awareness of and demand for learning science research that could yield better products and services?

Given limited resources and scholarly/technical capacity, heuristics such as these are important ways of determining in what research to invest initially.

Recommendations for Further Meetings on Postsecondary Learning and New Technologies

Holding additional workshops, meetings, and conferences to deepen, extend, and publicize the ideas in this report is a major priority. The recommended invitational research workshops listed below are illustrative only:

- *Creating and validating encompassing learning maps (desired outcomes, evidence for their achievement) for postsecondary learning.* For practical feasibility, such learning mapping, while coordinated, should proceed in closely coupled but distinctive activities separated by disciplines, as the competencies behind the health care field are not the same as competencies for financial services, and competencies for research are not the same as competencies for industry practice. Participants who can discuss the best ways to get to outcomes that matter for practice would include researchers and practitioners engaged in cognitive task analysis and other methods for evaluating real-world expertise, decision-making, and task competencies. Participants who can describe how to create “learning maps”—sequences of objectives that lead to real-world competencies, and possibly link those to instructional designs—are learning scientists examining at how objectives and instruction are best deconstructed (e.g., learning trajectories, practice models).
- *Exploring alternative certification and competency-based models.* Information technology allows us to connect, disconnect, and reconnect many activities previously “bundled” in a single institution. Alternative provisioning models have expanded well beyond food service and bookstores to courses

and credentials. For example, colleges and universities are contracting with third parties to “private label” services that range from student support, to website services, to online degree programs. Students are “grazing” or assembling their learning from multiple sources.

Large-scale online programs, such as MOOCs, have similar connect-disconnect-and-reconnect attributes. Premier institutions or independent “star” faculty can offer a MOOC. The “course” is disconnected from institutional credentialing systems. But it can be reconnected to those systems through testing and competency-based assessment. This raises new challenges for how higher education understands and assesses academic quality. For example, in a world where individuals and institutions may bring a bit of everything—from anywhere—together into a degree, should accreditation be at the institution level, the course level, or the provider level? Is what constitutes quality different in an online environment compared to a face-to-face one?

Interest in prior learning assessment (PLA), credit transfers and competency-based programs have expanded significantly. How would we describe the various forms of extra-institutional education (e.g., MOOCs)? What are the connections between extra-institutional education and traditional degree-granting colleges and universities? To what extent is extra-institutional education a pathway to traditional institutions and a degree or other credential? Can information technology streamline the transfer of credit? How is the quality of extra-institutional education judged? What are the quality expectations?

- *Scenario-based planning on alternative futures for postsecondary learning.* In scenario-based planning, interdisciplinary teams dive deeply into exploring distinct alternative futures (Schwartz, 1996; Chermack, 2011), in this case for postsecondary learning. Imagine a future 20 years hence in which only half of the place-based universities and institutions comprising today’s American postsecondary learning infrastructure still exist. The extinct institutions would have lost out to the availability of disintermediated educational certifications and credentials offered with reduced costs and improved quality by new for-profit and non-profit organizations. Detailed investigations of alternative scenarios can better enable enlightened planning for strategic choices that could be made today to mitigate against undesirable aspects of some scenarios and to make more likely desirable aspects of other scenarios.

The questions such a workshop might explore include: What are the roles of education and training faculty when high quality educational experiences become routinely accessible on the Web, or whatever forms the emerging global information infrastructure takes? How might these faculty use digital resources to productively transform the learning experiences they now provide? How does an institution foster education and training innovation while preserving the essential personal interaction between faculty and students? How does an institution articulate the added value of their faculty and residential educational experiences to student success, near- and longer-term, in this new environment? How does an institution measure the effectiveness of teaching and learning experiences, and how does it develop curricula that blend the best of digital and residential learning to enhance student success after leaving the institutions? How does the traditional model of a residential learning experience change in this new domain? Does this new domain provide opportunities for postsecondary learning institutions to broaden their base of successful learners beyond the borders of their campuses, to the large numbers of students who are well beyond the entry level, as well as more geographically dispersed and culturally diverse?

Other types of workshops are desirable as well, including events centered on the illustrative research agenda in the Appendix.

Conclusions

Future models for postsecondary learning may take many forms. For the relatively uninitiated, a first step in preparing for transformation might be simply to learn the vocabulary—MOOCs, wikis, social media, back channel, learning analytics, peer assessment—and the other catch-phrases and acronyms that are part of the growing lexicon of educational technology. Faculty and other instructors who are already using technology, or who plan to use it soon, should examine ways in which the field is identifying best practices around the use of specific tools and should familiarize themselves with what is now known about how learning actually works (and doesn't). . New models for technology-enhanced education are being designed at an ever-increasing pace, and instructors at all levels need to educate themselves about those innovations, and how to identify which are helping learners and which are not. Otherwise, new models—effective and ineffective—may appear in their organizations with the potential to rapidly scale before faculty and instructors are prepared to deal with them constructively.

At this point in history, the primary barriers to altering curricular, pedagogical, and assessment practices towards the transformative vision of postsecondary learning this report advocates are not conceptual, technical or economic, but instead psychological, political, and cultural. We now have all the means necessary to implement effective models of education that truly prepare all students for a future very different from the immediate past. Whether we have the professional commitment and societal will to actualize such a vision remains to be seen. We should rise to this occasion.

Acknowledgements

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Appendix Delineating Five Areas for R&D Investment

This Appendix draws on a variety of prior sources (NSF, 2003; Learning Federation Project, 2003; Computing Research Association, 2005; NSF, 2008; U.S. DoEd, 2010; PCAST, 2010; NRC, 2011; REAL Commission, 2012; U.S. DoEd, 2013; PCAST 2013) for its recommendations about illustrative R&D investments needed.

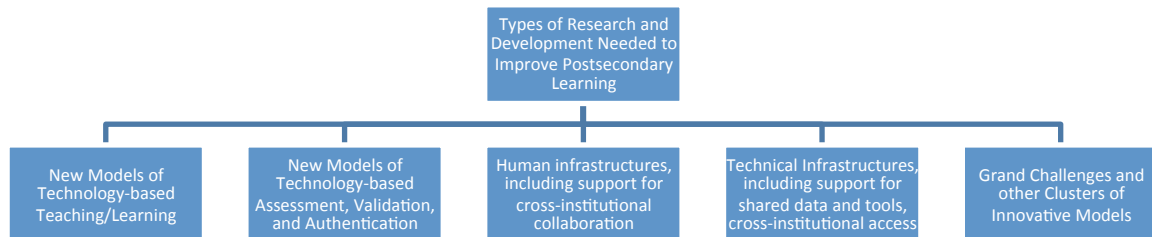


Figure 4. Types of Research and Development Needed

New models of technology-based teaching and learning

The U.S. Department of Education’s 2010 National Educational Technology Plan (NETP) frames a vision of 21st century learning, lifelong and life-wide (2010, pp. 9, 12):

We live in a highly mobile, globally connected society in which young Americans will have more jobs and more careers in their lifetimes than their parents. Learning can no longer be confined to the years we spend in school or the hours we spend in the classroom: It must be lifelong, life-wide, and available on demand... The challenge for our education system is to leverage the learning sciences and modern technology to create engaging, relevant, and personalized learning experiences for all learners that mirror students’ daily lives and the reality of their futures. In contrast to traditional classroom instruction, this requires that we put students at the center and empower them to take control of their own learning by providing flexibility on several dimensions.

The research areas below addressing this vision are illustrative rather than inclusive.

Research Areas	Goal
<u>Virtual simulations of internships</u>	Build a virtual vocational internship that approximates the learning outcomes of a physical internship experience.
<u>Online learning games that engage and educate</u>	Develop engaging games that foster academic learning and intrinsic motivation
<u>Support learners’ and teachers’ connections to human and digital resources</u>	Enable connected learning and teaching
<u>Supporting independent learning for a broad spectrum of participants:</u>	Enable people with a wide variety of learning strengths and styles to learn independently
<u>Next generation online tutoring systems</u>	Customize motivation and learning to individual needs
<u>Remixing learning resources at multiple levels of granularity</u>	Provide mechanisms for reuse of educational resources and for integrating learning across multiple providers

Virtual simulations of internships: As discussed earlier in this report, immersive authentic simulations via virtual worlds can enable active learning and close the knowledge transfer gap. Animated pedagogical agents (APAs) are lifelike autonomous characters manipulated by the computer. They can provide engaging diagnostic and mentoring interactions with learners (Bowman, 2011). Transformed social interactions (TSI) based on immersive interfaces help transcend real-world limits on social interaction without user awareness and can lead to increased engagement (Blascovich & Bailenson, 2012). Some research questions critical to the development of virtual internships.

- What is the best way to weave individualized competency instruction (guidance and availability) with team projects? Does it depend on the domain? How to trade off pre-screening for pre-requisites vs. making requisite skill and fluency training available to individuals on the fly?
- To what extent do various forms of TSI improve retention? Increase learning outcomes?
- To what extent do APAs improve learning outcomes?

A research agenda for developing features of these agents is presented below in the section on intelligent tutoring.

The 2008 Report from the NSF Task Force on Cyberlearning articulates one form of these simulations with a call for the development of virtual laboratories. (2010, pg. 37):

We recommend that NSF mount a program to stimulate development of remote and virtual laboratories and to research effective ways to deliver this type of instruction. Many studies reveal the weaknesses of both hands-on and virtual laboratories (Singer et al., 2005). We recommend funding centers to identify effective ways to provide laboratory experiences given the power of cyberlearning technologies.

Online learning games that engage and educate: The Learning Federation Project's (LFP) report on using simulations and games in learning (2003) states (page 12), "Exploiting the inherent motivational aspects of games and simulations for education and training must be based on a sound understanding of which features of these systems are important for learning and why." The National Research Council report on games and simulations in science education (2011) recommends that research is needed to develop guidelines that assess the quality of engagement, immersion, and mastery orientation in learning games. As one example, research is needed into the conditions in which attaining 'powers' through accomplishments can be applied to learning games. Like leveling up in games, students can attain new powers through reaching a threshold of experiences and accomplishments. These new capabilities document team achievements, promote engagement, facilitate learning, and offer additional opportunities for interwoven assessment. Both of the sources cited provide detailed recommendations for research agendas in this area.

Enable connected learning and teaching: This report has argued that connected learning is enabled by globally networked collaboration technologies. Connected learning facilitates personalization and personal agency, cuts across formal and informal contexts, and leverages the affordances of digital and networked media. Similarly, the NETP presents a vision in which instructors are, "connected to their students and to professional content, resources, and systems that empower them to create, manage, and assess engaging and relevant learning experiences for students both in and out of school. They also are

connected to resources and expertise that improve their own instructional practices, continually add to their competencies and expertise, and guide them in becoming facilitators and collaborators in their students' increasingly self-directed learning" (2010, page 40).

Fulfilling the potential of these connected learning environments requires that we:

- Study how to engage learners as prosumers in generative scholarship, where they help build the knowledge of the field and use the tools of the profession to draw their own conclusions.
- "Leverage social networking technologies and platforms to create communities of practice that provide career-long personal learning opportunities for educators within and across schools, preservice preparation and in-service educational institutions, and professional organizations...
- Provide preservice and in-service educators with professional learning experiences powered by technology to increase their digital literacy and enable them to create compelling assignments for students that improve learning, assessment, and instructional practices...
- Develop a teaching force skilled in online instruction." (NETP, 2010, pp. 49, 50)

Supporting independent learning for a broad spectrum of participants: The NETP identifies some of the unique challenges confronting a broad range of adult learners (2010, pp. 21, 23):

Many adults in the workforce are underproductive, have no postsecondary credential, and face limited opportunities because they lack fluency in English or other basic literacy skills. Unfortunately, they have little time or opportunity for the sustained learning and development that becoming fluent would require. For these learners, technology expands the opportunities for where and when they can learn, enabling them to catch up and continue to learn. Such resources as Learner Web and USA Learns make it possible for working adults to take online courses anytime and anywhere... The always-on nature of the Internet and mobile access devices provides our education system with the opportunity to create learning experiences that are available anytime and anywhere. When combined with design principles for personalized learning and UDL, these experiences also can be accessed by learners who have been marginalized in many educational settings: students from low-income communities and minorities, English language learners, students with disabilities, students who are gifted and talented, students from diverse cultures and linguistic backgrounds, and students in rural areas.

To this end the report suggests that we (pp. 23, 49):

- Develop and implement learning resources that exploit the flexibility and power of technology to reach all learners anytime and anywhere.
- Use technology to provide all learners with online access to effective teaching and better learning opportunities and options in places where they are not otherwise available and in blended (online and offline) learning environments.

One specific opportunity for advancement in this area is outlined in the report of the Education and the Advancement of Learning (REAL) Commission, *Taking Steps to Invest in the Promise of Their Future and Ours* (2012), suggests further research into the "flipped" classroom model (page 8):

In this model, students use digital resources outside the classroom for topic introductions and explorations and use classroom time for direct collaboration and support with teachers and peers. While there has been some research regarding the needs for training and support for teachers, several critical issues remain and demand additional research. These include defining the role and

value of adult supervision and learning coaches in this model and identifying how these supports can be delivered outside the school day for all learners. The group also recommends further research into supporting students with learning differences. The goal of this research is to explore whether independent content learning is possible and optimal for students with learning differences. Further, there should be research to investigate what types of supports and accommodations are available and necessary when critical learning happens outside of the school day.

Next generation online tutoring systems: The LFP report on question generation and answering systems states (2003, pp. 61-62), “If the computers can implement even a portion of the ideal tutoring strategies, then there should be substantial learning gains. Available meta-analyses of human tutoring (Cohen, Kulik, & Kulik, 1982) reveal learning gains of .42 standard deviation units whereas the estimate for ITS systems is 1.0 (Corbett, 2001) or higher.” This report provides ten research topics for furthering these systems,

1. The learning environment that stimulates learner questions.
2. An interface for learners to ask questions.
3. Computational mechanisms for interpreting learner questions.
4. Computational mechanisms for answering learner questions.
5. An interface for the learning environment to answer learner questions.
6. Computational mechanisms for generating questions.
7. A facility for learner modeling in interpreting and answering learner questions, as well as asking questions.
8. An interface for asking the learner questions.
9. An interface for learners to answer questions, both individually and collaboratively.
10. Computational mechanisms for interpreting learner’s answers.

The 2010 PCAST report provides two additional suggestions (pp. 31-32):

- Linking people into the question generation and answering facilities
- Incorporating good pedagogy.

Remixing learning resources at multiple levels of granularity: As discussed earlier in this report, postsecondary education providers need to conceptualize what is designed and provisioned as “learning resources” at multiple levels of granularity, smaller than courses on the one hand (units or modules of variable size), and the ‘remix’ potentials of course components created in many different universities”. The NSF Task Force on Cyberlearning stated, “we also need a stronger emphasis on the importance of reaching out to users in the codesign and construction of tools and archives from the beginnings of their inceptions, not as afterthoughts. It is important to recognize that multipurposing must go beyond merely adapting the content to providing appropriate training and support targeted to educators and learners in very diverse settings.” (2008, page 27). The report also identified the following research questions.

- What are the general principles that can guide adaptation of materials to different learning and educational settings?
- What tools can be used to facilitate this adaptation?

- What cyberlearning design principles are emerging from current work, and how can they guide developers so that materials meet the needs of diverse audiences and work in diverse settings, including home, school, and informal learning?

Regarding educational resources that are developed with NSF funding, the report advocates that (page 41):

- NSF should require clear intellectual property and sustainability plans as part of grant proposals for educational materials it supports. The default expectation around intellectual property is that the materials should be released on the Web as open educational resources under a license provided by Creative Commons, where appropriate (perhaps with attribution only), at some identified point within the term of the grant. This will facilitate machine searching and processing of the material and also help with reuse and recombination of materials. As part of the evaluation of proposals, grant reviewers should give careful attention to these plans, and also to any arguments advanced for more restrictive.
- NSF should launch a program to identify and demonstrate sustainable models for providing open educational resources, whose goal is to create mechanisms whereby educational materials developed by grantees will continue to have impact long after NSF support has ended. All materials development grants should include required discussions of sustainability, and this should be an important criterion in proposal evaluation.

New models of technology-based assessment, validation, and authentication.

The NETP describes the importance of assessment in its vision of 21st century education (2010, pg. 25):

Just as learning sciences and technology play an essential role in helping us create more effective learning experiences, when combined with assessment theory they also can provide a foundation for much-needed improvements in assessment... These improvements include finding new and better ways to assess what matters, doing assessment in the course of learning when there is still time to improve student performance, and involving multiple stakeholders in the process of designing, conducting, and using assessment... Equally important, we now are acutely aware of the need to make data-driven decisions at every level of our education system on the basis of what is best for each and every student—decisions that in aggregate will lead to better performance and greater efficiency across the entire system.

Research Area	Goal
<u>Unobtrusive assessments from log files:</u>	Design and analysis strategies for unobtrusive, log file-based assessments that provide diagnostic data to guide instruction
<u>Behavioral and physiological responses:</u>	Design and analysis strategies for behavioral and physiological measures that provide data to guide instruction
<u>Analysis and visualization methods for distilling assessments from big data:</u>	Develop ways to rapidly extract and display insights from large datasets about students
<u>A metatheory of competence:</u>	Develop a map of disparate models for domain expertise, competency and pedagogy that synthesizes a cognitively valid model
<u>Assessment object strategy:</u>	Develop automated modular assessment design, development, delivery and analysis to support performance models

Unobtrusive assessments from log files: The NETP states that (2010, pp. 29-30):

When students are learning online, there are multiple opportunities to exploit the power of technology for formative assessment. The same technology that supports learning activities gathers data in the course of learning that can be used for assessment... An online system can collect much more and much more detailed information about how students are learning than manual methods. As students work, the system can capture their inputs and collect evidence of their problem-solving sequences, knowledge, and strategy use, as reflected by the information each student selects or inputs, the number of attempts the student makes, the number of hints and type of feedback given, and the time allocation across parts of the problem.

To this end the report recommends (pp. 37, 28),

- States, districts, and others should design, develop, and implement assessments that give students, educators, and other stakeholders timely and actionable feedback about student learning to improve achievement and instructional practices.
- Build the capacity of educators, educational institutions, and developers to use technology to improve assessment materials and processes for both formative and summative uses.
- Conduct research and development that explores how embedded assessment technologies, such as simulations, collaboration environments, virtual worlds, games and cognitive tutors, can be used to engage and motivate learners while assessing complex skills.
- Conduct research and development that explores how UDL can enable the best accommodations for all students to ensure we are assessing what we intend to measure rather than extraneous abilities a student needs to respond to the assessment task.
- Revise practices, policies, and regulations to ensure privacy and information protection while enabling a model of assessment that includes ongoing gathering and sharing of data for continuous improvement.

Physical and physiological responses: The LFP report on games and simulations states (2003, pg. 48):

With respect to monitoring learner performance, an issue that needs attention involves how to dynamically collect performance data during learning in both human-to-human and computer-to-human instructional situations... In particular, unobtrusive methods to collect and interpret data such as keystrokes, button or mouse actions, eye movements, verbal responses, protocol analysis, and even facial expression and gesturing must be further developed.

An example of collecting and integrating a range of physiological data to assess student affective response is provided in AlZoubi, D’Mello, and Calvo (in press).

Analysis and visualization methods for distilling assessments from big data: The Computing Research Association report on cyberinfrastructure and learning for the future (CLF) states (2005, pg. 22):

New methodologies of “visual analytics” will be needed for the analysis of enormous, dynamic, and complex information streams that consist of structured and unstructured text documents, measurements, images, and video. Significant human-computer interaction research will be required to best meet the needs of the various stakeholders. Stakeholders ought to be able to “drill down” into these assessments to see the justification for them in terms of learner performance. Analyses should be auditable, particularly when they have an impact on decision-making, including college admissions and school-system performance assessments. These tools must be designed to give high priority to protecting the privacy and security of the data and users.

The President's Council of Advisors on Science and Technology (PCAST) 2010 report outlines a research agenda that underpins this use of big data (2010, pg. 51):

- *Representations*: How to adopt and evolve standards for important categories of information. These representations must allow different companies and organizations to create software tools that generate, manipulate, and analyze societally important data. Left on its own, the software industry is likely to create a number of incompatible, proprietary standards that become obsolete. (Consider, for example, the case of word-processing formats and the fact that the Federal Government still mandates using WordPerfect format for official documents, long after most organizations have transitioned to other software.)
- *Detecting and correcting errors or inaccuracies in the data*: Although various forms of outlier detection have been developed and applied, these methods need to be more sophisticated and comprehensive when applied to data sets of societal importance.
- *Support for data management policies*: Systems to support data privacy and access limitations, retention requirements, requirements for mechanisms to reduce the risk of data loss or damage, and other aspects of increasingly stringent data policy and regulatory requirements.
- *Data provenance*: Tracking how, where, and when data are created and modified. This is an important and often overlooked aspect of data stewardship.
- *Data integrity*: Ensuring that data are not corrupted either accidentally or maliciously.
- *Data storage engineering*: Ensuring reliability, reducing power consumption, incorporating new technology. Management of data across multiple storage technologies and multiple hierarchies, and with replication across multiple geographic locations. Continued research is required to adapt to changing technology (e.g., nonvolatile RAM), performance requirements, and the need to provide consistent views of data worldwide.
- *Development of sustainable economic models*: Necessary for supporting data access and preservation over the long term, especially beyond the durations of typical research grants.

A metatheory of competence: The LFP report on learner modeling calls for an overarching framework for assessment (2003, pg. 19): the “mapping and reconciliation of disparate models of domain expertise, competency and pedagogy into a metatheory of competence,” “something akin to the Human Genome project to map this landscape and standardize on a cognitively valid model”. The report presents research tasks needed to integrate existing models into one metatheory (page 21):

- Map content/competency models and agree on a metatheory
 - Map representative domain-specific and domain-general content/competency models
- Map pedagogical models and agree on a metatheory
 - Map of main pedagogical models by domain
 - Identification of common elements
 - Proposal of a metatheory and map it to subsets of existing models
- Create cognitive task analysis tools
 - Review and synthesis of cognitive task analysis methods
 - Study results comparing the efficiency and utility of multiple cognitive task analysis methods
 - Demonstrations of cognitive task analysis outputs aligned with common content and pedagogical models

Earlier in this report, we articulated key questions that will determine the efficacy of this work:

- How can we efficiently and objectively determine and describe dependent sequences of learning objective and under what conditions each are applicable?
- How do we store and communicate these dependent sequences of objectives for use by multiple stakeholders/learning environments?
- How can we classify and make explicit relationships between and among knowledge components?
- How can we usefully demonstrate how similar concepts appear and reappear in various disciplines, domains, and contexts?

Assessment object strategy: The LFP report on learner modeling describes an Assessment Object Strategy that involves the “automated modular assessment design, development, delivery and analysis to support performance models” (2003, page 24). Such a “strategy will have to specify the reusable components of multiple assessment task types and multiple response types within those task types... An assessment object strategy will also include reusable mechanisms for scoring and combining evidence from multiple sources to generate probabilistic inferences about mastery of particular objectives or competencies... Another approach is to determine the number of independent dimensions that characterize the content and specify the location of the assessment object on each of several scales or dimensions.” This report highlights three types of research needed:

- reusable components of multiple assessment task types and multiple response types
- reusable mechanisms for scoring and combining evidence from multiple sources to generate probabilistic inferences about mastery
- the number of independent dimensions that characterize the content and specify the location of the assessment object on each of several scales or dimensions

The NSF initiated “Reusable Learning” website articulates some of the challenges that need to be addressed for such an reusable assessment strategy to be effective (Robson, 2003):

In the case of digital learning resources, there are many problems to be overcome before we can expect widespread reuse and sharing. Learning tends to be highly contextual, and context is not as easy to disseminate as data alone. The specialized nature of learning resources sometimes requires specialized formats and specialized software to interpret them. Interactive resources seem harder to break up into smaller components than those consisting solely of text and graphics, making them less convenient to reuse than a book. Validity and trustworthiness are important issues for educational material, militating against the emergence of peer-to-peer educational file sharing networks. The simple metadata (title and author) and full text searches that seem adequate for searching and discovering entertainment and news content may not suffice for educational content. There are also elements of the academic and educational cultures that discourage a high degree of reuse.

Human infrastructures.

Technological advances without the accompanied advances in human capital will undermine our efforts. Research is needed in building enabling competencies in current educators, developing new specialist programs to address emerging needs, and in establishing new practices of collaboration across differentiated roles.

Research Area	Goal
Development of data scientists:	Every major research university should have an interdisciplinary graduate programs aimed at developing educational data scientists.
A vibrant Cyberlearning field:	Develop a vibrant, generative and interdisciplinary Cyber-learning field
Support the integration of new technologies into the professional development of educators:	Educators involved in postsecondary learning should receive continuing professional development on technology-based models of teaching and learning, utilizing similar mechanisms as those used with students.
Collaborative design-based implementation research:	Stakeholders in postsecondary learning should collaborate on research that improves the usage of new technology-based models of teaching and learning.

Develop data scientists: The U.S Department of Education’s policy report on *Expanding Evidence Approaches for Learning in a Digital World* (EEA) recommends developing a generation of data scientists for education (2013, page 84):

Interdisciplinary teams of experts in educational data mining, learning analytics, and visual analytics should collaborate to design and implement research and evidence projects. Higher education institutions should create new interdisciplinary graduate programs to develop data scientists who embody these same areas of expertise. Educational data mining that incorporates learning analytics is a new field experiencing rapid growth (Bienkowski, Feng, & Means, 2012). It draws on multiple disciplines including statistics, machine learning, and cognitive science. Experts in these areas report that one cannot learn the necessary combination of skills without access to large datasets and guidance from mentors.

A Vibrant Cyberlearning Field: The NSF Cyberlearning Report states that (2008, pg. 21):

The new field of cyberlearning requires new forms of expertise, new collaboration skills, new kinds of public-private partnerships, as well as flexibility and agility in the planning and conduct of research, development, and funding. Preparing the next generation of cyberlearning leaders parallels the challenge NSF met for the field of nanotechnology. A similar approach is needed, including support for centers that bring the emerging leaders together to rapidly develop the field of cyberlearning. Cyberlearning has the added challenges of needing to leverage rapid industry developments and of developing a cyberliterate citizenry.

The report calls for research to address the following questions (page 22):

- How can we leverage the best of cyber-learning advances in the universities and industry to attract and prepare a new, diverse generation of leaders?
- How does cyberlearning change the nature of lifelong and life-wide learning?
- Taking advantage of new ways to document progress, what are the varied pathways and trajectories that newcomers follow, and which ones are optimal?
- What are effective forms of professional development to stimulate the field to build on the successes of others using open-source learning environments, platforms, and other community supports such as “cloud computing”?

- What are promising methods for bridging international communities to form a vibrant, multinational field?

Support the integration of new technologies into professional development of faculty: The REAL report recommends (2012, page 10):

Update and expand professional development and pedagogy. Introducing advanced technologies into the learning environment without appropriate changes in pedagogy and associated professional development will have little real or sustained impact. New models for learning are evolving that make greater use of social networks, multimedia, and video content that dramatically changes traditional classroom models of instruction. The delivery device will continue to evolve and so must the pedagogy and associated professional development, to make sure teachers can use and integrate new technologies effectively.”

The CLF report calls for the “meaningful integration of cyberinfrastructure skills and resources (e.g., networked instruments, data sets, visualization, and modeling software) into formal learning environments... providing the means for harnessing the potential of cyberinfrastructure resources for teachers to engage in developing and deepening subject content knowledge and pedagogical content knowledge.” (2005, page 27)

Collaborative design-based implementation research: The EEA report cites the importance of design-based implementation research and “calls for sustained partnerships between developers, education researchers, and practitioners who jointly select a problem to work on and engage in multiple cycles of design and implementation decisions with data collection and analysis embedded in each cycle so that implementation can be refined based on evidence...” (2013, pg. 79). The report suggests three benefits of such an approach:

- Desirable as part of large-scale implementation of complex digital learning systems to maximize the likelihood that the innovation will be well implemented and to learn from each iteration cycle as part of a continuous improvement process.
- Brings data-informed decision making to the level of local practice.
- Can inform subsequent effectiveness studies but is important also for innovations on which effectiveness studies have been done to maximize local benefits from the innovation and to build knowledge of how to scale up the innovation without degradations in its impacts

Technical Infrastructures

The NSF report on Cyberinfrastructure in science and engineering (CSE) notes that the concept of cyberinfrastructure “is premised on the concept of an advanced infrastructure layer on which innovative science and engineering research and education environments can be built... If *infrastructure* is required for an *industrial* economy, then we could say that *cyberinfrastructure* is required for a *knowledge* economy.” (2003, pg. 5). The report goes on to describe (2003, pg. 7):

The base technologies underlying cyberinfrastructure are the integrated electro-optical components of computation, storage, and communication that continue to advance in raw capacity at exponential rates. Above the cyberinfrastructure layer are software programs, services, instruments, data, information, knowledge, and social practices applicable to specific projects, disciplines, and communities of practice. Between these two layers is the cyberinfrastructure

layer of enabling hardware, algorithms, software, communications, institutions, and personnel.” Cyberinfrastructure is seen both “as an object of research, and other (“domain science”) research communities who see it as a platform in service of research.

Research Area	Goal
<u>Advance Seamless Cyberlearning</u>	Advance seamless cyberlearning across formal and informal settings by galvanizing public-private partnerships and creating a new interdisciplinary program focused on establishing seamless cyberlearning infrastructure and supports
<u>Fundamental research to develop foundations for new educational technologies</u>	Develop insights that can guide the design, implementation, and improvement of next generation educational tools, media, and infrastructures
<u>Research on human-machine interaction</u>	Create a research program that augments the study of individual human-computer interaction with a comprehensive investigation to understand and advance human-machine collaboration and problem solving in a networked, online environment.
<u>Supporting funders’ cyberlearning investments</u>	Increase the size and sustainability of NSF’s and other funders’ cyberlearning investments

Advance Seamless Cyberlearning: One of the pillars of the NSF report on Cyberlearning is the development of seamless cyberlearning across formal and informal settings. The report argues that (2008, pp. 35, 36):

Seamless cyberlearning is learning supported by cyberinfrastructure so that it can be pursued productively either through learner intent, driven by interests or demands in the moment and regardless of location, or through intentionally designed educational activities, which learners can take advantage of as needed or when the situation requires... Creating environments for seamless learning requires vital cyberlearning infrastructure research and development differentiates context as “that which surrounds us” and “that which weaves together.” The latter definition makes clear how important cyberlearning infrastructure is likely to become, as it provides the technical substrate for weaving together in new designs the disparate learning and educational intentions and resources to make seamless cyberlearning a reality.

The report recommends that the NSF “advance seamless cyberlearning across formal and informal settings by galvanizing public-private partnerships and creating a new interdisciplinary program focused on establishing seamless cyberlearning infrastructure and supports” (pg. 26). It specifies the following research questions:

- How can cyberlearning infrastructure be used to mediate personalized learning across all the contexts in which it happens?
- How can the “right” resources, from digital assets to human peers and mentors, be provided in any context to support learning needs in the moments in which they arise?
- What different needs exist for different age populations and STEM learning domains?
- What scaffolding systems are necessary to support learning in these distributed learning environments?

- How should theories of learning and instructional design be expanded to encompass learning across the boundaries of all the settings in which people learn?
- What forms of digital portfolios will be necessary to manifest evidence demonstrating learning activities and performances?

Fundamental research to develop foundations for new educational technologies: Both the PCAST's 2010 Report on "Designing a Digital Future" and its 2013 extension argue for foundational research to support new educational technologies. The 2010 report recommends that (page 42):

- The US Department of Education, in collaboration with NSF, should provide robust and diversified support for fundamental NIT R&D that will lay the foundation for educational technologies such as personalized electronic tutors, serious games and interactive environments for education, and mobile and social education technologies. The support for NIT-based education should extend from pre-school settings to lifelong learning.
- The US Department of Education, in collaboration with NSF, should have a long-term program to evaluate promising technology coming out of the research community in trials that include large numbers of sites and participants. Technology that proves its worth should be transferred into the schools. This program will require evolution of curricula and school processes and procedures.

Research on human-machine interaction: The 2010 PCAST report recommends (page 78):

The modes and the ease with which people interact with computers have improved as richer forms of interaction and better understanding of human capabilities have informed the design of interactive systems. The advent of widely available networking and the introduction of digital consumer products have further empowered people. We are now experiencing another spurt of growth – into the realms of social computing and media, NIT (Networking and Information Technology)-enabled social science, and collective interaction.

These richer interactions have obvious application for advancing education platforms. The report recommends that (page 78):

NSF, DARPA, and NIH should create a research program that augments the study of individual human-computer interaction with a comprehensive investigation to understand and advance human-machine collaboration and problem solving in a networked, online environment. The program should:

- create a science of social computing that, for example, gives insight into how to organize human contributions, how to incentivize participants, and how to design generic social-computing frameworks that could be used by different organizations for diverse purposes;
- foster research that pushes the field beyond the current examples of crowd-sourcing;
- encourage theoretical, algorithmic and engineering foundations that guide the design of peer-production systems (in which large groups of individuals, sometimes tens or even hundreds of thousands, collaborate online) for a wide variety of tasks;
- design novel mission-specific uses of collaborative computing; and
- create shared privacy-preserving research platforms to enable researchers in computational social science to share and exchange experimental designs, behavioral experimental data, and human subject panels and subjects. For example, a promising application area for such experimental research is the study of human decision-making regarding security and privacy issues, so as to inform technology and design considerations in those areas.

Increase the sustainability of funders' cyberlearning investments: The NSF report on Cyberlearning articulates a number of approaches that could be taken to increase the sustainability of cyberlearning investments (2008, pg. 33):

- *Fund incubations.* NSF should investigate incubation activities to fuel innovation in cyberlearning. One model is a derivation of the thriving IdeaLab13 concept (with central hub/exchange and core services—but freedom for innovators) that could be offered to higher education faculty during the summer. Imagine a number of universities with appropriate facilities making their campuses open by hosting multidisciplinary teams focused on rapid prototyping of cyberlearning tools, thus leveraging the availability of information and communication technology (ICT) resources to develop proofs of concept. These “technical swarms” around a creative core could produce viable scenarios and feasible technologies that would attract the attention of invited venture capitalists and research teams.
- *Establish competitions and challenges.* In conjunction with select partners (foundations or commercial entities or both), initiate several high-profile grand challenge competitions. These could be multiple small events or a limited set of more significant undertakings. The best recent example is the X-Prize Challenge, 14 in which an initial single concept has morphed into a broader set of opportunities, resulting in true, feasible solutions and functioning businesses. A more closely related project is the Digital Media and Learning Competition¹⁵ sponsored by the MacArthur Foundation and administered by the Humanities, Arts, Science and Technology Advanced Collaboratory.
- *Motivate participation across the private sector.* Open up requests for proposals or agree to co-fund/cost-share the development of cyberlearning technologies with the private sector to stimulate innovation and encourage new businesses and business models. NSF could solicit proposals from private industry and high-tech industry firms to build out cyberlearning platforms or modular technologies to ensure that the ecosystem is cooperatively working around established community protocols. Consider partnerships with the higher education sector contacts at Apple, 3Com, EMC, HP, Intel, Microsoft, and others, who would be likely to invest in developing or partnering on the buildout of cyberlearning (test) environments if it would lead to additional business and services in the future.

The report also articulates three research questions to address in advancing this agenda.

- What should the life cycle of an educational resource be, and what kinds of professionals and organizations are needed to support the different phases of this life cycle?
- What are viable sustainability models for NSF-supported innovations?
- What are the characteristics of an organization that can sustain the quality of these resources?

Grand challenges

To integrate the areas of research delineated above, the NETP advocates a Grand Challenge strategy (2010, pg. 77):

American computer science was advanced by a grand challenge problems strategy when its research community articulated a set of science and social problems whose solutions required a thousand-fold increase in the power and speed of supercomputers and their supporting networks, storage systems, and software. Since that time, grand challenge problems have been used to catalyze advances in genetics (the Human Genome Project), environmental science, and world health. To qualify as grand challenge problems suitable for this organization, research problems should be:

- Understandable and significant, with a clearly stated compelling case for contributing to long-term benefits for society
- Challenging, timely, and achievable with concerted, coordinated efforts
- Clearly useful in terms of impact and scale, if solved, with long-term benefits for many people and international in scope
- Measurable and incremental, with interim milestones that produce useful benefits as they are reached.

Research Area	Goal
<u>A real-time, self-improving learning system:</u>	Design and validate an integrated system that provides real-time access to learning experiences tuned to the levels of difficulty and assistance that optimizes learning for all learners, and that incorporates self-improving features that enable it to become increasingly effective through interaction with learners.
<u>Assessing complex 21st Century skills:</u>	Design and validate an integrated system for designing and implementing valid, reliable, and cost-effective assessments of complex aspects of 21st century expertise and competencies across academic disciplines.
<u>Big data in education:</u>	Design and validate an integrated approach for capturing, aggregating, mining, and sharing content, student learning, and financial data cost-effectively for multiple purposes across many learning platforms and data systems in near real time.
<u>Design principles for effective and efficient online learning systems</u>	Identify and validate design principles for efficient and effective online learning systems and combined online and offline learning systems that produce content expertise and competencies equal to or better than those produced by the best conventional instruction in half the time at half the cost.
Detailed descriptions of expertise for the top 1000 jobs to come	Use (and improve) objective techniques like cognitive task analysis to unpack the tacit and conscious decisions and tasks done by objectively determined experts in the top 1,000 job categories that will drive our economy for the next 20 years.

A real-time, self-improving learning system: The first Grand Challenge described by the NETP states that (2010, page 78):

Today, we have examples of systems that can recommend learning resources a person might like, learning materials with embedded tutoring functions, software that can provide UDL supports for any technology-based learning materials, and learning management systems that move individuals through sets of learning materials and keep track of their progress and activity. What we do not have is an integrated system that can perform all these functions dynamically while optimizing engagement and learning for all learners. Such an integrated system is essential for implementing the individualized, differentiated, and personalized learning called for in this plan. Specifically, the integrated system should be able to

- Discover appropriate learning resources;
- Configure the resources with forms of representation and expression that are appropriate for the learner's age, language, reading ability, and prior knowledge; and

- Select appropriate paths and scaffolds for moving the learner through the learning resources with the ideal level of challenge and support.

Assessing complex 21st Century skills: The second Grand Challenge described by the NETP states that (2010, page 79):

... the development of a validated, cost-effective, single system, applicable across content domains. Such a system should involve integrating the following features:

- Systematic analysis of the claims about student competence (including competence with respect to complex aspects of inquiry, reasoning, design, and communication) intended by academic standards and the kinds of evidence needed to judge whether or not a student has each of those aspects of competence;
- Specifying assessment tasks and situations that would provide the desired evidence;
- Administering complex assessment tasks capable of capturing complex aspects of 21st-century expertise through the use of technology; and
- Developing and applying rules and statistical models for generating reliable inferences about the learner’s competencies based on performance on the assessment tasks.

Big data in education: The third Grand Challenge described by the NETP states that (2010, page 79):

Although underlying technologies for exchanging data sets exist, education does not yet have the kind of integrated Web-enabled data-sharing system that has been developed for the health-care, telecommunications, and financial sectors. Such a system must be capable of dealing with both fine-grained data derived from specific interactions with a learning system and global measures built up from that data, and it must be able to collect, back up, archive, and secure data coming from many different systems throughout a state. It must also be capable of integrating the financial data essential for managing costs. Addressing this challenge will require:

- A data format to represent learning and financial data;
- A service to discover and exchange data;
- A data security standard for the service;
- A specification, test suite, and reference implementation of the service to ensure vendor compliance; and
- Best practices to guide the deployment of such services.

Design principles for effective and efficient online learning systems: The final Grand Challenge described by the NETP states that (2010, page 80):

Research labs and commercial entities are hard at work developing online learning systems and combined online and offline learning systems that support the development of expertise within and across academic disciplines. Although we have isolated examples of systems producing improved learning outcomes in half the time, we have yet to see this kind of outcome achieved within the K–12 system and particularly in those schools where students need help the most. In addition, in both K–12 and higher education, we have yet to see highly effective systems that can be brought to scale. We have evidence that learning can be accelerated through online tutoring, restructuring curricula, and by providing guiding feedback for improvement throughout the learning process. Further, we know that the current “packages” of learning that define semester and yearlong courses

are generally arbitrary and a result of long-standing tradition rather than of careful studies. Achieving twice the content expertise and competencies in half the time at half the cost through online learning systems seems very possible, but it will require careful design, development, and testing.

Clear layouts of expertise for the top 1000 jobs to come. All the technology and techniques for learning in the world will not be helpful unless we have the right educational objectives. Research (Feldon, 2007) suggests that, when experts are left unguided to teach novices, they miss telling students 70% or more of what novices need to decide and do at an expert level. There are techniques to improve this situation – indeed, a recent meta-analysis (Tofel-Grehl, 2013) shows that using cognitive task analysis techniques can lift learning by more than 30% - more than 45% if you restrict to the most successful techniques. The challenge is how to do this at scale: how to identify, objectively, the best experts in each of a large number of critical professions, and then execute efficiently the analysis and descriptions of the decisions and tasks these experts do at scale. Developing these findings and updating them as jobs evolve could have a very large payback for businesses and our economy.

Collectively, these and other Grand Challenges provide a way of integrating the research themes described in the illustrative agenda above.