

MOOCs: A Perspective from the Learning Sciences

Michael Eisenberg and Gerhard Fischer
Department of Computer Science and Institute of Cognitive Science
University of Colorado, Boulder USA
duck@cs.colorado.edu, gerhard@cs.colorado.edu

Abstract: Massive Open Online Courses (MOOCs) have—with astonishing rapidity—become a formidable presence in global education. Such courses have obvious strengths in their ability to convey (usually lecture-based) content at extremely low cost to widespread, and often underserved, student populations. At the same time, MOOCs, for the time being at least, reflect traditional (and often contested) values in education: the default assumption for a MOOC is that a teacher or professor will present facts or interpretations, record these as video or slide presentations, and convey them to an extensive audience of (usually individual) students. This paper addresses the default assumptions of MOOCs in the light of two decades of research in the learning sciences, focusing on themes of collaborative work, embodied cognition, and both the limitations and opportunities of learning analytics. With these themes in mind, we suggest paths for research and exploration into the next generation of MOOC design.

Keywords: MOOCs, collaborative learning, embodied and extended cognition, isolation problem, shop-oriented MOOCs, learning analytics

Introduction

To anyone who has been attentive to global education over the past several years, the importance and explosive growth of *Massive Open Online Courses* (MOOCs) is both striking and undeniable [Scientific-American, 2013]. Arguably, MOOCs—or, more generally, the advent of online education—can be viewed as the most urgent subject for discussion in the learning sciences for the coming decade. There are, unsurprisingly, dozens of controversies and unresolved issues [Daniel, 2012] regarding such courses: (1) whether they are destined to grow in impact or (alternatively) whether their importance is overrated, and a symptom of media "hype"; (2) whether they represent an improved or cheapened educational experience; (3) what effects they may have on the structure and future of residential universities; (4) how their impact might vary across dimensions of geography, of demographics (are MOOCs as important for elementary education as for undergraduate education?), and of discipline (are MOOCs more easily designed for technical material?).

The state of the art in online education is both relatively short-lived, and fluid; generalizations made about a "typical MOOC" today are liable to be out of date in a matter of weeks or months. Recent technological history should be a chastening experience in this respect: it is not hard to find statements made about the nature of personal computing in (say) 1977, or about the importance of the internet in (say) 1995, that upon reflection embarrass their authors. Even with this caveat in mind, however, it is important for those in the learning sciences both to reflect upon and to attempt to shape the development of large-scale online education; and we have no choice but to make the attempt in real time, as events unfold. For the purposes of this paper, we begin by noting that despite the novelty of the transmission channel, in many respects MOOCs tend to represent a highly traditional portrait of education, in which a teacher or professor delivers lecture-based material to a (relatively passive) audience of students. This portrait of a "typical course" is hardly unusual in most universities, as can be seen by attending a standard introductory-level course in calculus, or chemistry, or Western history. At the same time, this traditional portrait has been challenged in numerous respects by various communities in the learning sciences over the past two decades. Such notions as collaborative learning [Koschmann, 1996], embodied and extended cognition [Dourish, 2001], and constructivist learning [Johnson, 2010] are staples of learning sciences research, but in many ways they run against the grain of what, for now, could be called a traditional lecture-course structure for course design. In residential universities, the limitations of lecture courses are often addressed through creative strategies such as "flipped classrooms", intensive recitations or tutorials, and study groups; these strategies not infrequently employ MOOCs or online lectures as components. Still, in contrast, a stand-alone MOOC outside a residential setting (based as it is on "pure" traditional lectures) might find these strategies tricky to implement. In other words, while both MOOCs and residential universities might employ the traditional lecture-to-passive-students format for education, the residential settings are able to experiment with alternatives or additions that are harder to implement in a purely online format.

Background

This paper is intended to "take a step back" and discuss the current limitations and potential progress of MOOC design from the perspective of the learning sciences. It is thus intended as a complement, or counterweight, to many other accounts that discuss the subject from an *economic* perspective (scalability, productivity, low cost) [Bowen, 2013] or the *technological* perspective (platforms supporting large numbers of students in online environments, enrichment components such as forums, peer-to-peer support, automatic grading) [Kolowich, 2013]. Our perspective is derived from our own research over the past two decades in creating computational environments for learning, incorporating notions such as collaborative, embodied, and extended cognition [Arias *et al.*, 2001; dePaula *et al.*, 2001; Eisenberg & Eisenberg, 1999]. Our interest is also intensified by a newly-begun (arguably quixotic) project in which one of the authors is attempting to create an unorthodox MOOC based as much on the format of a reading seminar as a lecture course. With these experiences as both foundation and motivation, we discuss *the challenges to incorporating learning sciences research within MOOC design*, and we outline several *promising directions* for integrating the work of the learning sciences with the near-term future of large-scale online education.

Collaborative Learning in the Context of MOOCs

One of the notable features of MOOCs is their flexibility from the standpoint of the student: in general, an online course can be taken from any Web-enabled site around the globe, at any time of day, in any setting. This advantage of flexibility is accompanied by a concomitant problem of isolation: many, perhaps most, students of MOOCs are placed in a situation in which they are taking a course without the immediate presence of a roomful of classmates. As a result, it is tricky or effortful for MOOC designers to incorporate elements of collaboration or group work in a MOOC: one can use online tools such as student blogs, chat sites, shared documents, and so forth for these purposes, but they require additional effort on the part of both the professor and students beyond the natural affordances of the physical classroom.

A significant thread in learning sciences research over the years has in fact focused on the characteristics of successful (or sometimes, unsuccessful) collaborative learning. Without attempting a summary of the extensive literature, suffice it to say that there are situations in which problem solving can be facilitated by conversation [Roschelle 1992]; in the same vein, the literature of self-efficacy theory in education takes note of the potentially positive role of "vicarious experiences" in which a student benefits from watching the techniques of a successful colleague [Bandura 1997, p. 86 ff.]. Beyond these considerations, group work allows for creativity from the professor's standpoint: in many disciplines there are challenging projects or assignments that are most naturally undertaken not by a single student, but rather by a small group or team [Fischer, 2011]. Collectively, these considerations suggest that there is an essential tension between the default structure of MOOCs and the potential advantages of student collaboration. (For fascinating reflections along these general lines from a "MOOC practitioner", see also [Downes 2012, p. 503 ff.])

All of this suggests that there is a strong incentive for applying the lessons of learning sciences research to the "isolation problem" of MOOCs. Some of the natural avenues for work are incremental: finding modest, realistic means of enhancing Web-based tools for collaborative student work and real-time conversations over a distance. Just to take a representative example: it is well-known that the simple act of pointing to an object as a focus of conversation plays an important role in human learning. (Indeed, Tomasello [1999] among others argues that pointing is a fundamental act differentiating human culture from that of other primates. For a recent study of the role of pointing drawn from mathematics education, see [Alibali & Nathan, 2012].) Pointing is, of course, a natural act for two humans in conversation working at a lab desk, but it can be an unwieldy operation for students conversing at a distance, particularly when the object being referenced is a physical entity, not on a computer screen. Conceivably, then, a learning-sciences-motivated research effort could be undertaken in which a user (call her "Alice") can point to a physical object present in the space of a second user (call him "Bob") through the use of a remotely-operated robotic hand. Roughly, the image here is that Alice can use some type of glove-like input device at her site to manipulate a robotic pointing output device at Bob's desk, enabling her to point directly to (say) a misplaced wire on a breadboard or a troublesome spot in a mechanical construction.

Other possible research projects might be a bit more futuristic or far-fetched, but nonetheless plausible. Conceivably, for example, individuals could advertise their services not as local *tutors* for course material, but as local *colleagues*: people whose job it is to learn alongside a student and act as a "sounding board" for conversations and lab partner for projects. Such people could, in effect, specialize in joining others to take courses [Fischer, 2013]; the skills required of a successful "co-learner" might, over time, come to be seen as comparable to (but distinct from) those of a successful teacher or student. Still another possibility, along these same lines, would be to design artificial, computer-based colleagues (again, in contrast to the tradition of work in computer-based tutors [Anderson *et al.*, 1995]); that is, the intent would be not to create computer-based presentations of existing material, but rather to create (where achievable) computer-based "learning partners" [Choua *et al.*, 2003] whose role would be similar to those of the hypothetical human specialists just mentioned. The purpose of an "artificial colleague", then, would be to provide at least some of the benefits of real-time

collaboration (e.g., by assisting in problem-solving, note-taking, finding resources related to lecture material, and so forth). This, too, would represent a potentially interesting novel direction for the learning sciences and artificial intelligence: indeed, in some ways, it may in fact be more achievable (and more useful) to create a working artificial *student* to accompany a human learner, rather than an artificial *teacher*.

Weaving Embodied and Extended Cognition into Online Education

Perhaps the most vexing and fundamental problem associated with MOOCs (and arguably with online education in general) is the overwhelmingly "virtual", screen-based nature of the presentation channel. Screen-based education seems to lend itself fairly naturally to the recording of lectures, along with slides, text, audio, and video; it can also, to a fair degree, accommodate text-based exchange of information (as in student blogs or email), and audio or video conferencing. All of this, in combination, makes for a powerful medium that can be tailored to the presentation of a wide variety of course material: one could imagine well-done introductory courses in history, philosophy, computer science, and English literature developed along these lines. In general, the types of courses that one associates with large lecture rooms on college campuses ("Calculus 101") seem to lend themselves reasonably smoothly to translation into MOOC form.

A recurring theme heard from critics of MOOCs in higher education, however, is that there are many courses that *do not* fit especially well into this mold. What about, for instance, lab courses in physics, or organic chemistry, or cell biology? All the equipment, staffing, materials, safety precautions, and so forth are parts of *physical settings* for learning experimental science; what happens to those elements in the MOOC format? Can one possibly learn experimental natural science exclusively through an online medium? For that matter, what about field trips in domains such as geography, or paleontology, or archaeology? The very essence of MOOC education is precisely that it is *indifferent* to settings; one can take a MOOC anywhere, at any time, all over the globe. But a physical geography course takes on a different character if it is held in (say) Buenos Aires, or Minneapolis, or Hong Kong. To raise yet another issue, what about the example (so often mentioned by college faculty) of seminars or small-scale conversation? Is it possible to convey, through online form, anything like the value of a group of committed students sitting around a table [Arias *et al.*, 2001] discussing a work of literature, or a philosophical argument?

The difficulty of bridging the gap between MOOCs and the wide range of models (beyond the lecture hall) of undergraduate education connects with several running themes and traditions in learning sciences research. One natural place to start here is with the twinned themes of *embodied and extended cognition* [Dourish, 2001; Menary, 2010; Clark 1997] In the context of this discussion the two themes, though distinct, have shared pedagogical implications. Extended cognition characterizes cognition and learning in the presence of external artifacts—for our purposes, such artifacts might include lab equipment, shop tools, sports equipment, and so forth. To the extent that learning chemistry takes place through the use of pipettes, burettes, and separation funnels, it would be difficult to teach "true" chemistry exclusively via video, in the absence of such equipment. Embodied cognition characterizes cognition and learning as an activity of the entire body (often with a disproportionate focus on the hand), which again implies the importance of pedagogical tools and settings. To the extent that learning how to observe an infant in the laboratory is a matter of posture, tone, and "body knowledge", or to the extent that learning to shoot a basketball is a matter of information beyond the purely verbal, it seems unlikely that video will be a sufficiently expressive medium; this is why we have lab apprenticeships and sports coaches.

If the very real, but very specific, advantages of MOOCs are to be enriched beyond the context of lecture hall material, it seems imperative that learning scientists work with designers to incorporate the findings of extended and embodied cognition research into novel artifacts and settings. We might begin this process by reflecting on some exemplary disciplines. Is it possible to teach a student to conduct a safe laboratory experiment exclusively via online communication? Or to operate a drill press? Or to shoot a basketball? Or to give a haircut? If not, why not?

On the "*extended cognition*" side of these questions, we might ask (among other questions) just how much it is possible to replicate or simulate the presence of physical tools in MOOC-accessible settings. Perhaps it would be feasible to augment online communication with desktop 3D printing so that at least some implements could be output in physical form at the student's site. Admittedly, this would be only a very partial, or stopgap, means of addressing the absence of laboratory equipment: desktop 3D printers at present output objects in limited materials (typically plastic) and of small size (no more than about a cubic foot). Still, the ability of students and staff to communicate via transmission of physical objects would be an important extension to a strictly screen-based medium. The role of learning sciences research in such an effort would be to understand just *how* important, or meaningful, such an extension might be, and to direct design research whose goal is to move beyond the current limitations of educational desktop 3D printing.

There are other ways of addressing the "laboratory gap" in MOOC education beyond the purely technological. The growing "maker movement" [Anderson, 2012] of amateur, hobbyist, and student construction is increasingly associated with a burgeoning network of physical sites—"makerspaces", or "hackerspaces"—in

which participants (usually for a modest fee) can make use of physical materials and equipment for their own projects. Combining the presence and growth of settings such as these might allow for extended versions of "shop-oriented MOOCs": for instance, one might create a course that includes "shop videos" whose intent is to be shown and followed in a local makerspace setting. This would represent a strategy of *infrastructural* rather than purely technological design—creating accessible educational settings that are distinct from schools or universities (or even school laboratories) [National-Research-Council, 2009]. The role of the learning sciences here would be to understand and enhance the learning process in such settings. Much as learning scientists have studied processes of social learning, language-making, and domain-oriented dialogue in schools (for particularly provocative foundational discussions in a vast literature, see for instance [Brown, 1992] and [Schoenfeld, 1985]), there would be a necessity to understand the adaptation of these ideas to makerspaces, with their greater emphasis on physical construction.

More important, at least in the near term, it would be useful for the learning sciences to pay increased attention to the educational dimension of the maker movement itself, as it currently exists. For those children and undergraduate-age students who participate in "Maker Faires" and similar events, what sorts of projects are they doing? What content are they learning (and how does that content contrast with that of traditional schools or universities)? What are the means by which learning takes place, and how can (or can't) these be integrated with MOOC design? By understanding the educational dimensions of the burgeoning "DIY" culture, the learning sciences can direct attention to precisely those aspects of "hands-on" learning that for the present seem to elude MOOC-based education.

As to the *"embodied cognition"* side of this discussion, there are again a variety of approaches—technological and infrastructural—that could enhance MOOC design. On the one hand, we could see a vast expansion of innovative wearable or body-based devices for communicating with computational systems. A MOOC student who can make use of a data glove, or a device like the soon-to-be-marketed MYO (with input derived from large-scale arm movements; <https://www.thalmic.com/en/myo/>), or sensors placed on arms and legs, might be able to take effective online courses in violin, painting, or how to throw a curveball. There are vast unexplored regions for the learning sciences in integrating an understanding of such devices into cognitive models and educational design; indeed, the increasing popularity of MOOCs might well spur a new round of input techniques and body sensing that could only be accomplished with the assistance of a rich theory of embodied cognition. We could imagine the use of these new-generation devices being employed to create MOOCs for (currently) unexpected subject matter: an online system, equipped with the right sort of input device, might be able to help a student wield a paintbrush, or conduct an orchestra, or titrate a solution, or grip a tennis racket.

There is an infrastructural side to the "embodied cognition" dimension of this discussion as well, focusing on the integration, within MOOC education, of settings for full-body interaction. Conceivably, MOOCs might be tailored to work with local science museums, with participating playgrounds, or with national parks. For example, a MOOC on the subject of geology might include a "general component", not specific to any location, and consisting of standard online material; and it might be augmented with a localized component tailored to the proximity of specific public parks or spaces. Again, this represents new questions for the learning sciences to explore in order to make courses of this type meaningful for the students: what makes for an educationally useful (or memorable) field trip? How should one structure these trips? (Are individual visits to, e.g., public national parks worthwhile, or should these visits be done in groups, and, if so, of what size?) How can one tailor the structure of these courses to international settings [Lewin, 2013]?

The essential point in this discussion is that, without the participation of researchers who understand the role of gesture, physical surroundings, and full-body movement in learning, MOOCs are destined to be highly cramped, constrained media of education. Designers of online courses need the learning sciences to create worthwhile experiences; and learning scientists can use the MOOC phenomenon as a source of new research and design for exploring embodied and extended cognition.

Learning Analytics and the Challenges to a Truly Worthwhile Online Education

One of the most interesting aspects of MOOC education is that it affords researchers access to large data sets of student choices, behavior, and responses. *Learning Analytics* (with its own society (<http://www.solaresearch.org/>) and its own conference series (<http://www.solaresearch.org/events/lak/>)) focuses on the way in which researchers can study the order in which students understand particular concepts or material, the patterns of errors that they make in answering questions, the portions of lectures that they watch (or re-watch) in their studies, and so forth. These questions have antecedents in the literature of computer education (e.g.: in intelligent tutoring systems), but what is novel about MOOCs is the sheer volume and variety of the data sets: it is now possible to study the learning behavior of thousands of students on specific questions, where before it would have been effortful to derive similar data sets for dozens of subjects. The large numbers of students also allow statistical analyses of students' behavior "broken out" by factors such as age, geographic region, socioeconomic status, prior educational experience, and so forth.

The growth of MOOCs, and the associated growth of techniques for learning analytics, poses interesting philosophical challenges for the learning sciences. We can begin by asking whether this data is in fact what people interested in learning really *need*? To what purpose will the data be put? For instance, if the goal of education is to ensure that students make fewer errors in answering questions, then learning analytics can clearly be put to that purpose. Certainly "making fewer errors" is *one* goal of education—everyone would prefer to answer questions correctly—but is it an important or primary goal? Likewise, we might use the patterns of a student's answers to speed up or slow down the pace of a course. No one would object to this practice, but is it the foundational issue facing the learning sciences?

To put the matter another way: even assuming that all the currently envisioned benefits of learning analytics are eventually realized in full, it is not at all clear how much students' educational experiences will be improved. This is an empirical question, but it is at least arguable that a better-paced course with fewer errors made in answering questions will make only a modest impact on the educational issues that matter most to human beings.

There is actually a *cautionary* note here for the learning sciences. It is conceivable that the growth of MOOCs will result in a narrowing of the portrait of the learner necessary for educational improvement. That is, the "learning sciences" might become increasingly the study of very large patterns of data in answering questions or viewing video segments; such study would increase insight in some dimensions while suppressing it in others. We might find that the learning sciences pay less attention to the idiosyncratic, necessarily individual patterns of interest growth [Csikszentmihalyi, 1990]; or that studying anthropological factors in education (family dynamics, peer pressure among teenagers, how close friendships influence the development of academic interests, and so on) is increasingly "under the radar" of the sorts of large-scale data collected by MOOC enterprises. If we want to answer more biographical questions about education—such as: What is it about certain settings that makes them inspirational for children? What kinds of experiences do children have with handheld mathematical puzzles? Why do adolescents sometimes admire peers who actively spurn intellectual activity? Why don't some children ever read for pleasure?—then we have to energetically pursue a type of learning science that goes well beyond the content of learning analytics, at least as that field is currently envisioned.

There might be still other ways in which this tension between the "big data" style of MOOC research and the "biographical", or "narrative" type of questions described here could be alleviated. One might, for example, design novel types of online education created expressly to be addressed to "best-friend pairs"; that is, the "student" unit in this scenario would be a pair of close friends working together. Or MOOCs could be designed to be used by a family, or group of buddies at a lunch table, or the population of a neighborhood. In scenarios of this sort, we could imagine the powerful techniques of learning analytics being turned to investigate the behaviors of friends or families or close-knit groups. Large quantities of data could be gathered on how families interact with course material, or how peer groups support (or suppress) learning, or how friendships evolve in the presence of intellectual challenge; the data gathered in this way might be unavoidably limited, but nonetheless point toward new questions for ethnographic observation. MOOCs could thus be tools for (at least some measure of) anthropological inquiry, and not merely a tool for massive-scale abstract cognitive modeling. This discussion returns us to some of the ideas of the earlier discussion on collaboration, and "going beyond the individual student"; the techniques described above for encouraging collaboration could also be augmented by large-scale means of data collection and analysis.

Some Closing Reflections: the Learning Sciences in Changing Times

Learning science, as an academic enterprise, is approximately 20-25 years old; though young, as scientific disciplines go, it already has an identifiable history. The origins of the learning sciences, as we understand them today, are traceable in cognitive science, developmental psychology, and computer science in the second half of the twentieth century. It is fair to say that the learning sciences have, throughout this period, been closely interwoven with an understanding of the technology of the moment. The very ideas of cognitive modeling, intelligent tutoring, identifying problem-solving strategies, and the like emerge from metaphors closely associated with computation and information processing; the tools and innovations most closely associated with learning sciences research tend likewise to be computational systems and languages.

The technology of the moment, in education, seems increasingly to lean away from classroom instruction and toward online instruction, particularly in higher education. In some ways this is a promising shift—it might herald democratized access to high-quality education, and a vast increase in numbers and diversity of committed students. At the same time, there are presently clear limitations of MOOCs as means of human communication. One could of course point out (and many do, persuasively) that there are substantial limitations to conventional classrooms or lecture halls; but the rapid advent of MOOCs compels us to reconsider all these limitations with fresh eyes. The learning sciences, by focusing on several of these limitations—of isolated individuals as students, of screens as media of embodied learning, of learning analytics as portrait of data collection—can help us re-imagine a technological landscape for education that moves beyond the emerging

portrait of higher education: (1) Techniques that foster *in-person conversation and collaboration*; (2) artifacts that increase (e.g., through gesture, or direct physical fabrication) the *expressiveness of online communication*; (3) infrastructure that respects the processes of *learning "through the hands" or "through the body"*; and (4) an attention to *anthropological and individual biographical data* in addition to the massive population-level data collection associated with MOOCs—all these are suddenly urgent tasks for the learning sciences, where they may have seemed relatively peripheral before.

A profitable way to approach these questions might be to step back and re-examine fundamental questions associated with our field in the light of new technology. When we speak of "the learning sciences", what portrait of learning do we have? What comes to mind? One interesting division is between "learning *about*" and "learning *to be*" [Brown, 2005]. To learn *about* is to focus on the accumulation of intellectual capital, organized into a curriculum that stresses the communication of culturally central theories, facts, and skills [Hirsch, 1988]. A curriculum of this sort is most naturally structured as a sequence (ideally, a fine-grained sequence) of educational objectives; and the methodology for "learning about" is frequently linked to the introductory lecture-hall style of delivery, augmented with readings, problems, and tests. In short, when we think about "Calculus 101" or "American History 101" we are drawn into a portrait of "learning about" as an objective for education.

In contrast, learning *to be* is to focus less on teaching mathematics, physics, or history, and more on what it means and takes to be a mathematician, a physicist, or a historian (or, for that matter, a "Wikipedian", skier, or surfer). Education in the "learning-to-be" mold centers on engaging students in personally meaningful problems, encouraging teachers to model problem-solving activities in front of or alongside their students rather than lecturing (cf. [Schoenfeld, 1985]), and enculturating students into communities of practice or professional behavior (cf. [Nash & Shaffer 2011]) via techniques such as "legitimate peripheral participation" [Lave & Wenger, 1991]. In the context of this discussion, the current limitations of MOOCs (and the need for learning science research) could be characterized as enhancing the ability of new modes of education to foster "learning to be" through conversation, varied communities, physical activity, participatory settings, and anthropological methods.

The objectives of "learning about" and "learning to be"—like other twinned objectives in educational discussion (e.g., between "informal" and "formal" learning, or between "symbolic" and "kinesthetic" understanding)—represent *antinomies* [Bruner, 1996]: pairs of complementary truths, each worthwhile to be pursued in different contexts, but also presenting learners and educators with tensions and contradictions. Antinomies of this kind have woven their way, historically, into enduring questions in the learning sciences: for instance, whether computers should be designed as independent stand-alone "intelligent tutors" or (by contrast) as "intelligent assistants", or "expressive tools of communication", or as some mixture of these and other artifacts (for an early example of these debates, see [Taylor 1980]). Over time, we are likely to come to view MOOCs and their offspring through the lenses of similar antinomies. Are we after *uniform, standard, globalized* high-quality education (a chance to take the very best "Calculus 101" course for every student in the world)? Or are we after *highly personalized, idiosyncratic* pathways of learning [Collins *et al.*, 2009] (a chance for a student with any particular interest—say, in the study of European ferns, or the geography of the planet Mercury, or Viking ship design—to fashion a unique educational experience geared toward their own preferences)? To take another example: are we after an *inexpensive* educational infrastructure (in which students can easily afford at least a minimal education, and in which the resources associated with residential universities are scaled back) or an *expanded* infrastructure (in which online education is complemented not only by residential universities, but by more widespread resources for construction, laboratory work, or field trips)?

It is in the nature of such educational antinomies that they elicit multiple responses, depending on the material to be learned, the students, the setting, and many other factors. The essential goal of the learning sciences in the face of new technology is to identify the various sides of the antinomies latent in the technology; once identified, we can use the technology in an informed way, research its role in learning, and design alternative or complementary technologies that mitigate the problems of one-sidedness. Where MOOCs (and online education) are concerned, we are faced with a potentially powerful technology—especially powerful in economic and political terms. It is plausible that not only higher education, but also K-12 education, professional training, vocational education, and graduate work may be increasingly defined by the characteristics that we see, in embryonic form, in MOOCs today. If the science of learning is to serve our ends as human beings, we must pitch our theories to the types of learning that really matter to us, and address our designs to the creation of artifacts that enable us to fulfill our aims.

References

- Alibali, M. and Nathan, M. (2012) Embodiment in Mathematics Teaching and Learning: Evidence from Learners' and Teachers' Gestures. *Journal of the Learning Sciences* 21(2), pp. 247-286.
- Anderson, C. (2012) *Makers - the New Industrial Revolution*, Crown Business, New York.

- Anderson, J. R., Corbett, A. T., Koedinger, K. R., & Pelletier, R. (1995) "Cognitive Tutors: Lessons Learned," *The Journal of the Learning Sciences*, 4(2), pp. 167-207.
- Arias, E. G., Eden, H., Fischer, G., Gorman, A., & Scharff, E. (2001) "Transcending the Individual Human Mind—Creating Shared Understanding through Collaborative Design." In J. M. Carroll (Ed.), *Human-Computer Interaction in the New Millennium*, ACM Press, New York, pp. 347-372.
- Bandura, A. (1997) *Self-Efficacy*. New York: W. H. Freeman.
- Bowen, W. G. (2013) *Higher Education in the Digital Age*, Princeton University Press, Princeton.
- Brown, A. (1992) Design experiments: theoretical and methodological challenges in creating complex interventions in classroom settings. *Journal of the Learning Sciences*, 2(2), pp. 141-178.
- Brown, J. S. (2005) *New Learning Environments for the 21st Century*, available at <http://www.johnseelybrown.com/newlearning.pdf>.
- Bruner, J. (1996) *The Culture of Education*, Harvard University Press, Cambridge, MA.
- Choua, C.-Y., Chanb, T.-W., & Lin, C.-J. (2003) "Redefining the Learning Companion: The Past, Present, and Future of Educational Agents," *Computers & Education*, 40, pp. 255-269.
- Clark, A. (1997) *Being There*. Cambridge, MA: MIT Press.
- Collins, A., Fischer, G., Barron, B., Liu, C., & Spada, H. (2009) "Long-Tail Learning: A Unique Opportunity for CSCL?" In *Proceedings (Vol 2) of CSCL 2009: 8th International Conference on Computer Supported Collaborative Learning, University of the Aegean, Rhodes, Greece*, pp. 22-24. Available at: <http://l3d.cs.colorado.edu/~gerhard/papers/2009-CSCL-symposium.pdf>.
- Csikszentmihalyi, M. (1990) *Flow: The Psychology of Optimal Experience*, HarperCollins Publishers, New York.
- Daniel, J. (2012) *Making Sense of MOOCs: Musings in a Maze of Myth, Paradox and Possibility*, available at <http://www.jime.open.ac.uk/jime/article/viewArticle/2012-18/html>.
- dePaula, R., Fischer, G., & Ostwald, J. (2001) "Courses as Seeds: Expectations and Realities." In P. Dillenbourg, A. Eurelings, & K. Hakkarainen (Eds.), *Proceedings of the European Conference on Computer-Supported Collaborative Learning*, Maastricht, Netherlands, pp. 494-501.
- Dourish, P. (2001) *Where the Action Is — the Foundations of Embodied Interaction*, The MIT Press, Cambridge, MA.
- Downes, S. (2012) *Connectivism and Connective Knowledge*. Available at: http://www.downes.ca/files/Connective_Knowledge-19May2012.pdf
- Eisenberg, M. and Eisenberg, A. (1999) Middle tech: Blurring the division between high and low tech in education. In Druin, A. (ed.), *The Design of Children's Technology*. San Francisco: Morgan Kaufmann, pp. 244-273.
- Fischer, G. (2011) "Understanding, Fostering, and Supporting Cultures of Participation," *ACM Interactions* XVIII.3 (May + June 2011), pp. 42-53.
- Fischer, G. (2013) "From Renaissance Scholars to Renaissance Communities: Learning and Education in the 21st Century." In W. Smari, & G. Fox (Eds.), *International Conference on Collaboration Technologies and Systems*, IEEE, San Diego, pp. 13-21. Available at: <http://l3d.cs.colorado.edu/~gerhard/papers/2013/CTS.pdf>.
- Hirsch, E. D. (1988) *Cultural Literacy: What Every American Needs to Know*, Vintage, New York, NY.
- Johnson, S., ed. (2010) *Neconstructivism: the New Science of Cognitive Development*. New York: Oxford University Press.
- Kolowich, S. (2013) *With Open Platform, Stanford Seeks to Reclaim MOOC Brand*, available at <http://chronicle.com/article/With-Open-Platform-Stanford/142783/>.
- Koschmann, T. D. (Ed.) (1996) *CSCL: Theory and Practice of an Emerging Paradigm*, Lawrence Erlbaum Associates, Mahwah, NJ.
- Lave, J., & Wenger, E. (1991) *Situated Learning: Legitimate Peripheral Participation*, Cambridge University Press, New York.
- Lewin, T. (2013) *U.S. Teams up with Operator of Online Courses to Plan a Global Network*, available at <http://www.nytimes.com/2013/11/01/education/us-plans-global-network-of-free-online-courses.html>.
- Menary, R., ed. (2010) *The Extended Mind*. Cambridge, MA: MIT Press.
- Nash, P. and Shaffer, D. (2011) Mentor modeling: the internalization of modeled professional thinking in an epistemic game. *Journal of Computer-Assisted Learning* 27, pp. 173-189.
- National-Research-Council (2009) *Learning Science in Informal Environments — People, Places, and Pursuits*, National Academy Press, Washington, DC.
- Roschelle, J. (1992) Learning by collaborating: convergent conceptual change. *Journal of the Learning Sciences*, 2(3): 235-276.
- Schoenfeld, A. (1985) *Mathematical Problem Solving*. San Diego, CA: Academic Press.
- Scientific-American (2013) *Learning in the Digital Age (Special Report)*, available at <http://www.scientificamerican.com/editorial/digital-education/>.

Taylor, R., ed. (1980) *The Computer in the School: Tutor, Tool, Tutee*. New York: Teacher's College Press.
Tomasello, M. (1999) *The Cultural Origins of Human Cognition*. Cambridge, MA: Harvard University Press.

Acknowledgments

The challenges, reflections, ideas, and envisioned developments articulated in this paper are based on (1) the collaborative research of the two authors in technology enhanced learning over the last two decades in the Center for Lifelong Learning & Design (L3D) and its support by the National Science Foundation; (2) the numerous contributions of the researchers and PhD students in L3D; (3) the discussions with colleagues in the learning science community (specifically: Allan Collins, Mark Gross, Sharon Derry, Frank Fischer); and (4) the interactions with researchers who have developed or are developing MOOCs (specifically: Mitchel Resnick, Don Norman, Pierre Dillenbourg, Sriram Sankaranarayanan). This work was also supported in part by the National Science Foundation under grant IIS0856003.