# Big Data and Research Priorities for the Future of Learning Analytics

Stephanie D. Teasley, Principal Investigator
Henry Kelly, Senior Scientist
University of Michigan

## Introduction

This paper reports outcomes from a NSF-funded workshop that took place at the University of Michigan in Ann Arbor, MI, March 18-19, 2019. The workshop brought together individuals with key expertise in the wide range of disciplines to describe the research needed and propose research priorities in learning analytics for the coming decade. This included people with expertise in cognitive and behavioral sciences, modern data analytics including machine learning and data mining, instructional design, and expertise in specific disciplines. A major goal of the workshop was to bring together scholars with expertise that has not yet been closely connected with learning research. Foremost among these were data scientists who have made dramatic contributions in other parts of the economy, and people in the business community who have made major investments in areas like "people analytics" and various methods for defining and measuring workplace competence. The workshop was intended to provide insights that can improve all contexts of post-secondary education and will not be limited to strategies that can only be implemented at elite universities. This paper reports on the outcome of that workshop, and provides recommendations for priority research needs in learning analytics that can guide public and private research support in these areas.

## Workshop Motivation: Opportunities and Challenges

Debates about the goals of education and measuring educational attainment are perennial, but the stakes are increasingly high because a growing fraction of all employment now depends heavily on post-secondary education. Universities, however, are not doing an effective job in providing prospective employers with people who have the needed capabilities and competence or providing employers with useful measures of these capabilities (e.g. what graduates can do, not just what they know). Only 11% of CEOs strongly agreed with the assertion that "Higher education institutions in this country are graduating students with the skills and competencies that MY business needs."[1] Two thirds of employers don't ask for college transcripts; firms like Google, EY, and Penguin/Random House have concluded that they aren't a useful measure of future success.[23] The needs of employers are increasingly difficult to measure as the technology-driven economy continually redefines the nature of work. Employers also put a high value on a broader set of non-technical capabilities that are easy to list but usually poorly defined. These include the ability to think critically, to communicate, to participate in group

efforts, to give and receive feedback, and to understand the behavioral, economic, and social aspects of decisions in addition to the technical issues involved. Many of these abilities are integral to the study of the liberal arts, and are often referred to as "21st century skills" or "non-cognitive skills." But skills and competence gained *outside* of formal classrooms are also critical since people frequently change jobs during their careers and strong evidence that talented people often fare poorly in standard instructional environments. Unfortunately, there is little consensus about techniques for measuring competence and 21st century skills, especially those acquired outside of classrooms.

The challenges are clear and merit close attention by employers and educational institutions. New technologies may themselves bring some powerful new tools to the task. New sources of data and new tools for translating data into actionable insights may provide powerful new ways to define and measure needed competence and to evaluate new strategies for building competence. Increasing volumes of information about an individual's competence are available both from activities in educational institutions and in the workplace. These include both what the individual can do and the demonstrated competence in non-technical areas such as communicating and collaborating. There has been massive growth in the use of these tools in business recruitment in recent years, often called "people analytics," but most of the innovation and research has been conducted by private firms and much of the work remains proprietary. Academic research in these areas is urgently needed so that institutions of higher education can become a more effective partner in creating productive career paths. Research is also essential because the dangers of using huge volumes of information about individuals creates unforeseen ways that can it impact their futures. Issues of privacy, the risk of embedding prejudices into algorithms, and many other hazards need careful and open discussion that only academic research can fully address.

While the potential use of data and new analytic tools to address some of the most vexing questions in education is very real, we are still largely in the dark about what can actually be achieved. The following discussion will focus on the potential, what research has already achieved, and the enormous landscape of unknowns. It will focus on the current and potential future use of data and advanced analytics to address three research questions:

1. How can we define the educational outcomes, competencies, and habits of mind that are goals for higher education?
2. How can these competencies be measured and communicated?
3. How can innovations in approaches to learning (technology and pedagogy) be evaluated?

Most of the discussion explores the link between education and employment. This is not to deny that the core goal of education will always be enriching each individual's life by communicating the richness of human cultures and values, building an understanding of the majesty the physical world, and participating in constructive dialogue and debate. But the problems in defining and measuring competence is being driven by increasing percentage of people needing access to higher education for employment, and the growing need to refresh skills and learn new ones throughout a career. Post-secondary education is all but essential for

a prosperous career in the modern world and the institutions that provide educational services urgently need to adapt to these new needs, and to the fact that their services will be needed throughout an individual's lifetime. In 2006, 69 percent of students said that "To be able to make more money" was a "very important reason for going to college" up from 49.9 percent of incoming students in 1976.[4] The need for new approaches is also driven by the fact that about a third of post-secondary spending goes to acquire traditional degrees[5], and only about half of the people in post-secondary education are in a program to get credits for a degree.[6] Forty-seven percent of college students are now more than 24 years old.[7]

# The State of Play: A Brief Review of What We Know

## RQ1. How can we define the educational outcomes, competencies, and habits of mind that are goals for higher education?

Defining the competencies needed by employers is increasingly difficult. Studies of job requirements show a steady increase in the level of "substantive complexity" of jobs (cognitive demand, analytical reasoning, and synthetic reasoning) and an increasing demand for "interactive skills" (negotiating, instructing, persuading, speaking, taking instructions). About half of the increases resulted from changes in employment by industry type and half from changes in demand for different skill levels within industry groupings.[8] The problem is exacerbated by the fact that technology, trade, and other forces are continuously reshaping the workplace and the role that humans play. There is little doubt that most routine tasks will be automated during the next few decades and this may profoundly reshape the employment experience of a large fraction of the population. Three quarters of the fastest growing occupations in the US required some form of credential; half required a BA or higher, and a quarter required a graduate or professional degree.[9] Thirty-four percent of working American adults reported that their occupation had legal or professional requirements for continuing education, and 20 to 30% of people with a high school degree or less have some form of credential or license.[10]

Employers are looking for more than mastery of specific bodies of knowledge or technical expertise. A recent survey of employers found that "Nearly all those surveyed (93%) say that "a demonstrated capacity to think critically, communicate clearly, and solve complex problems is more important than [a candidate's] undergraduate major."[11] Employers have a strong interest in "soft skills" such as integrity, personal initiative, professionalism[12] (Lumina Foundation, 2014). Since the specific skills needed for employment are almost certain to change over the course of a person's career, there is also a clear need to define the foundation needed lifelong learning. An ability to learn quickly, to find information quickly, to adapt, to function in situations of great ambiguity are often much more important than the ability to regurgitate an array of facts.

It is often difficult, however, to get a clear picture of what employers actually need because they seldom provide clear descriptions of competencies actually needed in jobs. This is particularly true of soft skills where terms are vague and the concepts may take very different forms in different occupations.[14] But even technical skills are challenging; expert descriptions of competence are often very inadequate. Since experts are frequently unable to explain how their

> *Employers do a poor job of signaling their needs. They tend to overload their job postings with a litany of hard, technical skills and then sprinkle in some general human skills of communicating well, providing or receiving feedback, or managing other people well. It's not enough for employers to say they're looking for great communicators, critical thinkers, or collaborator*s[13]. Michelle Weiss

own thought processes or the knowledge they actually use in approaching a task. In a recent experiment, experts were asked to write a detailed description of how to assemble a laser, but their detailed description didn't include critical steps which meant that non-experts weren't able to perform the needed assembly. In another case, a video of experts debugging a computer system was compared with the experts' description of what they did. The expert descriptions missed 53% of the problem-solving steps.[15]

An artifact of this inability to define competence in meaningful ways can be seen in the widely varying, and highly changeable links between wages, occupations, and educational backgrounds.[16] It can also be seen in the seeming disconnect between formal degrees and employment, particularly when people change jobs frequently.[17] Between 2010 and 2013, 38% of liberal arts graduates ended up working for internet or software companies.[18]

The need to modernize and rationalize learning goals has launched a number of projects and studies.[19,20,21,22,23,24,25,26,27,28,29] These reports all appear to be in agreement on a key innovation: goals should be specified in terms of outcomes – what the individual actually knows and can do – rather than in terms of inputs such as credit hours or seat time.

Private employers are attempting to improve their definitions of competency using new sources of data and new analytic methods to better understand the characteristics of most effective employees. The Chamber Foundation, an affiliate of the U.S. Chamber of Commerce, for example, has developed a program designed to help businesses articulate their human capital needs to education partners.[30] The "cognitive task analysis" advocated by the Chamber and other groups is extremely complicated and expensive to implement in practice.

The rapidly growing field of "People Analytics" is attempting to use advanced data analytic techniques to address this problem. This community has developed a variety of strategies for both understanding the characteristics of highly successful performers and to trying to identify these competencies in job applicants.[31,32,33] This practice is made possible by the amount of information generated as an integral part of a workplace using modern information processing and communication tools using in most occupations. These data are often supplemented with

data gathered with the explicit goal of tracking employees. A recent review found that employees in a third of firms interviewed had some form of wearable devices to monitor employees.[34,35]

Analytics tools are being applied across a very broad set of competencies, including finding ways to define skills of recognized experts. This has been tried for defining the skills needed to maintain complex equipment and even the characteristics of highly rated professors.[36] The tools are also being used to define and measure desirable competencies in social skills such as the characteristics of effective teams and work groups.[37,38,39]

## RQ2. How can these competencies be measured and communicated?

There are two central challenges for measuring and communicating competencies: the need for (1) measures gathered in a formal learning environment that have a strong correlation with competence in future jobs or courses, and (2) ways to evaluate and credential competence gained outside of a formal learning environment.

Even if educational institutions are able to describe the kinds of competence an educational institution aspires to help their students achieve, devising valid ways of measuring these competencies and communicating these measures is an will be a challenge. Measuring competence requires both a clear definition of the desired competency, a theory about how a person can acquire and demonstrate the competency, and a rich set of information about the way each individual functions.[40,41] While creative approaches have been proposed, they can be challenging to implement at scale and further work is needed to ensure that the results are calibrated and reproducible.[42,43] Proofs of validity are all but nonexistent.

> *In spite of its growing economic importance, our postsecondary education and training system and labor market information systems remain disconnected.*[44]
> Anthony Carnevale

The flaws in conventional test designs are becoming increasingly apparent: “Many existing standardized tools, because they were developed decades ago, are misaligned with contemporary priorities for student learning, not to mention being out of step with modern assessment technology.”[45] One obvious problem is that these tests measure the performance of a person in an environment likely to be experienced only by anchorites -- isolated from external sources of information and conversations with colleagues.[46] Several promising ways of defining “soft skills” have been proposed, including characteristics like “growth mindset”[47], ”intrapersonal competencies” (self-management), and “interpersonal competencies” (communicating and participating). [48] But is has been frustratingly difficult to develop reproducible measurements of these

characteristics or to show how these measurements translate into success later in life.[49]

A metric commonly used in many occupations links competence to a specified number of hours of time on task. However, it is difficult to find any basis in data to justify the numbers chosen and there is considerable evidence for large individual differences in the time required to reach mastery. One commonly cited study concluded that large amounts of deliberate practice are essential for acceptable levels of performance and 10,000 hours is needed to achieve real mastery.[50] Clearly practice and experience are essential to master most tasks, but a recent meta-analysis clearly shows that practice contributes at most 30% to mastery with many sophisticated professions requiring much less. Simple repetition of a process is not enough. The effectiveness of deliberate practice depends on the domain, the "degree of intellectual processing", and the "predictability of the task environment."[51] This is reflected in the US Navy's new personnel policy which now emphasizes that "with a few exceptions, the time-in-grade requirements have been largely removed."[52]

## Some new approaches

Employers are frustrated by the lack of progress. Many have no interest in transcripts and there is growing skepticism about the value of standardized tests, particularly since they tend to favor people able to afford tutors and undervalue people from demographic groups traditionally under-represented in college populations.[53] Large corporations like Ernst & Young and Penguin Random House have lost faith "that success at university correlates with achievement in later life"[54] ; two thirds of employers did not ask recent college graduates for their transcripts.[55] A data-driven study of success in a major corporate sales division found no correlation between success as an employee and the school the candidate attended, their GPA, or references.[56] Many companies using advanced analytic methods were hiring people with a college degree for jobs in technology, high end sales, and management.[57]

> *…the credential landscape is crowded, chaotic, and confusing to individuals, institutions, and employers.*[58]
> Center for Postsecondary and Economic Success

There have always been alternatives to traditional higher education degrees; two thirds of all post-secondary education spending is not being spent to acquire traditional degrees.[59] But there has recently been an explosion of new forms of credentials, and companies are turning increasingly to private recruitment firms instead of relying on information from traditional institutions of higher learning.[60,61] MOOCs, badges, bootcamps, certificates, and a variety of "micro-credentials" are competing for visibility and relevance.[62] For example, the company called Degreed is offering a service where an individual can certify and validate specific skills.[63] The Credential Engine organization has identified "334,000 confirmed credentials in the US

alone" and is developing tools to standardize the way these credentials are reported and the way their quality is evaluated.[64]

Mismeasurement can be extremely expensive. Estimates of the cost of hiring, onboarding, and training a new person range from $4,000- $15,000.[65,66] A number of new firms and higher education institutions themselves have begun offering a variety of new credentials. MIT is considering using blockchain technology to keep track of them.[67] The Western Governors University (WGU) and other universities have attempted to shift from traditional transcripts to credentials that certify clearly articulated competencies.[68] Rivera has developed a sophisticated method for matching data about individuals assembled from the rich set of information now available about individuals to match them to job characteristics. They claim to have reduced the volume of applications companies need to review 33% using their tools and the firms spend 41% less time to find candidates while increasing the volume of deals by 86%.[69]

There is clearly growing interested in a portfolio of credentials that demonstrate specific areas of competence. It is possible that for all but the most elite institutions, degrees will be replaced with a set of "unbundled" credentials (representing competencies) that are constantly being refreshed.[70] The trend is further reinforced by the need to constantly upgrade skills to perform effectively in an ever changing workforce or to move through several jobs during a career (now a typical career history). The challenge, of course, is the proliferation of credentials, the lack of standard definitions allowing comparisons, and the shortage of data validating their value. One central issue is the scale of the credential. College degrees have been a lingua franca for generations, but many have come to believe that the degree has value more because of the skill of the institutions' admissions team than any value added during the course of instruction.[71] On the other end of the spectrum, certification in a narrowly defined skill seldom provide employers with the information they need.

## The potential of data science

Data science may contribute the growing need for measuring competence by providing a set of tools for establishing verifiable credentials outside conventional instructional settings. The central goal for these tools is to provide a method of measurement that is "valid (i.e., assess what they are supposed to assess), reliable (i.e., consistently produce similar results), and authentic (i.e., match similar challenges learners will encounter outside of the classroom—in the workplace, for instance)" If built into a system of learning (as described in the next section) they should also be integrated with learning in ways that improve motivation and encourage social interaction.[72]

Information technology can provide at least a partial solution to the challenge of verifiable credentials by replacing conventional testing methods which rely on written tests or human evaluators. A variety of new technologies have opened the door to innovations that can make it practical to provide measures of competence that can both motivate students and provide a useful guide to future employers (or future instructors). Evaluations, for example, can make use of new tools to provide simulated environments that imitate real-world employment challenges, including such things as the practice of nursing, machine operation, and working with

sophisticated scientific equipment – approaches that would be prohibitively expensive given traditional methods of instruction. But new information tools have changed this equation by supporting continuous evaluation as an integral, and accepted, part of the learning process. Sophisticated computer games, for example, encourage players to move to the next game level only when they have demonstrated competence at the previous level.[73,74] In a well-designed game, players use the knowledge that they are not prepared not as failure, but an incentive to master the skills needed.[75] The games can provide highly sophisticated challenges, including challenges involving teamwork and timely communication. People who may take more time to master some competencies need not be penalized if the goal is to demonstrate real competence. The concept of "freedom to fail" is key in entrepreneurship and is a growing concept in education as well.[76]

Software based simulations of realistic tasks can reproduce many complex work environments in ways that allow individuals to practice complex skill sets, ranging from operating aircraft and other complex equipment, working with a team of nurses in a birthing-room, or exploring the ecosystem of a jungle. These systems can provide multi-dimensional measures of competence in technical areas as well as soft skills such as teamwork and communication under pressure. The core challenge, of course, is to demonstrate that the competence demonstrated in these artificial environments translates into competence in the workforce. This will require gathering and reviewing detailed information from both the simulations and from the subsequent performance of people when they leave the training environments to take new jobs. This will be a daunting and time-consuming challenge but in fairness, analyses linking conventional grades and test scores to job performance are not particularly impressive.[77]

The Department of Defense has used flight simulators and other tools with a great deal of success for many years (U.S. Army Program Executive Office for Simulation, Training, and Instrumentation, 2012). In many cases the simulators are far superior to actual field experience when safety considerations greatly limit the scenarios that students encounter. In most simulations, successful or unsuccessful demonstration of competence is immediately clear to the student and an integral part of the experience. Records of the exercises also provide a good tool for a "debriefing" discussion that can have enduring results.

Simulation based assessment is also being used effectively in a number of medical fields.[78,79] Experience has shown that "...once technology advances to the point that real tasks can be accurately simulated, truly demonstrating competence becomes an indispensable part of effective evaluation. Directions in credentialing indicate that it will eventually be more meaningful to actually demonstrate competency than to provide a surrogate for competency".[80]

Simulations, including multi-player games, are also being used to teach and evaluate non-technical skills, such as participation in teams, cultural sensitivity, physician-patient conversations, and preventing sexual harassment (USC Institute for Creative Technologies). In some cases the simulations can take the form of working with simulated patients (virtual or manikins) or simulated surgical equipment. Evidence of performance takes the form of readings from simulated monitoring equipment and videos of individuals performing a variety of tasks.

Skills in these cases are now measured with human observers. Would it be possible to extract meaning using some automated process? Could an automated evaluation provide constructive feedback during the learning process even if the final evaluation must be performed by human observers? Would it be possible to learn from tools developed by computer game designers to determine whether a player has mastered the skills needed to move to the next level of the game?

The challenge of finding a way to certify competence created outside of formal institutions of learning may also be addressable using new tools. The rich set of data on employee activities described earlier can provide much of the information needed to validate the competence of individuals. A number of organizations are offering "Prior Learning Assessment" tools for converting work experiences into a convincing resume. [81] There has always been concern about fraud[82] but the federal government has been actively searching for solutions, particularly for turning military experience into credentials[83] (White House, 2012).

## RQ3. How can innovations in approaches to learning (technology and pedagogy) be evaluated?

New information technologies open many new opportunities for building competence and have driven a wide range of experiments. These experiments include how information can be conveyed – using video, simulations, augmented and virtual reality, games, and other tools; the role that instructors, counselors, and other specialists can play; and, how the overall instruction is managed (e.g. multi-modal learning, flipped classrooms, peer evaluation).[84] Such experiments may play a key role in radically redesigned approaches to higher education where apprenticeships and other methods are used as an integral part of a lifelong educational experience. These opportunities have spawned an enormous international market, much of it not a part of conventional instructional institutions. In 2018, global spending on education technology was over $16 Billion -- of which 44% was spent in China, which surpassed the US in education technology spending for the first time. Growth was particularly rapid in use of Artificial Intelligence and gaming.[85]

Most business sectors have seen market forces transform their business models to make full use of new information technologies, but markets in education are dramatically different. The complex mixture of public and private investments in education, and their unique mix of public and private benefits, has created a dramatically different dynamic. The earlier discussion reviewed the difficulty of measuring the quality of educational attainment, which reduces competition between institutions and provides little incentive for innovation. Further, traditional regulation and funding is tied to a traditional models of degrees and course completion, although competency-based programs are making some progress.[86,87] There have been some efforts to invent new, incentive-based business models in higher education, such as the Purdue experiment where students agree to repay the university with a fixed percentage of their income for a fixed number of years after they graduate.[88]

Even if there were clear metrics of educational success, few post-secondary institutions have the resources needed to make full use of the new technologies needed for measurement. The technology-driven investments in markets like business services, entertainment, and retailing, required huge investments and fundamentally new business models. A major computer game production can, for example, involve a 700-person team and cost $400 million to complete[89] (Theodore, 2017) – orders of magnitude more than even the largest course development. Game developments require huge investments in testing and recrafting systems to ensure that the games are compelling and not unintentionally confusing. This kind of investment appears unreachable for education despite the size of the post-secondary education.

In spite of these limitations, there is compelling evidence that the new tools can dramatically improve the quality and reduce the cost of learning if they are carefully designed by a competent team. Some studies have provided hints that new systems can cut learning times 24-54% without sacrificing quality.[90] Bowen conducted a carefully constructed randomized trial comparing a hybrid (computer training with some classroom time) system for learning statistics compared with standard classroom instruction.[91] This project showed that student outcomes were the same regardless of the nature of the content delivery condition, although the hybrid course cost 67-75% less per student. Other work has shown that skills gained in simulation-based training transferred successfully into real skills on the job.[92,93] Simulations can cost much less than traditional classroom approaches and let students experience a far wider range of experiences – including emergency situations that someone on a job may encounter very infrequently.

Education technology generates an enormous amount of data that can be captured – including what materials an individual watched, how they behave in simulations and games, and how they communicate with each other and instructors. But extracting useful information from this heterogeneous data is difficult.[94] All too often this results in unused or poorly used "dangling data"[95]. It is clear that powerful statistical tools will be needed[96,97] to manage data of this scale and complexity. Machine learning, for example, may prove to be useful in both identifying skills actually used in the work environment and assessing them in a learning environment.

A number of groups are developing programs that use the extensive information developed by learning technology systems to continuously improve the methods of instruction as well as tracking student progress. Carnegie Mellon's Open Learning Initiative has developed powerful tools for tracking students against learning objectives and sub-objectives, and uses learning curves and other information to continuously improve their instructional systems.[98] Pearson has developed systems that use extensive data and analytic tools to analyze learners using a product through its life-cycle. This includes research that can lead to effective designs, exploratory data to improve the product during development, and validating data gathered when the product is used by larger numbers of people.[99] McGraw Hill's ALEKS program (developed originally with NSF funding) uses artificial intelligence methods to continuously evaluate student progress.[100]

The tools used to assess an individual's approach to a desired level of competence can also be useful in measuring an individual's emotional state, motivation, or other factors that would be useful to the people (and software) involved in instruction and counseling.[101] Tools are being

developed to understand how existing data from students can tailor instruction to increase the likelihood of success for the widest range of students.[102] Civitas Learning collects this data to provide "holistic advising."[103] Hobson's Starfish platform (which NSF funding helped to launch) uses data for "enhanced case management tools, predictive analytics, student support integration and academic planning."[104]

In spite of their growing sophistication, most of the analytic methods used to evaluate new methods of instruction focus on meeting "learning objectives", which, for reasons discussed earlier, are largely generated by instructors. The impact of the innovations in instruction on actual on-the-job performance is almost completely unmeasured. The Department of Defense has struggled with this problem for years .[105] One recent analysis notes that "Unfortunately, many current measures of training success rely upon subjective assessment by instructors, and personnel readiness is often determined in terms of time (e.g., flight hours) and qualification tasks."[106] One notable exception was a recent DARPA project, which was unfortunately expensive. Defining the actual competencies of the best repair technicians, developing a sophisticated intelligent tutor, and carefully comparing the actual performance of trainees with skilled and experienced personnel cost $40 million. However, it cut the time spent training shipboard IT systems personnel in half. In a careful assessment of the graduates, people trained on the new system not only attempted more tasks, and more difficult tasks, but succeeded at a much higher rate. The project was built around an extensive analysis of the behaviors of the most highly rated technicians with years of experience in the field.[107]

The medical profession has also made extensive use of simulation and invested in some sophisticated assessments.[108,109] A major statistical analysis conducted by the National Council of State Boards of Nursing which concluded that there is "…substantial evidence that substituting high-quality simulation experiences for up to half of traditional clinical hours produces comparable end-of-program educational outcomes and new graduates that are ready for clinical practice."[110] A number of companies are beginning to examine the effectiveness of their own instructional practice, and firms like Rivera are investing in systems that clearly have the potential to explore the links between new approaches to instruction and demonstrated on-the-job performance.

# Looking Forward and Recommendations

Post-secondary education is increasingly important for prospering in a modern economy and for the success of the economy itself. Technical changes and globalization are rapidly changing the competencies needed for success, and the rate of change is likely to accelerate. At the same time, technology is driving innovation in education including the use of data and analytic tools to guide instruction. However, the pace of change has far outstripped the ability of the research community to support these innovations, to explore their impact and utility, or to prepare us for potential liabilities in privacy and other areas. Meeting this challenge has become a core priority for publicly supported research. The earlier discussion reviews both what is known and the landscape of unknowns – unknowns where ignorance could lead to many missed opportunities and potential perils.

In the ***near term,*** it will be possible to design an aggressive research program that draws on the expertise of many different academic disciplines including education research, data science and analytics, and subject matter experts, including technical fields, social sciences, and the humanities. This program should also be designed to forge stronger partnerships between academic research and the rich array of research being undertaken by private investors. This partnership should include firms interested in understanding the competencies they need now and will need in the future as well as firms providing "people analytics" and other services designed both to help define needed competencies and to identify these skills in potential recruits. Two issues lie at the core of the needed research: finding a way to identify the competencies actually needed in a complex and rapidly changing economy and finding a way to measure and communicate the competencies individuals actually embody. Among other things, these metrics are essential for driving innovation that actually represents progress.

> We must move away from the industrial model that has been in place for well over half a century, where we bring new recruits in, give them the vast majority of their technical training in the accession pipeline, and then send them out to start their career path.
>
> Commander, U.S. Fleet Forces Command

There should also be a sharp focus on the host of ethical questions raised by such systems – both research and operations – that rely on enormous volumes of data about individuals.[111] Key questions include: How can research proceed, for example, without compromising the privacy of individuals? How should data be protected? How can we ensure that the systems meet both legal and social standards?[112,113] Can student records be structured like medical records where each individual has complete control over whether the data can be used by practitioners (teachers, physicians) for the individual's benefit, or by research teams trying to develop improved products? The NSF supported Asilomar conference in 2014 helped spotlight the most vexing issues in data privacy, and developed six principles that should guide privacy policy in education: "Respect for the rights and dignity of learners; beneficence; justice; openness; the humanity of learning; and continuous consideration of the ethical dimensions of learning research."[114]

Artificial intelligence and machine learning methods used in education raise their own set of problems. Will these systems inadvertently absorb biases and prejudices lurking in historic records? For example, if history shows that women are consistently promoted more slowly, will the machine learn to be biased against hiring them? A number of groups are working on these issues and having some success in identifying and removing problems like gender-based bias in recruitment.[115]

In the ***longer term***, research should consider how to support potentially dramatic changes in the way education and work are connected. The model of spending 12-20 or more years accumulating knowledge at the beginning of a career and then coasting on this knowledge for a lifetime is unlikely to survive the coming decades. Careers are much more likely to consist of a

series of work and learning activities, and the cumulation of a variety of credentials that will be a blend of formal degrees with certificates and competence demonstrated during a work career.

Apprenticeships and other intentional work-related programs of education have, of course, been used for decades. But there is growing interest in exploring new ways of combining work, formal education, and training. For example, Northwestern has been building on more than a century of experience with integrating apprenticeships with instruction.[116] The UK has an ambitious program in new apprenticeships, including an "apprenticeship levy", and global companies like IBM and Amazon are developing their own programs.[117]

The US Navy has an explicit policy of moving away from a system which tries to provide all training before deploying sailors to operational positions. They note that many skills atrophy if they are not put to use soon after the instruction has taken place. Their "Ready, Relevant Learning initiative aims "... to provide a continuum of training over an entire career that gives Sailors the knowledge and skills they need when they need them, rather than over-training too early."[118]

Simulations are increasingly providing a hybrid of formal instruction and workplace experience. Drawing on the technology underlying multi-player games and artificial intelligence, these simulated experiences have the potential to mimic many workplace experiences – including both technical and social aspects. A study of simulations in healthcare concluded that "...once technology advances to the point that real tasks can be accurately simulated, truly demonstrating competence becomes an indispensable part of effective evaluation. Directions in credentialing indicate that it will eventually be more meaningful to actually demonstrate competency than to provide a surrogate for competency."[119] While extracting valid, reproducible data from these systems may be difficult, new voice and image recognition may be able to extract sophisticated measures of competence by observing how individuals actually perform in a variety of circumstances. These could provide a reproducible way to measure and communicate actual job-related competence in ways that might, among other things, substitute for standard certification examinations.

As many innovative "people analytics" firms have learned, supporting this new reality will require: analysis of the competencies provided by formal education, analysis of competence gained on the job, analysis of the competence that firms should be trying to recruit, and possibly the competence demonstrated in simulated environments. The tools needed to understand the characteristics of successful employees in a dynamic economy will be similar to the tools needed to develop performance metrics for education.

While privately funded research has made major advances, the public benefits of research that can manage a transition to new approaches to defining, measuring, and building competence is essential. An ambitious and well-designed program of research has become essential.

Priorities include:

- ***Strong partnerships***: The research must be designed to draw on multiple academic disciplines and to close the gap now separating public and private research work.
- ***Explore competencies demonstrated in educational and non-educational settings***. Work to define the skills actually needed in different occupations, and ways to track changes can lead to improved definitions of competencies and help convert competence gained at work with academic credentials.
- ***Validated credentials***: The Carnegie Foundation found a way to encourage standardization of degrees and credit hours a century ago, but this has proven inadequate given the explosion of other credentials. One obvious need is a way to validate credentials by demonstrating their value in real-world conditions.
- ***Privacy, and Security***: Privacy and security of personal information must be a core element of any research and participants must be aware of how their data will be used. Data is, however, essential for valid research in this field. Methods such as differential privacy are becoming available that can make it possible to conduct research with large data sets while protecting individual privacy.
- ***Careful use of artificial intelligence*** Machine learning will play a key role in defining, measuring, and building competence but care must be taken to avoid it's dark side: the very real possibility that the data used to train the system is burdened by biases that could be incorporated in the new tools or their applications.

A research program capable of meeting these ambitious goals will not be easy to design or implement. Among other things it will require moving away from the comfortable distinction between education and training, STEM and the liberal arts, analysis of learning in formal education and work, to understand how the modern workplace actually operates now and in the future. This research program will necessitate collaboration and data sharing between industry and higher education. But it is hard to find any set of research issues that are more important as we hurdle into a world where continuous learning is essential to individual and national prosperity.

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