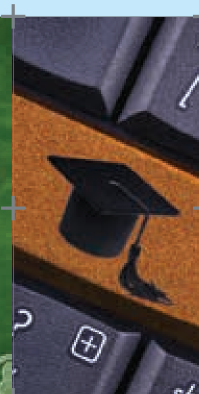
CCC
COMPUTING COMMUNITY CONSORTIUM

MULTIDISCIPLINARY RESEARCH FOR ONLINE EDUCATION



www.cra.org/ccc/

REPORT ON THE CCC-CRA WORKSHOP ON MULTIDISCIPLINARY RESEARCH FOR ONLINE EDUCATION

February 12-13, 2013, Washington, DC

Report prepared by Douglas H. Fisher and Armando Fox, co-chairs

Acknowledgements: We thank the workshop Organizing Committee (Mark Guzdial, Cindy Hmelo-Silver, Anita Jones, John Mitchell, Beverly Woolf) and the CCC Council liaison (Lance Fortnow) for their many contributions to the success of the workshop, and thanks to all participants for an engaging workshop; this report is informed by their ideas! We thank Marie Bienkowski, Cindy Hmelo-Silver, and Mary Lou Maher for each providing very useful comments on a draft of this report, though we are exclusively responsible for the content. Finally, we thank Andrew Bernat, Kenneth Hines, Erwin Gianchandani, Ann Drobnis and the entire CRA staff for their outstanding work on the workshop.

1. INTRODUCTION

An explosion of public and academic interest in online education accompanied the early high-profile offerings of massively open online courses (MOOCs) in 2011 and 2012 by some of the country's leading education and research institutions, as well as by non-profits, companies and other content providers. This surge has particularly focused on undergraduate education, but is occurring in the context of a long-standing online education landscape of research and practice for K-12 education, lifelong learning, as well as higher education. The new ingredients

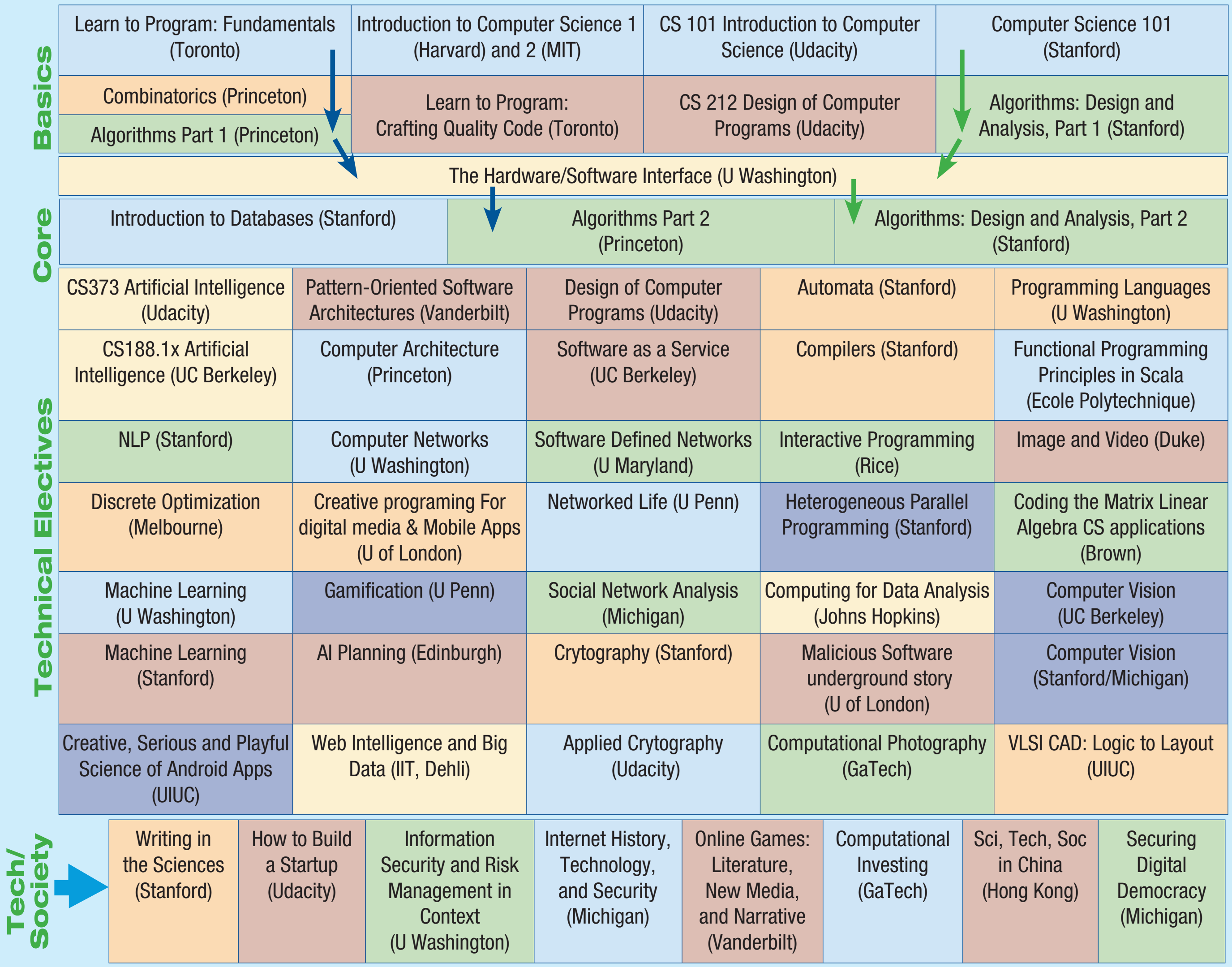


Figure 1: A MOOC Computer Science Curricula circa 2012, with blue (partial) curriculum on left and green curriculum on right

of large scale (or massive) and free-accessibility (or open) add significantly to the transformational possibilities on education, for accessibility, quality, flexibility, affordability, as well as definitional changes to its boundaries, form, and content. For example, as early as Fall 2012 there were sufficient MOOCs being offered that a student could pursue a good approximation of an undergraduate computer science curriculum, including technical-society electives! Moreover, as illustrated in Figure 1, the space of courses allowed for alternative paths through the CS undergraduate-level space, and paths spanned multiple institutions, enabling significant ways of personalizing a curriculum, though challenges such as coordinated scheduling still remain.

In the longer term, today's highly visible, accessible, and large-scale efforts may help drive education into an oft-touted and idealized "hiding-in-plain-sight" ubiquity, blurring boundaries between formal and informal education.

1.1 Two Pillars of Online Education: Learning and Computing Sciences

The two research pillars on which the workshop was based are information and computing technology and the learning and behavioral sciences. Learning and behavioral sciences are poised to address questions of pedagogy in a new age of massive scale and openness. Underlying the challenges and promises of such research is computing, the vital enabling technology that facilitates geographically and temporally distributed interactions.

The goal of the workshop was to elaborate a research agenda for computing-enabled online education over the next 5-10 years. By "agenda" we mean the identification of scientific questions to be addressed, rather than answers per se, and enabling technology to be developed. Figure 2 illustrates part of the space that was within scope of the workshop, crossing areas of computing and the learning sciences, to identify research opportunities, challenges, and imperatives at the intersections of these fields.

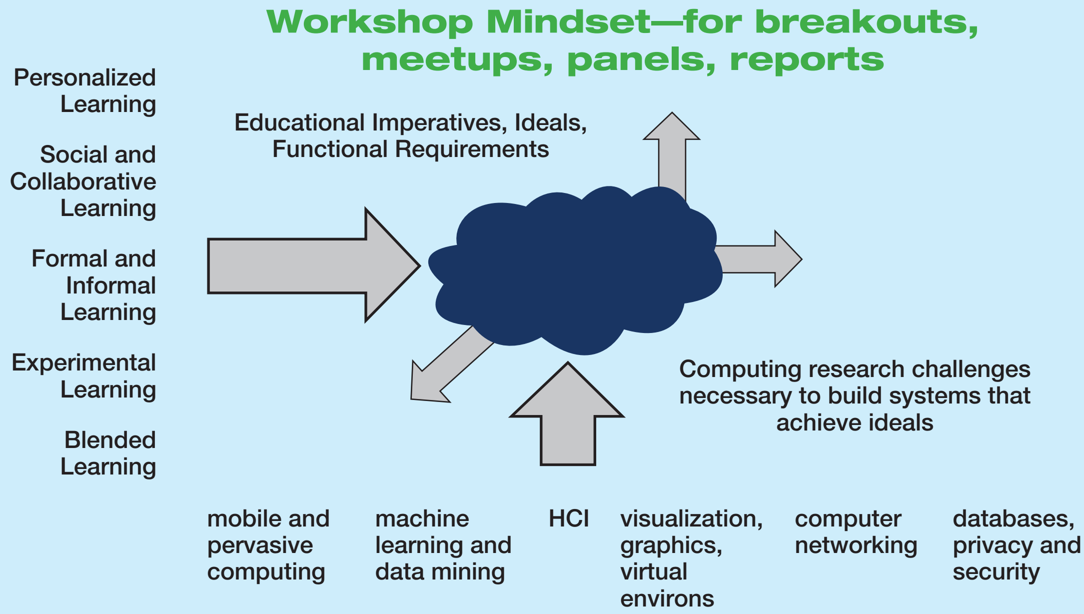


Figure 2: The MROE Workshop goal was to elaborate a research agenda for online education at the intersection of computing and the learning sciences

1.2 Workshop Organization

The Workshop on Multidisciplinary Research for Online Education (MROE) brought together researchers and practitioners in computing, education, learning sciences, and cognitive psychology, to identify research opportunities, challenges, and imperatives at the intersections of these fields.

Two reports were supplied to participants as background to MROE. The first, a CCC/CRA-supported report, was *A Roadmap for Education Technology* (ARET, 2010) [1], which identified research areas for online education to 2030. ARET-2010 grew from a series of visioning workshops of the Global Resources for Online Education (GROE) initiative. The second report, on the role of data mining in education, was *Enhancing Teaching and Learning Through Educational Data Mining and Learning Analytics* (EDM-LA, 2012) [2].

The ARET report identified educational grand challenges of personalizing education, assessing student learning, supporting social learning, diminishing boundaries (of many types), alternative teaching methods, enhancing the role of stakeholders, and addressing policy changes; and focused on enabling, computing technologies of user modeling, mobile tools, networking tools, serious games, intelligent environments, educational data mining, and rich interfaces. The EDM-LA report drilled down as the name suggests, motivating these empirical methods (e.g., for personalized learning), surveying research in the area (e.g., relationship mining, visual analytics), and identifying challenges to adoption, both technical and otherwise (e.g., institutional capacity, privacy and ethics).

MROE would not simply revisit the earlier material, but update prior conceptualizations with a new appreciation for dimensions of *scale* and *openness,* which MOOCs have made explicit because of their extreme values along these dimensions. Indeed, scale and openness can each be better viewed as multidimensional spaces rather than a single dimension each. By design, the two-day workshop did *not* address issues of business models, public policy, and shorter term concerns such as credentialing, except as these informed longer-term research agenda.

The workshop was held on February 11 and 12, 2013 in Washington, DC. There were approximately 90 participants from the computer sciences and the learning sciences; most were academic researchers and educators, but some represented Federal agencies and industry.

Featured plenary speakers were:
- **Dr. Farnam Jahanian,** Assistant Director of the National Science Foundation's Directorate of Computing & Information Science & Engineering (CISE), who highlighted the importance of interdisciplinary research;
- **Dr. Beverly Woolf,** University of Massachusetts, Amherst, lead editor of ARET 2010 [1], who identified educational grand challenges (e.g.,modeling of student *traits* as well as student knowledge states), and enabling technologies to meet these challenges; and
- **Dr. Roy Pea,** Stanford University, who highlighted the report of Transforming American Education [5], and made the case for a "marriage" between learning sciences and analytics: while current MOOCs reflect very limited influence by learning sciences, future online courses can and should be informed by both pedagogical theory and the unprecedented ability to instrument the learning environment.

Two panels summarized online-education methodologies, technologies, and pedagogies, and considered adapting these to massive and open contexts. The first, a computing-centric panel, was on *Educational Data Mining and*

Learning Analytics [49], and a second pedagogy-focused panel addressed *Translating Collaborative Project-Based Learning to Online and Blended Environments.*

The dominant activity of the workshop, and one that was heartily endorsed by participants, were topical breakout groups that were arranged according to practitioner expertise and interest areas. Fourteen breakout groups, spread over two sessions, were held on day 1. The topics of day-one breakouts were selected by the organizing committee, and informed by participant polling two weeks before the workshop. Assignments to these breakout groups were made a few days before the workshop, with 7-10 participants assigned to each breakout. Each breakout was roughly balanced between persons with computing and learning science expertise. In two cases a topic defined a breakout in both the morning and afternoon sessions of day 1.

- Personalizing Education
- Assessment of Student Learning (2 sessions)
- Supporting Social Learning
- Machine Learning and Data Mining (2 sessions)
- Formal and Informal Learning
- Pedagogical Needs and Constraints of Various Domain Areas
- Interacting with Objects
- Social Computing & Networking
- Long-term implications of online learning for cultural interactions
- Implications for Computer Science Education
- Human-Computer Interaction
- Games & Gamification

Based on day 1 activities and insights, day 2 breakouts were defined in a town hall meeting at the end of day 1. In contrast to the day 1 breakouts, no assignment was done in advance for these next-day breakouts, but rather participants self selected. The day 2 breakouts were:

- Crowdsourcing of Assessment
- MOOCets (K-6) & MOOCoids (65+)
- Blended/Flipped Classrooms
- Communities of Learners
- Alternatives to MOOCs

Each breakout was moderated by an assigned leader and notes were taken by an assigned scribe on Google Drive. Breakout notes were further summarized on a single slide and presented in 2 minute presentations at plenary sessions.

Details of the workshop can be found at [0], with a tab at the bottom to "workshop speaker videos," including those of the keynote speakers, the two panels, and brief report-outs of the many breakout groups. The workshop concluded with an animated town hall meeting, also captured in the video presentations, where workshop participants elaborated future directions and resources in online education, with an emphasis on what had not been otherwise captured in the workshop (e.g., workforce development, an important broader impact).

2. CROSSCUTTING THEMES FOR A RESEARCH AGENDA

Rather than narrating the workshop proceedings in detail (which are online, as noted), this report attempts a partial synthesis and elaboration of workshop discussions and insights, as eclectic as they were. The workshop organizers reviewed resulting workshop material, most notably breakout group summaries, and extracted *multifaceted and overlapping research themes.* These themes form the basis of interdisciplinary research agendas, and a set of follow-on questions that may be of particular interest to practitioners in a subset of those disciplines.

The cross-cutting themes are summarized here, and we go into more depth in a subsequent section.

1. **Next Generation MOOCs and Beyond MOOCs:** Who isn't being served by current MOOCs and why? How can online education benefit on-campus and other physically co-located learning? What is the role of collaboration and community in the future of online education? How can we improve diversity of students in computing through massive, open, online education? What advantages for learning and interdisciplinary activities will follow from the development of curricular-level constructs, such as sequences of MOOCs that have conceptual, even prerequisite, relationships?
2. **Evolving Roles and Support for Instructors:** What are the evolving roles for teachers in the new digital learning world, and what new instructor-facing and student-facing technology will be needed to help them, especially at large scale? To what extent will instructional collaborations emerge across institutional boundaries analogous to research collaborations that have existed for a long time?
3. **Characteristics of Online and Physical Modalities:** Which traditional instructional practices "scale up" well and map effectively to online environments, which ones represent the unique value of physical experience, and how can we blend the two effectively for different activities and different populations?
4. **Physical and Virtual Community:** How can collaborations, so common in face-to-face environments, be encouraged and supported in online education? How can we enable social interactions/community online, and how can we measure effects of such interactions on learning? What advantages emerge when global virtual communities interact with local, often physically co-located learning communities?

Again, a research agenda, particularly one that claims to be looking 5-10 years out, is about scientific questions and goals, rather than answers per se. Moreover, the CRA/CCC-funded MROE workshop was interested in future computing and information technologies that will achieve desirable outcomes and guard against undesirable ones. In selected cases we also elaborate possible broader impacts of educational and technological developments, since broader impacts have been recently affirmed by NSF as very important in the larger research milieu and in research proposals specifically.

Some of the particularly novel insights growing out of the workshop were attention to instructor support, instructor modeling, and instructional communities, particularly those that crossed institutional boundaries. Training and supporting teachers in new tools, skills, and domain knowledge further amplifies the effects of online education. To adapt another, like-minded expression—if you teach a teacher, you teach a village—at least this is a hypothesis that should be expanded and evaluated. Attention to issues of community generally, such as changing roles and managing discourse at large scale, were foci of the workshop.

While workshop participants were keenly interested in and discussed STEM higher education, other relatively unique discussions at MROE were on technological and social concerns regarding (a) possibly underserved populations (e.g., K-12, retired, disabled), (b) underserved disciplines (e.g., humanities, arts), and (c) long-term cultural influences of, and (d) other broader impacts of massive open online education, with selected workshop invitations directed specifically to include these important perspectives.

We elaborate on the research themes next, to include scientific questions of interest, and their motivations in terms educational desiderata. We adopt the acronym *MOOE* (massive, open, online education) when we mean to generalize beyond today's MOOCs, while still retaining the focus on *massive* and *open.* Even these terms are changing in their meaning, with possible new interpretations that education should be ubiquitous.

2.1 Next Generation MOOCs and Beyond MOOCs

The goal of the workshop was to look beyond the current crop of MOOCs, to a more expansive vision of online learning across dimensions of scale and openness. There is much to explore beyond our current use of MOOCs, and in a few years we will likely see the current MOOC focus questions as naïve and limited. In this section we survey future visions of online education that grew from the workshop, again with a special emphasis on issues of scale, openness, and research, particularly in the computing area. This section is also something of an overview of some of the more detailed discussions in subsequent sections.

2.1.1 Access to education

The question of access to education is both potentially alleviated and exacerbated by MOOE systems. On the one hand, these may improve access to educational materials, especially on topics unavailable in many K-12 schools, such as computer science. MOOE could perhaps even be used to help train teachers who lack access to good mentorship and to provide opportunities and resources with specific domain knowledge for teachers who are not domain experts. On the other hand, students who need to go to the library or an Internet café because they lack Internet connectivity at home may not realize the potential benefit, though a repurposing of community centers to be *high-bandwidth hubs of learning with online education* may strengthen community in important respects. In any case, discussion of how online materials can improve access must be coupled with a discussion about the basic infrastructure, technical and otherwise, required to access those materials. For learners who lack this basic technological infrastructure, MOOE may exacerbate gaps between the more and less wealthy members of society.

A related question is *who is being underserved by current MOOCs* and why? [26] For example,very young learners and elder learners are typically in the "tails of the distributions" of technical access, technical competence, motivations and learning goals, and the set of enabling technologies whose affordances they find appealing; yet these constituents, whose ability to commit to in-person "formal" courses in traditional settings is limited, might be among those who could potentially benefit most from online education. What are the needs of these learner groups that lie outside the current "target audience" of MOOCs and what formats will best meet those needs? How can we increase the diversity of persons being served by online education, not simply through basic accessibility, but human-computer interaction designs and tools that encourage people to participate and support their goals?

Moreover, can we design MOOE experiences that are explicitly intended to *promote cross-generational learning,* for example, MOOCs designed for grandparents and grandchildren?

Finally, what assistive technologies will be most relevant to enabling MOOE for those with disabilities, to include learning disabilities, but also physical disabilities that are not particular to learning concerns, such as sight and auditory disabilities? In general, there could be important broader impacts of research at the intersection of assistive technologies, and online and blended education.

2.1.2 Integrating cloud and campus

Much discussion at the workshop involved how online education could enhance residential-campus courses, and vice versa. Some on-campus instructors are already using online material (e.g., from YouTube channels, MOOCs) to augment their on-campus courses, most notably by facilitating active learning in the classroom. Undoubtedly, online education is already supporting some selected middle and high school education, to include homeschooling, though as we have noted, the focus is very much on undergraduate education thus far.

There are various models for integrating campus and cloud courses, which we detail later, but suffice it to say here that such use to date is largely opportunistic, and this experience suggests design principles for future MOOE. First, *design with on-campus adopters in mind* (and local learning communities generally). Strongly suggested by the first principle, is to *design with remixing and other forms of customization in mind.* For example, will one-week MOOCs, really modules (MOOMs), promote adoption and customization on campus (and elsewhere) relative to MOOCs designed for quarters or semesters? To what extent are even finer-grained lessons (MOOLs), at the level of YouTube or Khan Academy videos, being adopted already? What would such availability mean for the composition of degree and finer-grained credentialing programs, for both on-campus and online? What would be related effects of MOOx granularity for retention and completion? What granularity "optimally" trades off flexibility and structure for designing blended, possibly remixed courses and *curricula* of the future?

Using MOOE for course customization fits into a larger landscape of *learning objects* (e.g., [33]) and repositories of such objects [13]. Learning objects are educational content made available for reuse, and range from assignments, labs, assessments, simulations, and the type of content that will be used in MOOE, including videos, autograders, lessons, modules, and courses. Learning object "theory" includes an *object* orientation ("object" in the object-oriented programming sense), and is an interesting way that computational thinking has arguably moved into other realms.

2.1.3 Collaborations and community

MOOE introduces many opportunities for social interactions among people locally, regionally, globally, and thematically, to include relationships between local campus students and a global population as a special case. Discourse is currently enabled through rather routine mechanisms such as discussion forums, chat, video conferencing, and the like. We imagine that new technologies can mediate more compelling interactions among groups at multiples levels of granularity, to include interactions that cross between physical and virtual. Other kinds of interactions will emerge as MOOE integrates mobile technology and social media as standard mechanisms for interaction.

Collaborations are interactions of longer duration and otherwise tighter coupling between participants. While some MOOCs of today include collaborative student projects, collaborative MOOCs are far from the norm. Even in computer science and the engineering fields, which disproportionately led the MOOC charge, there has been relatively little experimentation with open-ended problems, such as design problems or other learning scenarios involving facilitated small-group activities, despite the fact that these are central to many computer science and engineering courses. Researchers will want to include the development of collaborative platforms and environments, leveraging research in computer-supported collaborative work (e.g., [17][19]) and other fields.

To increase characteristics such as emotional engagement, we imagine much more immersive interactive experiences, perhaps like those brokered by the Reflexion system [29], in which physically-distant discussants are ghosted onto each others computer screens. In general, can we imagine HCI designs and tools that don't simply seek to replicate the physical environment, but to "best it" in some respects? For example, we can imagine allowing new-found friends from across the globe to watch a MOOC lecture together, commenting on it, pausing it at will, looking into their friends' faces all along, none of which are things that they could hope to do in a collocated live lecture! Such tools may be of particular relevance in fields such as humanities and the arts, where subjectivity and nuance are critical, but we don't see these capabilities as limited to those fields. Of course, all these high-tech possibilities return us to questions of accessibility and equity.

In addition to collaborations among students, online media make it easy for faculty (and others) to collaborate across institutional boundaries in their teaching, much as they have done in research for many years. When paired with the possibilities for MOOE customization, noted above, collaborative teaching affordances might lead to a boon in design of interdisciplinary courses and even larger curricular constructs of multiple, coordinated MOOCs.

2.1.4 From massive and open to ubiquitous

MOOCs are currently embraced as vehicles for lifelong learning—as educational content that is delivered and received outside traditional classrooms. They are but the most recent addition in a rich and long history of outside-the-classroom learning opportunities, to include distance, correspondence, and extension programs; programmed instruction; educational television, learning objects; as well as a history of online educational programs and other materials (e.g., Khan Academy and many YouTube channels) (e.g., [51]). Certain aspects of massive, open, and synchronicity distinguish MOOCs, and their basis in computing offers possibilities of interactivity little known before. For example, not only can feedback be intelligent by the standards of an earlier time, as in autograders for programming assignments, but that feedback can be almost immediate, delivered at a distance, and on demand by each learner. MOOE invigorates ideas that education and learning can be *intentionally* continuous.

What mechanisms will seamlessly support education and learning inside and outside of class time? How can MOOE of the future be merged with other widely used computational and communications media to further advance ubiquitous learning? For example, games encourage the player to "fail-and-recover," in stark contrast to traditional courses in computer science that praise correct answers and give only negative feedback, such as error messages from a compiler. Can games be adopted to overcome some of the negative aspects associated with traditional course offerings? Can games and other virtual environments that include high-fidelity simulations be adapted that enable learners to explore wrong paths so as to better learn the consequences of mistakes? After all, we would all like our physicians to have made mistakes during their training, and learned the consequences of wrong decisions—just not on us! In general, can there be an effective merging of paradigms such as massively multiplayer online games (MMOGs) and MOOE, with the MMOG aspect providing capabilities of rich exploration and socialization, and the desirable educational outcomes, lessons, and other scaffolding coming from the MOOE genealogy?

Greater integration of mobile applications with MOOE delivery systems will likely further drive learning and education towards ubiquity (e.g., [1, pp. 47-50]). Consider possibilities of designing and using mobile apps in conjunction with a nutrition course or a sustainability course, to carry lessons into the grocery store and backyard.

Broader impacts of integrating online education with both mobile apps and gaming will likely stem from the opportunities that emerge for computer science students, professionals, and entrepreneurs, be they online education aficionados or not, to contribute to educational infrastructure that supports ubiquity and openness.

2.1.5 Designing MOOE for research

Research with MOOCs has been opportunistic for the most part, and largely focused on data mining to benefit the learning sciences (e.g., [9]). Increasingly, we expect MOOE to factor opportunities for research into the design of material. These can include designing *lightweight interventions* during a MOOC, for example, for purposes of A/B testing with the student population to inform learning science ("lightweight" because the intervention does not affect the course structure). Going even farther, iterative design, development and feedback methodologies are being advocated to systematically collect, analyze, and act on learners' data [4].

MOOE can also be compelling vehicles for research *outside l*earning sciences, for exploring and evaluating new computing technologies, in human-computer interactions, artificial intelligence, machine learning, database, semantic Web, social computing, gaming, visualization, and mobile computing, to name but a few. Nor should computing researchers ignore the possible broader impacts of computing-enabled online education at scale, from areas as distant as preserving rare natural languages, to broader impacts for cultural blending and accommodation, and for organizational development.

2.2 Evolving Roles and Support for Instructors

Support for instructors in a new era of education was a common theme at the workshop. Most often, the concern was for instructors in the type of blended courses described in Section 2.1.2. While a blended on-campus course may not seem to fit the bill of education at a large scale, workshop attendees were cognizant of the various ways that large-scale could be realized, which included the possibility that massive and open might stem from a large, distributed collection of local, small, often on-campus, cohorts.

Undoubtedly, there will be some instructors who resist a transition from "sage on the stage" to "guide on the side" that is likely in blended models, and perhaps they should depending on circumstance! It is likely, however, that the extent to which a change in culture will be embraced or resisted will depend in part on the support that instructors receive in adapting to new educational formats. Changes will also be determined by acceptance among students (and parents). How will students perceive new roles of their teachers (always an issue when these roles change)? Will students perceive their instructors as more or less engaged and interested in their studies, and how will these perceptions vary with circumstance and instructional design? Will these perceptions influence any student outcomes? Under what conditions do some instructors appear to disengage with their classes as a result of using online content? Can computer-mediation be designed that encourages active classroom designs by instructors instead of disengagement?

A second theme was support for instructors in developing online content, be it as components in blended courses, or for entirely online courses.

In many ways, this section presages issues that will be relevant for student and other learner support, which we discuss later. Workshop participants highlighted instructor support out as a primary theme, because of a perception that it is often lost amongst other concerns with students, but is nonetheless critical. Visions such as pervasive, personalized education will not be fully realized if those in teaching roles don't find it rewarding to produce and manage open educational content for a global community.

2.2.1 Community resources

There is an incredible amount of educational material that is freely available online that supports learning, with or without the direct guidance of instructors, but such resources benefit instructors as well. In section 2.1.2 we discussed the possibility of finer grained modules (MOOMs), of say a week duration, as a means of encouraging remixing in course design, as well as even finer grained units, such as lessons (MOOLs) of the sort we find on Khan Academy or a large number of YouTube channels. In addition, many instructors make available assessments and materials to support active learning in the classroom (e.g., [14][15]). Such collections of *learning objects* [33], regardless of the multimedia modalities, are hardly research per se, but there is important research to be done if the utility of these resources are to be maximized.

Computational tools will be increasingly needed to organize, navigate, and recommend educational material, in order to put instructors (and learners) together with the most useful content. These organizational tools will include database and semantic web, crowdsourcing for annotating and vetting resources, and data mining and machine learning approaches that group similar material. Advanced strategies will also be desirable, for example, by applying object and activity recognition to the problem of identifying relevant content in video. Recommender systems for educational content that go beyond cursory assessments of popularity stemming from longevity biases (i.e., older content has had more opportunity for endorsement), which can identify epsilon improvements in quality of educational material, perhaps in ways that are quite nuanced and specific to individuals and specific to course designs (e.g., textbooks and other multimedia) that instructors have already laid out.

Instructors will also need support in creating content, as well as finding and using the content of others. Importantly, creating one's own content, and making this content available to a community, may have important implications for instructor and student attitudes towards online content remixing by instructors, a point that we return to shortly. With respect to content design and production, tools are needed that make multimedia revision, for purposes of correcting mistakes and bringing content up-to-date, next to trivial. For those instructors wanting to create content strategically, there may be utility in intelligent tools that recommend educational niches that an instructor is well suited to fill, both in terms of content and teaching styles. As with learner populations, there are concerns with accessibility and equity among instructors to participate in a global community of content and tool creation.

In addition to simply collecting and producing educational content, there is the challenge of synthesizing this content. How will community practice evolve to synthesize over the vast amount of online multimedia content, in a manner that a great textbook synthesizes over a large number of sources? Can computing tools, such as clustering, topic modeling, and other AI methods, be adapted to help in synthesis? Wikipedia and other text-based collections, for example, might be relatively low hanging fruit (compared to multimedia collections) to investigate the ways that intelligent artificial agents that are injected into knowledge-rich, collective-human activity, can improve knowledge synthesis (e.g., [50]). Such activity is not on the "front lines" of instructor support, but it does illustrate computing research that looks 5-10 years out that would ultimately benefit instructors (and learners).

2.2.2 Managing courses

Particularly for those instructors who are running courses at large scale, there is a great need for support during the course. Among the most important functions will be attending to worldwide discourse among learners, and giving and managing assessments at a massive scale. We postpone the discussion on managing discourse, and discussion of *peer assessment,* until section 2.4, because many of the issues raised are much more general than direct instructor support. However, there are issues regarding other assessments that we address here. Most notably, is the need for improvements in semi-autonomous means, which we imagine is the best that can be expected in the next 5-10 years, of assessing short answers, essay, and other free form text. For example, *"power-grading"* [27] is an instance of interactive machine learning, which organizes *short-answer submissions* into rough equivalence classes so that the manually-provided grade of a much smaller number of prototype submissions can be adopted and/or adapted to other members of the prototypes' class [27]. How far can this and like approaches be taken? Will deep natural language understanding enable similar approaches on essays, albeit with perhaps very different proportions of human and machine effort? Can we imagine adapting research on *computational creativity* [6], to include generation and analysis of fiction, music, and visual art, to enable even a modicum of machine input to the formative or summative assessment of learners in those fields?

Even within better trodden paths such as automated grading of programming assignments and the like, there is plenty of opportunity for research and development. For example, some of the ideas of power grading could be adopted to support grading of programming comments and style, perhaps using program parse trees and other formal semantics to generate deeper representations of computer programs. New mechanisms for testing of assignments may be developed, ranging from adopting methods of formal program correctness to generating novel test cases from problem-specific grammars.

Finally, the increased flexibility of online delivery might enable *dynamic assessment* at scale, a functionality not typically found in MOOCs of today, but perhaps critical in the future as a way of directing students down ideal paths in terms of the content, student cohorts, and teaching assistants that are recommended to them. From the perspective of the instructor, mechanisms like dynamic assessment, which will lead to more uniform subpopulations of students in terms of their readiness for material, would be welcome support indeed.

2.2.3 Support from instructional communities

Instructional collaborations and larger instructional communities may be important support structures for instructors in the future. We should not underestimate the influence that community may have on teaching, as it has had in research, particularly attitudes towards new teaching formats. There are the beginnings of online social networks for instructors, but currently they are little more than repositories for content like those of section 2.2.1, to which instructors may contribute, but with limited interactions with each other. Nor, as yet, are there systematic attempts to collect data on adaptation of one's content by others, to say nothing of more dynamic aspects of social networks.

A challenge is to create infrastructure and policy (e.g., perhaps requiring feedback on content as a condition of content licensing for use) that facilitates data collection/analysis about content sharing among instructors. This data collection can be important if we hope to measure the influence that one's educational content has, just as we track the importance of research contributions through citation analysis. How will academic culture change if and when data is systematically collected on the "citations" to an instructor's educational content? To some extent platforms like YouTube collect and display such data (i.e., views, thumbs up and down, followers), but nothing that would count towards academic recognition. Rich social networks can be mined if they are instrumented. Researchers and practitioners will want to see how attitudes change among instructors as other instructors report back on their experiences. Attitudinal changes are an example of issues to be studied by behavioral/organizational scientists and computer scientists working together over long time spans.

What of the possibilities of instructors collaborating at a distance? Despite the technical challenges of online collaboration, online modalities make it possible for faculty to collaborate on designing and teaching both trans-institutional and transdisciplinary material. Studies suggest the importance of geographic locations in research collaborations (e.g., [39]) and undoubtedly proximity has been dominant in teaching collaborations to date, but changes in teaching culture (e.g., citation, as noted above) and continued improvements in virtual collaboration technology, such as high fidelity video conferencing and open-source development support tools, may encourage teachers to collaborate in course development, just as culture and technology influence collaboration in research (e.g., [47]).

Faculty collaborations to deliberatively design trans-institutional courses *and course sequences* are happening already, albeit in a nascent stage. Across-institution sequences free instructors from the limits of local expertise. For example, consider a four-MOOC sequence on mobile, cloud android development [30]. This sequence of four courses, to include a capstone project, is being taught by faculty members from two universities; no one faculty member among the instructors could easily teach this sequence, nor perhaps could either of the two institutions cover the sequence easily [30]. Even within an established curricular pathway like the first few courses in a typical computer science curriculum, there is theoretical flexibility (e.g., software-dominant vs hardware-dominant versions of "CS 3" on computer organization) that could be better acted upon if like-minded instructors could pair up across institutions.

Customization by one faculty member using the content of other faculty members is uncommon and probably opportunistic, but course platforms could be specifically created to facilitate deliberative design of courses by multiple faculty members (and students for that matter), anywhere in the world. What are the broader impacts of students seeing collaboration among their professors in teaching, the most apparent context for students to observe faculty? As computer scientists we may think that perceptions that CS is asocial are very wrong, but is the asocial perception truer of teaching, at least currently in higher education? Might instructional collaborations, across institutions or otherwise, serve to broaden participation?

2.2.4 Towards knowledge-rich instructional and learning infrastructure

As instructors move into the cloud, whether they stay with traditional educational institutions or not, it may be desirable to maintain records of learners across all courses or modules that they have taken (e.g., [10][5, pp. 33-34]). It may also be desirable to create tighter linkages between various kinds of educational content for reasons described above. To enable these capabilities, we foresee a merging of MOOE platforms with social networks, and other educational artifacts, such as electronic textbooks and learning management systems, which integrate instructor competencies, student activities and outcomes, vetting of materials, and discussions across a lifetime of learning.

Such an infrastructure can also be knowledge rich about content, perhaps across the great diversity of academic content, representing knowledge and skill units at fine granularity, and using these to index course materials and student experiences (e.g., [7]). Rich conceptual maps against which to assess curricular material and student experiences at varying granularity already exist in disciplines such as medicine (e.g., [31]), but can these approaches be expanded to a much wider collection of disciplines, perhaps to include the entirety of a university's disciplinary portfolio? Can existing research in knowledge-rich computing be leveraged for educational purposes? Broad and deep conceptual maps could be the foundation of recommendation systems to instructors on content creation and assessment of learners; for accrediting institutional and trans-institutional programs; and for recommendation systems for students on course and personalized curricular choices, an early vision indeed (e.g., [41]).

2.3 Characteristics of Online and Physical Modalities

In this section we address affordances, hindrances, and synergies in the ways that individual learners and instructors interact with online and face-to-face modalities. In the next section, we discuss differences in the online and physical at the level of group collaborations and communities. As technological and pedagogical advances are made, we will want to track the efficacy of online and face-to-face. At least in some settings the results on student outcomes are comparable (e.g., [3], [34]), but this is certainly not the case in all domains, and changes are likely to come in the future.

2.3.1 Differences in modality bandwidth

At present, virtual space lacks the opportunity for the high-bandwidth, embodied experience of a physical space. Are there parts of a physical education experience that can't be placed into a virtual space with the same effect? Are there benefits to the virtual space for learning over a physical space? For example, are there tasks in which lower bandwidth actually encourages greater attention by participants, precisely because it is lower bandwidth? Which practices can be adapted effectively to both media and which practices do not translate from one to the other?

Moving forward with these questions, researchers will need to contextualize their experimental designs, specializing questions of advantages of one modality over another, because the results are very likely to be more nuanced than "well, there is just something about face-to-face that can't be duplicated!" For example, do autistic students respond much more positively to selected online environments over specific face-to-face environments than those without autism? For certain tasks are there minimal fidelity representations of online persona that certain members of the population (e.g., children) find particularly compelling in learning contexts?

Because students in most online learning environments are not co-located in space and time, the nature of discussion and "accountable speech" may be quite different than their physical classroom counterparts. In a classroom discussion, the teacher might encourage interaction among students to clarify and challenge points of view. What platform affordances/technologies (e.g., learning objects, peer activities) are needed to support visualization, access to and navigation of community resources, and for preparing people for culturally-informed online communication skills? For example, to help advance discussions in asynchronous online discussion forums, the Reflect system invites students to rephrase or clarify the points in a posting authored by a peer [43]. How can affordances made for online settings (or physical settings) be understood in terms experiential bandwidth, both quantitative and qualitative?

There are also bandwidth-related challenges when it comes to accessibility of computing technology across the world. This will motivate continued work on enabling sufficient synchronous audio and video communication and asynchronous multimedia study in low bandwidth environments.

Research should also address the problem of accessibility to hardware, which effectively constrains bandwidth as well. In many parts of the world there may be only one computer (or power for only one computer) for a village, and development and evaluation of interfaces such as enabling multiple mouses to "simultaneously" interact with a single computer [48] would be of great interest. Are there any social benefits to interfaces that promote, or even require, tightly-coupled interactions among persons, even if those interfaces were initially motivated by the need to operate with few resources?

Mobile technology is a critical interface between the physical and virtual worlds, enabling capture of data, be it in the form of pictures, videos, or other sensor readings. How will instructional design factor into mobile capabilities? We can imagine that mobile devices will serve for data collection for project-based and experiential learning and science labs, to name two possibilities. There are of course social learning and assessment implications of mobile devices that we touch on later.

Finally, education at a distance has been happening for many years predating general internet accessibility, notably through correspondence programs like those implemented by the UK's Open University [11]. For those researchers interested in a pervasive openness, the correspondence modality is yet another dimension that should be considered for instructional design. For example, how can we design MOOE that allow for physical lab objects to be hosted at some home or community sites, perhaps having been shipped to some of these before the course, while those with high bandwidth internet access are able to manipulate high quality virtual objects?

2.3.2 Synchronous and asynchronous

Most MOOCs, and even physically-collocated courses today, assume a mix of synchronous and asynchronous elements. For example, a physical course typically assumes that students are "perfectly" synchronized with respect to lectures and various assessments such as exams, and that assignments are due at a particular date and time, but it is rare to find courses that attempt to further synchronize students relative to their work on assignments and readings (though some institutions may have required study hours that can be considered to be finer-grained synchronization).

Online courses relax synchronization among students substantially, allowing much more flexibility on when to watch lectures (e.g., anytime within a week-long window). Some online courses are completely self-paced, with no synchronization across students. It may require special characteristics and motivations to succeed in self-paced courses because there is no natural social cohort that will support students. Can technology be used to create social support structures in self-paced circumstances?

Generally, can we characterize the amount of synchronicity and asynchronicity in a course (online, face-to-face, blended), perhaps in terms of computing concepts such as non-determinism, and use these (a)synchronicity metrics to condition the results of teaching and other experimental interventions? Moreover, are there inherent natural constraints or desiderata that correlate physical co-location with temporal "co-location" (aka synchronization)?

2.3.3 Translating online capabilities to physical and vice versa

There are situations in which what has been learned in online contexts can be translated to a physical context, and vice versa. One example is translating the greater asynchronicity that exist in many online environments to on-campus contexts. This relaxation currently manifests in blended environments that require students study video and/or written material before class (asynchronous within a time window), and participate in active learning in the class itself—the so-called “flipped classroom.” Are there possibilities for introducing even more asynchronicity into campus courses? If so, what are the remaining advantages of a residential campus experience?

Another possibility of translation from online to on-campus is the use of MOOC-developed automation to support mastery learning in residential courses, allowing students to repeat quizzes or exercises until they master the material without having to allocate (human) resources to assess the repeated attempts. We can add this to the repertoire of desirable instructional support tools covered in Section 2.2.

Rather than making such translations from online to physical naively, we should evaluate student outcomes in varying contexts. Is the greater flexibility often found in the online medium, for example, always preferable to inherent constraints found in “physical” learning environments? In an on-campus setting, limiting submissions may be motivated by limited person-power for grading, but such a limitation may also have pedagogical implications. Does limiting the number of auto-graded submissions of a computer programming assignment to a small number of attempts, for example, lead to more generalized knowledge by students than unlimited attempts, because the limitation encourages a more considered, holistic approach to problem solving? Do these outcomes depend on other features of the auto-grader, such as whether novel test cases are used on each submission? These are questions that are intended to more generally address the impacts of bottlenecks (e.g., number of submissions) and uncertainties (e.g., unknown test cases) on the thoroughness of student thought and therefore the quality of student outcomes. Undoubtedly there are many such questions.

2.3.4 Blending online and physical modalities

We’ve noted that a promising educational avenue is blended learning, which requires understanding the unique value of physical presence and of the affordances or situations in which virtual trumps physical. However, we should not knee-jerk that one is better than another for all purposes. For example, we suggested in 2.1.3 that watching an online lecture with friends from around the world might be more compelling than watching a live lecture, given the right technology; and we suggested that there may be pedagogical advantages to limiting numbers of submissions, a “constraint” motivated by face-to-face settings, over complete freedom of submissions.

It remains to be seen, of course, whether blended courses lead to comparable or better learning (e.g., transfer, retention, preparation for future learning) than either strictly online or face-to-face, although the widely-known study of student performance in a fully-traditional versus a blended-online statistics course conducted by CMU’s Open Learning Initiative showed a striking improvement in both learning outcomes and learning speed for the blended students [45], with the authors hypothesizing that one possible cause being “accelerated OLI-Statistics students actually attended their class meetings in a much better prepared state than students usually do.”

In addition to the other coverage on blended learning, there was workshop interest in learning around objects, including tangible or virtual physical objects, chunks of content around a learning purpose, virtual or simulated humans, or simulated physical objects such as online labs (e.g., [21]). For example, remote learners could access real objects through Web interfaces for controlling physical robots capable of manipulation, with cameras and sensors reporting back the success of the manipulation to the user (e.g., [37]). Are there analogs to operating system time sharing that would allow manipulations of certain kinds of physical objects to scale up to large numbers of users, or is reliance on interfaces to real physical devices inherently limited to sequential over the space of all objects? Can physical objects that collect data, tell stories, and otherwise encourage ludic engagement [36], be adapted and leveraged to push education towards ubiquity, a theme that we have already addressed in 2.1.4? In the case where such objects are physically fixed (e.g., a historical or botanical landmark, a coffee table, a museum picture), they contrast with and complement possibilities with mobile devices elaborated elsewhere (e.g., [1, pp. 47-50]), perhaps with implications for education in history, sustainability, and other areas where place is a critical value to be instilled.

With virtual objects there will not typically be the same worry about bottlenecks of manipulation, but what are minimal representations of virtual objects that make them compelling to different populations for given tasks? How can the new affordances of online learning improve the design of virtual objects for recording, augmenting, or replacing physical interaction? What are the effects on learning outcomes of using physical objects in a traditional setting versus virtual objects in an online setting? What interaction design advances need to occur for people to collaborate on making, sharing and playing with physical and virtual objects online?

2.4 Physical and Virtual Community

While the relative benefits and limitations of virtual versus physical mark an obvious difference between online and face-to-face education, MROE participants were specifically concerned about issues of *community.* In a Vygotskian perspective, learning is always a social experience. An online educational experience, particularly a massive one (with thousands of students), can't have a *physical community* (though it can and often does have many smaller physical communities). How can a *virtual community* support learning as well as, or otherwise differently from, a physical community? This section will generalize and otherwise add to an earlier discussion of instructional communities in 2.2.3.

2.4.1 Community roles and modeling roles

Online community may be redefining some traditional community roles. For example, the teacher may no longer be the embodied leader physically in front of the room, but is one voice in a virtual community, potentially changing educational culture from *"sage on the stage" to "guide on the side,"* as faculty (openly) become *consumers* of online education and become members of learning communities with their students. What kinds of dashboard-like tools will the teacher and other guides need to understand individual, group, and sub-community norms and behavior, including cultural differences in expected behavior? How will changing roles and perceptions influence societal attitudes over long time periods about the role of instructors? How will these attitudes, in turn, change what those in new "instructor" roles are willing and able to "teach" outside their area of expertise by leveraging online content? Will instructors be regarded increasingly as "lead learners" and "learning coaches" within a learning cohort?

Inversely, students who are traditionally regarded as consumers of educational content can also be producers of educational content, notably online content in the form of Youtube videos or wikimedia. We have already discussed in 2.2.1 the need for computational tools that organize, navigate, and recommend the massive amount of online educational content. Within a mixed group of traditional instructors and students, how can computational intermediaries be designed to manage personal and cultural sensitivities around traditional roles, if in fact this is desirable?

What expertise-tracking and recommendation technology can match help-needers with help-providers, whether teachers or students? We see a need to extend student modeling technology and concerns [1, pp. 43-47] to include instructor modeling (e.g., their expertise, teaching style), and a need for both student and instructor modeling to reflect an ability of students and helpers to function in participant roles (i.e., their affinity as a matched pair) in addition to modeling their progress achieving and knowledge of course learning objectives. Note that this theme differs somewhat from an earlier theme in 2.2.1 and 2.2.4 of recommending resources. Rather we are talking here about recommending human resources, and while the underlying strategies may share much, matching a student with a human helper will require more complex conditioning information.

Beyond the teacher or guide roles, what other roles do we need to pay attention to and support at the community level *outside* of a single course, and what is their function? Indeed, we can take the role of instructor and subdivide it. In a blended course, for example, there may be instructors who create the content, and other instructors who serve as the "boots on the ground," leading the class in real time. There are teaching assistants in both online and physical settings. Whose job is it to foster community? What would motivate people to participate and contribute to a community? Will we need to help students learn new ways of interacting for a virtual community in order to prepare them for MOOC-based education—for example, socialization of "online learning survival skills" [23] or development of affordances for *"socializing civility"* [23]?

Apropos section 2.1.5's principle of designing MOOE for research, particularly A/B testing, we imagine evaluating whether certain social interventions (e.g., making students conscious of the possibility of becoming community TAs for subsequent course offerings) will be particularly strong motivators that help students scholastically as manifest in MOOC completion rates.

2.4.2 Learner collaborations

Online environments provide many opportunities for collaborations among students and instructors. We have considered the possibility of instructor collaborations in 2.2.3. Here we turn to learner collaborations, but as we noted just above, community roles are changing, and the points here could apply to persons in many roles. A common theme throughout is how to group learners, so that students in groups are similar, complementary, or grouped otherwise to ensure diversity. What automation in infrastructure and/or online materials design techniques are necessary to collect and log "useful" learner data for these purposes, and how can we discover *educationally significant events* (e.g., engagement, problem solving, cheating) that might inform groupings?[24]

2.4.2.1 Short-lived collaborations

Some collaborations can be transitory and ad hoc. For example, in physics education, research developed *peer instruction,* where students answer conceptual "clicker questions" then collaborate with peers to refine their questions. Could this process be adapted to an asynchronous, online setting? As a second example, now in computer science education, *pair programming* is where one student watches over the other's shoulder while the latter programs, and then they switch. Pair programming is a particularly effective mechanism for encouraging retention and getting past students' misconception of computer science as an asocial practice. Can online forms of pair programming be as effective?

The relative effectiveness of online and physical collaborations are largely open questions. Virtual forms offer flexibility, but there are challenges. One is creating a compelling affective experience. Would small-group teaming in immersive virtual world environments such as Second Life or game environments, for example, serve to mitigate some negative affective responses, such as flippancy? A second issue is that despite theoretical advantages, on-line practice doesn't always exploit what is possible. For example, using the Online Studio-Based Learning Environment (OSBLE) [38], students didn't take advantage of the capability for asynchronous peer code reviews of partners.

The important research questions are therefore how to create, incentivize, and steward communities in ways that blend the most appropriate physical and virtual aspects, recognizing that what is "most appropriate" will change with advances in research and development. There are also questions of scale-up for small-group work applied in a massive course. OSBLE, and other approaches, such as *3D teaming* in Second Life [46], assume a moderator or a coach for small student groups; how can such roles be best utilized, and under what circumstances, in MOOE contexts?

2.4.2.2 Peer assessments

Peer assessments are typically *not* collaborative per se, though peer assessment is part of a culture of participatory and collaborative learning, and so we place its discussion here.

There is much talk of peer assessment (e.g., [42], [44]), and in many circumstances the "average" case peer assessments may be quite good. But there is a need to attend to the "worst" case peer assessments, and in courses that number in the tens of thousands there may be quite a few "worst" cases. A poorly assessed piece of work might be one for which the dominant peer-grader scores are grossly out of line with what the instructor would assign, or be evaluations that are disparaging to an extreme. There are several strategies for improving peer assessments that involve computing technology.

Perhaps foremost is to improve ways of matching assessors and assessees. It is likely that some of the strategies for doing these matches will be like those used for recommending student support groups and instructional collaborations, which we have already discussed. But the recommender algorithms would be adapted for new purposes, finding a complementary set of assessors for assessment. These assessors could be selected from in or out of any existing support cohort a student is participating in, and that decision might well be informed by whether the assessment is intended as formative or summative. In addition, given that later in a course we would expect a higher proportion of "serious" students, can relevant information be found across the entire course population and its trajectory over time that would inform assessor selection?

2.4.2.3 Course-length collaborations

Learner collaborations can also be longer lasting. Some online courses have begun to engage students in group projects, following long-standing practices in campus courses that engage students in such activity. Project-based learning in groups is another challenge for the online medium, one that also requires attention to synchronous communication reliability and fidelity, as well as effectively managing and motivating asynchronous communication. But in a massive course, are there more opportunities for assigning students with complementary strengths and social affinities into groups for purposes of projects than there are in a typical on-campus course? Perhaps so, and perhaps most particularly for purposes of interdisciplinary projects where those with certain domain expertise would be paired with computer science students. To take advantage of the greater diversity stemming from massive numbers requires special kinds of recommender algorithms for grouping students, a theme we have raised in 2.4.1 on linking help providers with those needing help. Work within a possibly geographically dispersed group also requires enabling technology. Only then will opportunities to take advantage of diversity scale with numbers and variation of students.

2.4.2.4 Long-lived collaborations

In the opening of Section 1, we suggested that students could make their way through individualized paths of MOOCs, and in 2.2.3 we indicated that instructor collaborations were deliberatively designing pathways through a curriculum. Will broader student support groups form bottom-up within a single MOOC? Furthermore, will support groups persist and evolve over more than one MOOC, so that MOOCs and other MOOE are the basis for longer-term social partnerships? How can such support groups be facilitated through an artificially intelligent intermediary? These support groups can be tracked and evaluated, to include tracking the outcomes of student members as a function of group demographics and dynamics. A challenge is to obtain student behavioral data from across courses and other multimedia (e.g., remedial material that students accessed on Youtube), across platform, and across institutional boundaries; this recalls an analog challenge in 2.2.3 of tracking data in instructional communities. Even if such data is available, it may not be trivial to identify the same student on different platforms and in different settings, requiring the use of linkage algorithms that will identify students by different names.

There are clearly privacy and ethical concerns with such mining that must be addressed [2, pp. 41-44], and that may well trump technical feasibility of across-MOOC and across-platform data mining and other analyses in a truly open environment.

In addition to some of the possible negative broader impacts on privacy, online courses enable and encourage cross-cultural discourse, which can be studied by sociologists for evidence of cultural accommodation and blending; this is one broader impact, seemingly positive, of the enabling technology to support online education. How can we ensure—should we ensure—that MOOE is not simply sensitive to culture, but contributes to bridging cultures through design principles for cross-cultural learning? A general imperative is that researchers in online education that is open, massive, and ubiquitous look beyond no-brainers as possible broader impacts of their research, presumably strengthening research proposals and societal impact.

2.4.3 Larger communities in online and blended environments

Online social networking eases geographic constraints associated with student community, which focuses newly-sharpened attention on the question of the fundamental benefits of social learning, as well as whether those benefits "scale up" to larger and more geographically distributed courses. The freedom from geography allows us to pose new research questions such as: What community/social learning communication mechanisms/media can adjust to different scales (small groups, larger communities)? How do we design social groups of appropriate size and diversity for education? What social computing environments encourage different kinds of learning, and different kinds of mindsets, such as competition versus collaboration? What online course formats and content lead to diversity in the active, participating student populations, and what conditions lead to homogeneity? Will massive and online formats lead to interesting and important new forms of cultural accommodation and cultural blending? Can interactions be designed that encourage and mediate discussions among culturally and politically different players, using learning goals as the center that holds the conversation together and is a basis of wider respect, appreciation, and even understanding?

In section 2.1.2 we noted that residential universities want to leverage online learning to enhance their on-campus education, but that initial discussion was limited to “traditional” student outcomes, through flipped classrooms for example. However, there are undoubtedly broader cultural reasons for using online education for the benefit of on-campus students.

Figure 3 illustrates the rich possibilities for communities and collaborations at many grain sizes arise when on-campus courses are “synchronized” with MOOCs and other online offerings. [26][40] A campus-in-cloud (C-in-C) course is one in which a campus course proceeds simultaneous with a MOOC, with the MOOC requirements being a subset of the campus course. This has also been called a wrapper course [28], since the campus course is wrapped around a MOOC. This is different from a small private online course or SPOC [35], which uses online MOOC material, but without the benefit of a cohort of global students.

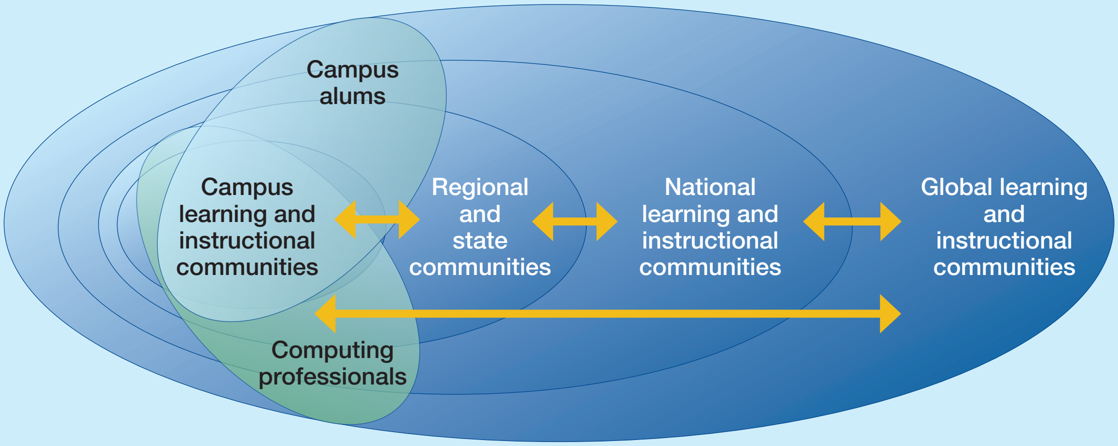


Figure 3: Communities, including collaborations, of instructors and students can exist at many grain sizes and interact effectively and at scale through enabling technology

In a C-in-C course, on-campus students can benefit from discussions with students from around the world along regional and/or thematic grounds. For example, for a sustainability course (C-in-C and MOOC), regional discourse about projected regional climatic changes can be protected discussions and projects between on-campus students and MOOC students in the region (and perhaps at other partner schools in the same region). In a computer science C-in-C (and MOOC pairing), discussion between on-campus students and various thematic groups (e.g., computing professionals, which are a group that is not uncommon in MOOCs, or perhaps women professionals) would be of great interest. Does participation in discourse outside the university improve selected student outcomes, for example, as classified by ABET accreditation criteria (e.g., *“an ability <and motivation> to analyze the local and global impact of computing ...”*)? Does community participation improve diversity in computer science? Our current best practice for encouraging women and under-represented minorities to persevere in a computer science degree program is to create a sense of *belonging.* Can a virtual community generate that same sense of belonging as a physical community? The tools that we have elaborated earlier in 2.4 as important in recommending people to each other would probably be highly relevant here, but more is required of MOOC platforms, which have a long way to go before they can effectively mediate and instrument complex paths of discourse among different subpopulations and create a community *esprit de corps* [23].

Online students can also help campus students by vetting and developing materials for physical learning communities. This vetting of material is an activity that an online population can provide to a campus population, but there is no reason that faculty can't use on campus students to vet material before it goes online. These vetting interactions are special cases of helper and helping roles that we raised in Section 2.4.1, and that have implications for student motivation and the like.

How do we analyze emergent structure in these new kinds of communities? What novel computational techniques will be capable of this? What data do we need—how many courses, over what time span? How long does it take community to form? What does dysfunction look like, and how can we detect it and turn it into learning opportunities both in the domain subject and culturally?

2.4.4 Managing global discourse

Anyone who has entered a MOOC discussion board, even a day after the class has started, knows that the the sheer number of posts can be overwhelming, with redundant forums and threads arising. MOOC platforms typically have rudimentary capabilities to manage redundancy, for example by providing suggestions of where a user's post might best fit as an alternative to starting a new thread. These real-time recommender capabilities will almost certainly improve with improvements in the natural language capabilities of the course-hosting platforms. While language translation by machine is quite robust for some languages, for others, not so much. But as translation capabilities improve, and the coverage of less commonly used languages improves, accurate translations into standard languages can be made. It is also possible that translations can be made "on demand," informed by knowledge of a user's native tongue and preferred language choice. *An interesting possible broader impact of work in discourse, translation, and MOOCs may relate to preservation (or not) of rare languages, and larger issues of cultural blending and accommodation.*

We also imagine that much can and will be done "offline," with intelligent software using clustering and topic modeling functionality to analyze posts and recommend merging and splitting the posts of threads and forums based on (dis)similarities of posts within a thread and across the discussion forums as a whole. Capabilities for relocating an individual post, or a copy of a post, in another forum are also desirable. Abilities to relocate copies of forum posts will allow intelligent assistants to copy a response from an instructor to one post, to other related posts by students, and in the longer term to recommend changes to an instructor response to one post before semi-automatically copying the adapted response to other student posts.

As the underlying technologies improve, the ambient intelligence that is scouring forums may move beyond making recommendations to the instructor team for changes in discussion forum organization, and become increasingly autonomous. In what circumstances will this inclination towards autonomy be most appropriate, and when not? How will the ambient intelligence communicate any changes it makes to users? Will the ambient intelligence software also be informed by social relationships, positive and negative, perhaps identified through sentiment analysis of posts, in making any changes to discussion board organization? In general there are rich possibilities for research in AI and machine learning over natural language in managing global discussions.

In addition to managing global discussions, there may be a desire to manage smaller, protected discussions within the global tumult. These protected discussions will likely correspond to the kind of collaborations and other communities that we described in conjunction with Figure 3. This creates still another layer of complexity in the management of discourse, with challenges for a multilayering of protections in what could amount to a very complex social network.

3. SUMMING UP: IMPLICATIONS FOR COMPUTING RESEARCH

The Workshop on Multidisciplinary Research for Online Education explored many and varied topics over its one-and-half days. This coverage was enabled by selected plenary sessions and the distributed breakouts, animated by participants spanning the computing and learning sciences. Ultimately, the deep synthesis across the relevant disciplines will happen through research, development, and deployment of computing technology that has been designed to enhance teaching and learning. Here we address a few enabling technologies, with a focus on relative novelties that we perceived in the workshop relative to other reports that we have referenced.,

3.1 Social Computing

Community and collaborations, and how to scale them to massive and open educational environments, were themes at the workshop. The following thoughts are taken from the extended summary of the breakout on supporting social learning [23].

"Ultimately, our research will lead us to development of new environments, which entails development of new technology. *An overarching goal is development of a communication medium that can accommodate emerging community/subcommunity structure—supporting the formation and sustenance of cohorts."*

"A key order of business will be development of supportive technologies including: development of new kinds of dashboards that display what instructors, facilitators, and research need to know about individuals, groups, and sub-communities as they form and function; development of technology for expertise tracking, for example, matching help needers with help providers and extending student modeling technology so that it models the ability of students to function productively in groups; and finally, development of computational techniques for monitoring and supporting norm formation and socialization. … All of this will be facilitated by platform/tool development that streamlines creation of affordances for visualization, access, and navigation of community resources and facilitates building large-scale, collaborative, educational applications." [23].

There are many potential broader impacts of social computing in the MOOE realm that researchers may want to study with partners from other disciplines. How do learning communities morph into global communities with orientations beyond education, entering into larger culture with both competitive and cooperative stances? How does community influence diversity of underrepresented groups in computing education at all levels, and the profession?

3.2 Human Computer Interactions

Many HCI issues are implicated by the challenges and opportunities of communities mentioned above, as well as more tightly coupled collaborations. What interfaces best support computer-supported collaborative learning, both collocated and at a distance, both synchronous and asynchronous? What is the process by which teams work in virtual, collaborative learning environments? Which tools will match learners with other learners and/or with mentors, taking into account learner interests and instructor styles? How can software both support collaboration and coach students about content?

In addition to community and collaboration, HCI will play important roles in personalized learning and assessment, and particularly so in massive and open settings. Much of the current attention in this area is on finding models of a learners' state of knowledge, along with when and how knowledge was learned. The workshop extended this thrust in several directions, asking questions about knowledge representations for student traits, propensities, and goals, as well as building models for instructors and other helpers [1, p. 43].

Continuing with the the personalized learning thread, there is still little in the way of dynamic assessment within online and hybrid formats at large scales, but such strategies will be critical in helping students navigate through opencourseware. How can algorithms identify pedagogy that worked best for each individual, and generalize models of best pedagogy across "like" individuals? How do we address the communicative interaction between learner and software and use multimedia to switch modalities as appropriate? How can intelligent ambient environments, virtual or physical, reason about student cognition? How can we design such environments to be "optimally" active in probing what students know and setting up test situations for students in the moment?

3.3 Data Mining and Machine Learning

Educational data mining and learning analytics were well represented at the workshop, with a panel dedicated to these methods, and two breakout sessions. Our report has alluded to various machine learning applications—for organizing learning objects for reuse, for grading, for developing evidence-based recommender systems to match students and instructors to content, and to each other. There are general questions arising from our examples. How can machine learning of student models be used to bring students together in like, or otherwise complementary, learning cohorts? Who are the potential consumers of this data, e.g., how can data be distilled for assessment content so it is useful for each stakeholder? How do we ensure security and privacy of student data?

We have also discussed the desirability of analyzing data across platforms, and more generally of *data interoperability* [2, p. 38]. Even if policy and privacy challenges can be overcome, however, there will be challenges of *"representational mismatch"* between data sources as suggested by the breakout groups in this area [24].

There are many machine learning methods that are applicable to educational data mining (e.g., see [2, pp. 9-12] for a brief survey). But many of these methods are inherently limited by the representation of data, often as a simple vector of values. How will application imperatives, such as automated grading of complex student inputs, inform new algorithms for data mining of complex relational structures, like computer programs that are represented by parse trees? Surely, more complex representations are desirable, if not needed, in many circumstances. These more complicated data representations require alternative machine learning approaches that appear underused in educational settings (e.g., *inductive logic programming* [32])

Finally, our concerns with unequal access to technology translate to other issues, such as under-representing some classes of learners, and therefore "under-learning" about those learners. More generally, learning "edge cases" of students, and edge cases of relationships between learners and other resources, would be a desirable focus in the MOOE space, for both the opportunities at a massive scale (e.g., larger numbers of learners and therefore larger numbers in the edge classes), but also challenges in an open environment that is (perhaps) less amenable to controlling confounds.

3.4 Mobile Computing

There was less discussion at the workshop on mobile technology than might be expected, though it was discussed in the Formal and Informal Learning breakout as a vehicle for seamlessly transitioning between these learning paradigms [25], and it was highlighted in the ARET report [1, pp. 27-28] for reasons of diminishing boundaries in learner and teacher roles. What is the nature of student/faculty interaction through mobile computing, and what are new kinds of interactions that are pedagogically useful? Which technical issues should be addressed to support tracking, personalizing, and supporting multiple learning activities?

There are probably several reasons that mobile technology was not discussed more. One reason may stem from one of the foci advocated for mobile computing in the ARET report.

> "... research that identifies *pedagogical challenges* relevant to mobile learning. The point of turning to new technologies is to find the pedagogies that promote higher quality learning of a more durable kind than traditional methods. We need to understand what it takes to learn and then develop the pedagogical forms that are most likely to elicit the cognitive activities learners need." [1, p. 49]

That is, as a subject of research, the pedagogical advantages of mobile technology may not be trivially clear. The ARET report continues

> "We definitely need to ask whether the task for us is that of adaptation of ourselves to technologies (including the social technologies) or whether the urgent task is a careful consideration of the utility in a wide range of ways of our adoption of technologies for considered purposes?" [1, p. 49]

Even if we might think that the most pressing stance is the latter, our interest in the pedagogy of mobile technology stems, at least in part, because it is ubiquitous, and this begs finding educational utility—what can "adaptation of ourselves" to mobile technology look like for learning? The hoped-for payoffs, as mentioned, relate to diminishing sharp boundaries between formal and informal learning, as well as issues of educational access to all. How does technology support universal access to global classrooms, including for the developing world where mobile technology has a more significant presence than other computing platforms?

Another reason that mobile technology might have been discussed less than expected is that while it clearly relates well to openness, its relevancy to MOOE suggests a new interpretation of "massive as ubiquitous" (see 2.1.4), rather than today's typical interpretation of "massive" as large-numbers in a semi-synchronous setting.

There are other possible benefits of mobile technology, of course. It can be an important vehicle for integrating online higher education with physically distributed course projects (e.g., involving data collection). Imagine a MOOC on sustainability, for example, with distributed "super sections" defined by collaborating institutions located in the same watersheds, with students collecting and sharing data on environmental conditions using mobile technology, as part of the global and local discourse.

3.5 Broader Impacts

Throughout this report we have described possible broader impacts that computer scientists can include as part of interdisciplinary teams working on MOOE. For the most part, these have been the broader impacts of MOOE research, and have included broader impacts for diversity, cultural discourse and change. However, to a large extent the workshop was premised on the idea that what is an intellectual merit contribution in computer science may have broader impacts (from the CS perspective) in the learning sciences and education, as intellectual merit to those fields, particularly in massive and open contexts.

There are some other broader impacts of MOOE that we mention before closing. One is for workforce development, an issue of national importance that was highlighted at the workshop's final town hall meeting. It would be valuable for researchers to measure and assess the influence of MOOE projects, both research and deployment, on regional and/or national workforce development.

Another possible broader impact of MOOE is on interdisciplinary research, not just in the learning sciences, but will any increase in trans-institutional teaching collaborations lead to an increase in research partnerships as well? If, as the ARET 2010 report suggests [1, pp. 26-27], online education will diminish boundaries, will one class of these boundaries be disciplinary research stovepipes? MOOE will allow faculty to more easily test the waters of trans-disciplinary partnerships in the teaching realm—will such activity translate to later research partnerships as well?

Longitudinal studies could track changes in interdisciplinary research, both in the learning sciences and otherwise, as a result of MOOE. Indeed, much of the technology we have talked about to promote community and collaborations could serve to promote pathways from teaching collaborations to research collaborations.

In any case, MOOE components on research proposals of all types could serve as part of broader impacts plans, both as a means of communicating science to the public (and other outreach) and as part of formal education plans.

4. REFERENCES AND OTHER RESOURCES

[0] Workshop on Multidisciplinary Research for Online Education, Feb 11-12, 2013 Washington, DC http://www.cra.org/ccc/visioning/visioning-activities/online-education/286-multidisciplinary-research-for-online-education. Links to workshop presentations, participants, and supplementary materials are on this site, as well as a links to *this report* and an *online workshop addendum* that contains written details on the workshop and breakout sessions; this addendum also includes selected materials made available since the workshop, and it will be updated periodically.

4.1 MROE Workshop background reports

[1] *A Roadmap for Education Technology,* Prepared by Beverly Park Woolf (2010). Prepared for the Computing Community Consortium of the Computing Research Association, Full report at http://www.cra.org/ccc/files/docs/groe/GROE%20Roadmap%20for%20Education%20Technology%20Final%20Report.pdf; short brochure at http://www.cra.org/ccc/files/docs/groe/Roadmap%20for%20Education%20Technology%20-%20Summary%20Brochure.pdf

[2] *Enhancing Teaching and Learning Through Educational Data Mining and Learning Analytics,* Prepared by Marie Bienkowski, Mingyu Feng, & Barbara Means. Prepared for U.S. Department of Education, Office of Educational Technology http://www.cra.org/ccc/files/docs/learning-analytics-ed.pdf

4.2 Other Selected Reports

[3] Evaluation of Evidence-Based Practices in Online Learning: A Meta-Analysis and Review of Online Learning Studies, Prepared by Barbara Means, Yukie Toyama, Robert Murphy, Marianne Bakia, & Karla Jones. Prepared for U.S. Department of Education, Office of Planning, Evaluation and Policy Development, Washington, DC, May 2009, 93 pp http://www.breining.edu/USDEDistLearning.htm

[4] Expanding Evidence Approaches for Learning in a Digital World, U.S. Department of Education, Office of Educational Technology 2013 http://www.ed.gov/edblogs/technology/evidence-framework/

[5] Transforming American Education: Learning Powered by Technology, National Education Technology Plan 2010, U.S. Department of Education, Office of Educational Technology http://www.ed.gov/technology/netp-2010

4.3 Selected Institutions, Societies, Agencies

[6] The Association for Computational Creativity http://computationalcreativity.net/

[7] Dynamic Learning Maps http://dynamiclearningmaps.org/assessment/whatisadlm.html

[8] International Educational Data Mining Society http://www.educationaldatamining.org/

[9] International Society of the Learning Sciences http://www.isls.org/

[10] MyData: Personal Learning Profile http://www.ed.gov/edblogs/technology/mydata/

[11] The Open University http://www.open.ac.uk/

[12] Society for Learning Analytics Research http://www.solaresearch.org

4.4 Selected Repositories

[13] Merlot II Multimedia Education Resource for Learning and Online Teaching http://www.merlot.org/

[14] Model AI Assignments http://modelai.gettysburg.edu/

[15] Nifty assignments http://nifty.stanford.edu/

4.5 Selected Conferences (others sponsored by societies above)

[16] ACM Conference on Learning @ Scale http://learningatscale.acm.org/

[17] ACM Conference on Computer-Supported Collaborative Work and Social Computing http://cscw.acm.org/

[18] MoocShop: a research-oriented workshop on massive open online courses http://www.moocshop.org

4.6 Selected Journals (others sponsored by societies above)

[19] *International Journal for Computer-Supported Collaborative Learning* http://ijcscl.org/

[20] *Journal of Learning Analytics* http://www.solaresearch.org/journal/

[21] *Journal of Online Engineering* http://online-journals.org/index.php/i-joe/index

[22] *Journal of Online Learning and Teaching* http://jolt.merlot.org/

4.7 Selected Breakout Extended Summaries

[23] Supporting Social Learning, extended breakout summary on workshop online addendum (Appendix B, section B.3) prepared by Carolyn Rosé; short summary in section 5.3

[24] Machine Learning and Data Mining, extended breakout summary on workshop online addendum (Appendix B, section B.4) prepared by Jack Mostow; short summary in section 5.4

[25] Formal and Informal Learning, extended breakout summary on workshop online addendum (Appendix B, section B.5) prepared by Marie Bienkowski; short summary in section 5.5

[26] Alternatives to MOOCs, extended breakout summary on workshop online addendum (Appendix B, section B.17) prepared by Irene Greif and Mary Lou Maher; short summary in section 5.17

4.8 Other References Cited

[27] Basu, S., Jacobs, C., & Vanderwende, L. (2013). Powergrading: a Clustering Approach to Amplify Human Effort for Short Answer Grading, *Transactions of the Association for Computational Linguistics, 1.* http://www.transacl.org/wp-content/uploads/2013/10/paperno32.pdf

[28] Bruff, D., Fisher, D., McEwen, K, & Smith, B. (2013). Wrapping a MOOC: Student Perceptions of an Experiment in Blended Learning, *Journal of Online Learning and Teaching* Vol. 9, No. 2, June 2013. http://jolt.merlot.org/vol9no2/bruff_0613.htm

[29] Cullinan, C., & Agamanolis, S. (2003). Reflexion: a responsive virtual mirror for interpersonal communication, Conference Supplement, ECSCW 2003 8th European Conference on Computer Supported Cooperative Work, Helsinki, 14 - 18 September 2003. http://web.media.mit.edu/~stefan/hc/projects/reflexion/

[30] Dasarathy, B., Sullivan, K., Schmidt, D., Fisher, D., Porter, A. (accepted). The Past, Present, and Future of MOOCs, To appear in Proceedings of the 36th International Conference on Software Engineering, May 31 - June 7, 2014, Hyderabad, India.

[31] Denny, J. C., Irani, P. R., Wehbe, F. H., Smithers, J. D., Spickard, A. III (2003). The KnowledgeMap Project: Development of a Concept-Based Medical School Curriculum Database, AMIA Annual Symposium Proceedings: 195–199. http://www.ncbi.nlm.nih.gov/pmc/articles/PMC1480333/

[32] De Raedt, L., Frasconi, P., Kersting, K., Muggleton, S.H. eds. (2008) Probabilistic Inductive Logic Programming Series: Lecture Notes in Computer Science, Vol. 4911, Subseries: Lecture Notes in Artificial Intelligence 2008, VIII

[33] Downes, S. (2001). Learning Objects: Resources for distance education worldwide, *The International Review of Research in Open and Distance Learning, V. 2, N. 1.* http://www.irrodl.org/index.php/irrodl/article/viewArticle/32/378%3A

[34] Fishman, B., Konstantopoulos, S., Kubitskey, B. W., Vath, R., Park, G., Johnson, H., & Edelson, D. C. (2013). Comparing the Impact of Online and Face-to-Face Professional Development in the Context of Curriculum Implementation, *Journal of Teacher Education,* http://jte.sagepub.com/content/early/2013/05/24/0022487113494413.full.pdf+html

[35] Fox, A. (2013). From MOOCs to SPOCs, *Communications of the ACM,* Vol. 56 No. 12, pp. 38-40. http://cacm.acm.org/magazines/2013/12/169931-from-moocs-to-spocs/fulltext

[36] Gaver, W. W., Bowers, J., Boucher, A., Gellersen, H., Pennington, S., Schmidt, A., Steed, A., Villar, N., & Walker, B. (2004). The drift table: designing for ludic engagement. In Proceedings of the ACM CHI 2004 Human Factors in Computing Systems Conference, April 24-29, 2004, Vienna, Austria.

[**37]** Goldberg, K. ed. (2000). The Robot in the Garden Telerobotics and Telepistemology in the Age of the Internet, MIT Press, A Leonardo Book ISBN: 0-262-07203-3. http://leonardo.info/isast/leobooks/books/goldberg.html

[38] Hundhausen, C., Agrawal, A., & Ryan, R. (2010). The Design of an Online Environment to Support Pedagogical Code Reviews. In Proceedings of SIGCSE '10, March 10–13, 2010, Milwaukee, Wisconsin, pp. 182-186. http://dl.acm.org/citation.cfm?id=1734324

[39] Katz, J. (1994), Geographical Proximity and Scientific Collaboration, Scientometrics, V. 31, N. 1 31-43. http://www.sussex.ac.uk/Users/sylvank/pubs/geo_prox_collab.pdf

[40] Kizilcec, R. F. (2013). Collaborative Learning in Geographically Distributed and In-person Groups. In Proceedings of the 1st Workshop on Massive Open Online Courses at the 16th Annual Conference on Artificial Intelligence in Education. July 9, 2013, Memphis, TN. http://people.csail.mit.edu/zp/moocshop2013/paper_6.pdf

[41] Klahr, D. (1974). Individualized Curriculum Design through Computer Aided Analysis, Presented at the Symposium on Improving the Effectiveness of Business Education through Innovative Technology, March 25-29, 1974, University of Texas at Austin.

[42] Kollar, I. & Fischer, F. (2010). Peer assessment as collaborative learning: A cognitive perspective. Learning and Instruction, 20, 344-348. post-print at http://epub.ub.uni-muenchen.de/12923/2/Peer_assessment_as_collaborative_learning.pdf

[43] Kriplean, T., Toomim, M., Morgan, J. T., Borning, A., & Ko, A. J. (2012). Is This What You Meant? Promoting Listening on the Web with Reflect,Conference on Human Factors in Computing Systems, May 5-10, 2012, Austin, TX http://dub.washington.edu/djangosite/media/papers/tmptxCAiy.pdf

[44] Kulkarni, S. C., Pang Wei, K., Le, H., Chia, D., Papadopoulos, K., Cheng, J., Koller, D., & Klemmer, S. (2013). Peer and Self Assessment in Massive Online Classes, *ACM Transactions on Computer-Human Interaction,* Vol. 9, No. 4. http://hci.stanford.edu/publications/2013/Kulkarni-peerassessment.pdf

[45] Lovett, M., Meyer, O., & Thille, C. (2010). In Search of the "Perfect" Blend between an Instructor and an Online Course for Teaching Introductory Statistics, Presentation to International Conference on Teaching Statistics: Data and context in statistics education: towards an evidence-based society (ICOTS-8). July 11-16, 2010, Ljubljana, Slovenia. http://iase-web.org/documents/papers/icots8/ICOTS8_9G2_LOVETT.pdf

[46] Mahaley, S. & Teigland, R. (2009). Advancing Learning through Virtual Worlds, In S. Murugesan (ed), Handbook of Research on Web 2.0, 3.0, and X.0: Technologies, Business, and Social Applications, IGI Global.

[47] Pan, R. K., Kaski, K., Fortunato, S. (2012) World citation and collaboration networks: uncovering the role of geography in science, Scientific Reports, V. 2, Article number 902. http://www.nature.com/srep/2012/121129/srep00902/full/srep00902.html

[48] Pawar, U. S., Pal, J., & Toyama, K. (2006). Multiple Mice for Computers in Education in Developing Countries, International Conference on Information and Communication Technologies and Development, ICTD 2006 May 25-26, Berkeley, CA.

[49] Siemens, G., & Baker, R. S. d. (2012). Learning analytics and educational data mining: towards communication and collaboration. In LAK '12 Proceedings of the 2nd International Conference on Learning Analytics and Knowledge, pp. 252-254

[50] Wick, M., Singh, S., Pandya, H., McCallum, A. (2013). A Joint Model for Discovering and Linking Entities. In Proceedings of the Third International Workshop on Automated Knowledge Base Construction (AKBC).

[51] Wikipedia, History of Virtual Learning Environments https://en.wikipedia.org/wiki/History_of_virtual_learning_environments

5. SUMMARIES OF TOPICAL BREAKOUT SESSIONS

This section contains summaries of individual breakout sessions provided by their respective participants, typically the breakout leader and/or scribe. The summaries are reformatted versions of slides used in breakout group plenary reports that were presented at the workshop itself. These brief summaries typically list general research areas and questions identified by the group. When available, longer writeups prepared after the workshop can be found in Appendix B of the *online workshop addendum* (see [0]).

5.1 Personalizing Education: Roles of Computing

Participants: James Lester (Lead), Dan Garcia (Scribe), Vincent Aleven, David Klahr, Norma Ming, Vitaly Shmatikov, Emily Dalton Smith, Loren Terveen, Beverly Woolf

- What is Personalization?
    - Everyone gets what they need (content, style [video, audio, text, ...] ...) when they need it (availability, PBL "pull," etc):
    - What happens when there are collaborations?
- META: Where is the pain in the classroom? Is personalization serving that? What is there demand for and what can we do?
- Big Research Questions
    - Non-STEM: What to do for ill-defined domains?
    - Data: How to connect it across systems, standards?
    - Doing it: What to adapt, how to adapt (using learning models)
    - Assessment: What if there's a wobbly start/finish?
- Concerns & Challenges
    - Who will build it (workforce), use it (not if we didn't build, policy), sustain it (if builder leaves), what happens to competition (what does it mean to be good), tracking (what if they stumble), privacy. Obv, start with low-hanging fruit.

5.2 Assessment of Student Learning

Participants (morning): Scott Klemmer (Lead), Dan Hickey (Scribe), Jeffrey Bigham, Knatokie Ford, Marcia C. Linn, Rob Miller, Jack Mostow, Beth Simon, Candace Thille, Mark Wilson
Participants (afternoon): Anoop Gupta (Lead), Derek Bruff (Scribe), Karen Brennan, Brian Butler, Sharon Derry, David Klahr, Chris Makler, Norma Ming, Dawn Rickey, Vitaly Shmatikov, Raluca Teodorescu

- Many flavors: How, when, for who? What's the landscape? ...and lamppost(s). What can we learn from and contribute to theory?
- How might we assess the experience? Free-range assessment, the value of process, and what are roles & opportunities for feedback?

- How might we combine people & algorithms? ...and leverage insights across classes?
- Less worried about cheating. Except... do we have to throw out all our great questions? (“keeping it fresh”)

5.3 Supporting Social Learning

Participants: Carolyn P. Rosé (Lead), Cindy Hmelo-Silver (Scribe), Sharon Derry, Dan Hickey, Anita Jones, Jihie Kim, Beverly Woolf, Trey Lathe, Norma Ming, Glynda Hull, June Ahn, Ben Bederson, Karen Brennan, Derek Bruff, Amy Collier, Irene Greif, Beth Mynatt, Gerry Stahl, John Cherniavsky

(also see the online workshop addendum at reference [0] for more complete write-up)

Research Questions

- [Analysis version] How can we design a communication medium that can adjust to different scales so we can have the whole community, but there can also be small groups or subcommunities that thrive within that larger environment?
- What can we learn and leverage from research on crowdsourcing? How can we balance concerns about community endeavors (getting work done in community, e.g., answering questions) with supporting the kinds of interactions that are conducive to the rich interactions that promote learning?
- How do best practices in design from existing online communities transfer into massive online learning contexts? What is similar/different in this context that might require new questions to be answered?

Research Directions

- Develop infrastructure for socialization of “online learning survival skills.” Perhaps MOOC to prepare people for MOOC based education. As a specific example: Develop affordances for socializing civility.
- [Design version] Design a communication medium that can adjust to different scales so we can have the whole community, but there can also be small groups or subcommunities that emerge and thrive within that larger environment.
- Platform development: Create affordances for visualization, access, and navigation of community resources. Facilitate building large-scale, collaborative, educational applications. And make it easy to integrate them with existing online educational platforms.

5.4 Machine Learning and Data Mining

Participants (morning): Emma Brunskill (Lead), Deepak Kumar (Scribe), Dan Butin, Sharon Derry, Ed Dieterle, Sidney D’Mello, Scott Rixner, Mehran Sahami, Juan Vargas.
Participants (afternoon): Jack Mostow (Lead), Amy Collier (Scribe), Marianne Bakia, Gautam Biswas, Lee Giles, Edith Gummer, Jonathan Huang, Jihie Kim, Chris Makler, Mack Olson, Roy Pea, Carolyn Rosé, Loren Terveen, Mark Wilson

(also see the online workshop addendum at reference [0] for more complete write-up)

Filling sensory, representational, and meaning gaps:

- How can we discover educationally significant events and features (e.g. dis/engagement, learning, complex problem solving, skills, gaming, cheating, ...) in low-level multimodal data of diverse types?
- What kinds of knowledge (e.g. about content, context, students, learning, instruction, social networks, …) can machine learning exploit to make sense of such data, and how?
- Can ML be used to automatically create new representations of content areas, modularizing and organizing course material into objects, and making tailored object recommendations to students?

What makes online learning data fruitful to mine?

- How can online learning be designed or transformed to log such data?
- What automation can support this design or transformation process?

Human-machine division of labor:

- How can online learning platforms combine ML and human computation (e.g. crowdsourcing, peer input, referral) to scalably assess learning, annotate, evaluate instruction, or teach better?

5.5 Formal and Informal Learning

Participants: Marie Bienkowski (Lead), Brian Butler (Scribe), Gautam Biswas, Gerhard Fischer, Jonathan Huang, Dorothy Jones-Davis, Taylor Martin, Roy Pea, Jenny Preece

(also see the online workshop addendum at reference [0] for more complete write-up)

Research Areas

- Embedded Learner...with mediated experiences that flow among settings, and reveal what happens in informal settings
- Social/Collaborative Learner...with shifting roles from teacher to learner, from consumer to prosumer, etc. (Digital Learning Commons)
- Creative Learner...how does learning the facts differ from creating, designing, making, doing?
- Activated Learner...how does technology help with developing agency and self-regulated learning

Representative Research Questions

- What role do informal experiences have on interest in STEM?
- Can we develop models to predict when learners will benefit from specific pedagogies and content?
- What role do so-called noncognitive factors play in across settings and across timescales?
- What are effective techniques for blending qualitative and quantitative data and methods in a big data world?
- What are the evolving roles for teachers in the new digital learning world?
- What new roles can multiple sensors play in establishing the learners context?

5.6 Pedagogical Needs and Constraints of Various Domain Areas

Participants: Mark Guzdial (Lead), Chris Makler (Scribe), Lee Giles, Mitch Green, Beki Grinter, Glynda Hull, David Karger, Lauren Resnick, Margaret Soltan, Raluca Teodorescu, Gary White

Research Areas: We recommend more research in:

- Automated evaluation of text discussion. Other domains rely more on discussion. We need to be able to facilitate discussion at scale, and judge content.
- Peer-teaching and the identification of good peer-teaching. We need peers to act as models, coaches, and evaluators. What makes for good peer-teaching, and how can we encourage the best to do more of it?
- Understanding mappings between different representations. Summarizing a diagram in text, or creating a network representation from text are skills we ask students to do in some domains. We should be able to create algorithmic assessment methods for these.

Research Questions:

- How do we support on-line learning for various ways of coming to know: Correct knowledge (STEM), humanities knowledge (different interpretations of same text), historical knowledge, and design knowledge?
- How we facilitate (guide and assess) productive, accountable talk for student learning?
- How do we automatically check problem-solving process?
- How do we recommend pace and face-to-face/blended/on-line learning?

5.7 Interacting with Objects

Participants: Mary Lou Maher (Lead), Fred Martin (Scribe), Tiffany Barnes, Winslow Burleson, Andrea Forte, Anoop Gupta, Rogers Hall, Dawn Rickey, Gerry Stahl, Tsuihsia Tseng, Janet Kolodner

Objects that are integral parts of learning:

- Physical objects: Froebel's gifts, tangible devices, lego
- Conceptual learning objects: chunks of content around a learning purpose
- Virtual objects: virtual humans, simulated physical objects, online labs
- Software objects: apps, MOOCs, games
- Communities that form around objects of learning

We distinguished between objects made for learners to use, and objects made by learners.

Research Questions:

- Physical vs virtual: How can online learning include physical and virtual objects for recording, augmenting, or replacing physical interaction? What are the tradeoffs of using virtual versus physical on learning outcomes?
- Motivate learning: How can the different layers of objects (e.g. physical, model, simulation, interaction) be designed to ask the right questions and motivate deep learning?
- Social learning: What interaction design advances need to occur for people to collaborate on making, sharing and playing with (physical) objects online?
- Objects tell stories and can be watchful

5.8 Social Computing & Networking

Participants: Candace Thille (Lead), Jeffrey Bigham (Scribe), June Ahn, Emma Brunskill, Rogers Hall, Cindy Hmelo-Silver, Irene Greif, David Karger, Scott Klemmer, Mary Lou Maher, Jenny Preece

How do we design/instrument online education environments in order to create effective learning environments and simultaneously answer questions that will allow us to contribute back to theory?

Current

- Most of the current use of social media to support learning is
  - Not designed.
  - Not collecting meaningful/accessible data
- Need to review
  - what people are doing now with existing social technology (e.g. discussion boards, blogs, youtube, facebook, hangout, etc.)
  - work from fields beyond cognitive science, learning science, education science, computer science.

Research Questions

- What are the fundamental benefits of social learning and how do they scale up?
- What about social learning persists/changes when you switch to online? How / when to blend?
- How do you design social groups (size, diversity) for education and scaffold social experiences?
- What social computing environments encourage what kinds of learning? (competition/collaboration)
- How do you design for different populations

Motivating questions: Once online higher education is embedded in larger social contexts, how can computational systems support student collaboration and engagement? What is the process by which teams work in virtual, collaborative learning environments? Which tools will match learners with other learners and/or with mentors taking into account learner interests? How can software both support collaboration and coach students about content? How do we examine learning communities, and what is the scope and other characteristics of these communities? How do learning communities morph into global communities with orientations beyond education? How do learning communities sustain, build on and share knowledge? How do we address infrastructure (API, management) and application level (representation) issues? What integrations/mash-ups of devices/ platforms would more effectively support social learning distributed across time, space and media?

5.9 Long-term implications of online learning for cultural interactions

Participants: Taylor Martin (Lead), Doug Fisher (Scribe), Ed Dieterle, Gerhard Fischer, Mitch Green, Dorothy Jones-Davis, Margaret Soltan, Gerry Stahl, Sharon Derry, Glynda Hull

A Few Themes

- Broadening participation
- Cultural relevancy, culture-informed course design
- Technology encouraged cooperation, community, competition

- “respect” cultural differences versus change culture
- Education culture; Implications for diversity (and uniformity) of content

A Few Questions

- What online course formats and content lead to diversity in the active, participating student populations, and what conditions lead to uniformity?
- “To what extent, why, when, and how online models work or do not work for different student populations, especially historically disadvantaged students and underserved populations?”
- How will online formats change educational culture from ’sage on stage’, not just because of ’flipped classroom’ guide on side interactions, but as faculty (openly) become ’consumers’ of online education and become members of learning communities with their students? (vice versa)
- How can MOOCs be customizable and personalizable in “real time”? (smart, not offend, create bonds)
- HCI to support massive global discourse; HCI for deep, compelling immersion (promote empathy?)

5.10 Implications for Computer Science Education

Participants: Beth Simon (Lead), Mark Guzdial (Scribe), Ivon Arroyo, Marie Bienkowski, Sidney D’Mello, Dan Garcia, Deepak Kumar, Fred Martin, Mehran Sahami, Tsuihsia Tseng, Juan Vargas

Research Questions

- Can we use games as a model for supporting development of a growth mindset in learning computing?
- We know that some face to face PP/PI (paired-programming / paired-instruction) works really well. How do we map these online?
- Why is it so often that undergrads in CS teach other undergrads? How do we create near-peer on-line tutors/mentors/guides?
- What is CS PCK (pedagogical content knowledge)?
- Existing MOOCs to date are incredibly not diverse. CS already has a massive lack of diversity. How can diversity be supported?
- What needs to change to increase retention and completion online. Is it the modularity? Should MOOCs be a week long? What about degree programs?

5.11 Human-Computer Interaction

Participants: Ben Bederson (Lead), Dan Butin (Scribe), Beki Grinter, Janet Kolodner, Beth Mynatt, Loren Terveen

HCI offers a perspective on many of the other topics:
- User experience design → learner experience design
- Motivation & participation
- Ethics & diversity
- Range of participants (learner, teacher, coach)

Motivating questions: How do we develop dynamic assessment within online and hybrid formats? How do we develop learning models that represent what learners know, along with when and how knowledge was learned? How can algorithms identify pedagogy that worked best for each individual? How do we address the communicative interaction between learner and software, and use multimedia to switch modalities as appropriate? How can intelligent ambient environments reason about student cognition? What interfaces best support collaborative learning, both collocated and at a distance, both synchronous and asynchronous?

5.12 Games & Gamification

Participants: Tiffany Barnes (Lead), James Lester, Vincent Aleven, Scott Rixner, Bev Woolf, Dan Hickey, Jihie Kim, Marcia Linn, Win Burleson

Research questions

- How do we integrate good assessment with games? In multiplayer?
- How can we create games that encourage connections between learning/life?
- How do we merge good pedagogy (e.g. reflection) with good games?
- How can we support teachers to use games? What is the role of the game and the teacher? How do we integrate games with learning/classes?
- How can we integrate automated feedback?
- What are the key features of game reward structures, or other ways that engage & motivate?
- How can we balance just in time with just in case learning?

Recommendations

- Help players and teachers see/understand game performance
- Design in/out of game experiences
- Design for alignment between game and the learning task(s)
- Look for ways to support collaboration in games

5.13 Crowdsourcing of assessment

Participants: Tiffany Barnes, Emma Brunskill, Dan Garcia, Jack Mostow, Jon Huang, Jeff Bigham, Chris Makler, Dan Butin, Mark Wilson, Loren Terveen, Lee Zia, Jeff Forbes, Armando Fox

- How can we promote learning by assessors? What resources do assessors need to learn the content better, and to be better assessors?
- What are effective incentive models for crowdsourcing of assessment? (required, paid, volunteer, etc)
- How do we best match assessors with assessees?
- How should crowdsourcing of assessment change based on its purpose? (e.g. for credentials, formative feedback)?
- What are desirable relations among the assessment task, the knowledge and skills of the assessor, the knowledge and skills of the assessee, what they know about each other and the purpose of the assessment?

- How do characteristics of people influence assessments? How can we make crowdsourced assessments personal (as opposed to impersonal)?
- How can you psychometrically evaluate crowdsourced assessment?
- How and when should we combine types of feedback: automated, expert, reputed, and general crowdsourced?
- How can we best combine effective models for crowdsourcing with effective models for assessment?
- How can we facilitate sharing of content and assessment across classes/domains? (e.g. one class uses assignments from another)

5.14 MOOCets (K-6) & MOOCoids (65+)

Participants: David Klahr, Doug Fisher

- Core idea1: MOOCs for populations outside the conventional "target audience age range"
    - Kids & Elders: in the tails of the distribution of:
        - technical access & competence
            - research needed for characterizing current and future state of digital divide for these populations
        - motivation and learning goals
        - attractive and enabling technologies (affordances) vary
            - educational games; (e.g. merge MOOC and MMOG concepts),
            - school based and out-of-school
- Core idea2: cross generational access to learning (GPs and GKs)
- Core idea3: Move "Commons" of material (Sesame Street) to MOOC for instruction & assessment (Teacher: how much do my students know?)
- Comfort of a common anchor (Mr. Rogers, Sheriff John, ... Khan Academy) across curriculum
- Synergies: interacting with objects, ad hoc technologies, culture,...

5.15 Blended/flipped classrooms

Participants: Beth Simon, Scott Klemmer, Lance Fortnow, Gautam Biswas, Lee Giles, Anoop Gupta, Scott Rixner, Fred Martin, Vincent Aleven

Definition: Basic information is acquired outside of classroom; classroom used to achieve deep learning
- Before class: Video lecture with quizzes, MC questions
- In class: Small group discussion spurred e.g. by carefully crafted MC questions or small projects (active learning)
- Fit with MOOCs: Watch Coursera course at home, discuss in class

Big question: how to help people get started; not whether to have flipped classrooms

Research Questions

- How do we make the every day instructor awesome?
- What are the key ingredients for blended learning?
- Do blended courses lead to better learning (e.g., transfer, retention, preparation for future learning)?
- How do we do experiments when technologies and attitudes are changing every year?
- What is the unique value of physical presence? Can the flipped classroom experience be converted to an online experience.

5.16 Communities of Learners

Participants: Cindy Hmelo-Silver (Lead), Carolyn Rosé (Lead), Sharon Derry, Dan Hickey, Anita Jones, Jihie Kim, Beverly Woolf, Trey Lathe, Norma Ming, Glynda Hull

Research Questions

- **Conceptualization:** Is community even the right way of conceptualizing the social spaces we're talking about? What would an "online campus" mean? What needs would that campus community meet?
  - Are we deeply leveraging the Communities of Practice theory/ model?
  - Contextual issues: domain structure, time, scale, and age
- **Understanding:** How do we analyze emergent structure in communities? What novel computational techniques will be capable of this? What data do we need—how many courses, over what time span? How long does it take community to form?
- **Function:**
  - What roles do we need to pay attention to and support? What are roles at the community level (outside of a single course), and what is their function? Whose job is it to foster community?
  - How can we turn dysfunction into learning opportunities? What does dysfunction look like? What about cultural differences in expected behavior?
  - What would motivate people to participate and contribute? Extending the literature on commitment and contribution to online communities? (Kraut and Resnick)

Research Agenda

- Build a theoretical framework with clear dimensions that facilitates understanding and prompts effective development
  - Fostering/Supporting
  - Assessing
  - Providing information for researchers/ teachers
- Build supportive technologies:
  - Develop new kinds of dashboards: what do we need to know about/report individual, group, and subcommunity norms and behavior?
  - Develop technology for expertise tracking: matching help needers with help providers, extending student modeling technology so that it models the ability of students to function in participant roles in addition to modeling their progress achieving course learning objectives

5.17 Alternatives to MOOCs

Participants: Mary Lou Maher (Lead), Irene Greif (Lead), … this was a very large group and other participants were not recorded

(also see the online workshop addendum at reference [0] for more complete write-up)

Research to understand MOOCs:

- Models: What are the many models for MOOCs (Coursera only being one): Open University, cMOOCs, xMOOCs, EDx, Kahn Academy, Udacity, Active Worlds
- Benefits: What do we want to preserve from MOOCs? Curiosity-driven learning, massive, single course, learning on demand, self-directed learning, online community

Research towards new models:

- Scale:
  What do we want to scale? teachers, courses, diversity of learners.
  What are the economics of scale for developing and distributing online learning? comparing intelligent tutoring to professors to crowdsourcing peer learning
- Technology: Can we achieve massive beyond high bandwidth online to reach low tech students?
- Learning: Design models for education systems that break down educational elitism: break down conventional course/degree boundaries, break down expectations about completion/credentials
- Populations and Culture:
  What research is needed to reach those people not served by existing MOOCs?
  What are the characteristics of MOOC participants and who is not using MOOCs?
  How can we adapt online learning environments to specific situations of underserved learners, specific situations, different cultures, parent-child learning?
  Design models for learning environments so students can tell different stories to satisfy the different constituencies that are important to them.

PARTICIPANTS

June Ahn, University of Maryland, College Park
Vincent Aleven, Carnegie Mellon University
Guy-Alain Amoussou, National Science Foundation
Ivon Arroyo, University of Massachusetts, Amherst
Ryan Baker, Columbia University
Marianne Bakia, SRI International
Tiffany Barnes, North Carolina State University
Ben Bederson, University of Maryland, College Park
Andrew Bernat, Computing Research Association
Marie Bienkowski, SRI International
Jeffrey P. Bigham, University of Rochester
Gautam Biswas, Vanderbilt University
Karen Brennan, Harvard University
Derek Bruff, Vanderbilt University
Emma Brunskill, Carnegie Mellon University
William Burleson, Arizona State University
Dan Butin, Merrimack College
Brian Butler, University of Maryland, College Park
John Cherniavsky, National Science Foundation
Amy Collier, Stanford University
Sidney D'Mello, University of Notre Dame
Emily Dalton, Gates Foundation
Sharon J. Derry, University of North Carolina, Chapel Hill
Ed Dieterle, Gates Foundation
Janice Earle, National Science Foundation
Gerhard Fischer, University of Colorado, Boulder
Doug Fisher, Vanderbilt University
Knatokie Ford, PCAST
Andrea Forte, Drexel University
Lance Fortnow, Georgia Tech
Armando Fox, University of California, Berkeley
Dan Garcia, University of California, Berkeley
Erwin Gianchandani, National Science Foundation
Lee Giles, Pennsylvania State University
Mitch Green, University of Virginia
Irene Greif, IBM
Beki Grinter, Georgia Tech
Anoop Gupta, Microsoft Research
Mark Guzdial, Georgia Tech
Rogers Hall, Vanderbilt University
Susanne Hambrusch, National Science Foundation
Dan Hickey, Indiana University
Kenneth Hines, Computing Research Association
Cindy Hmelo-Silver, Rutgers University
Vasant Honavar, National Science Foundation
Jonathan Huang, Stanford University
Glynda Hull, UC Berkeley
Anita Jones, University of Virginia
Dorothy Jones-Davis, National Science Foundation
David Karger, MIT
Jihie Kim, University of Southern California
David Klahr, Carnegie Mellon University
Scott Klemmer, Stanford University
Janet Kolodner, National Science Foundation
Deepak Kumar, Bryn Mawr College
Warren Lathe, National Science Foundation
James Lester, North Carolina State University
Jonathan Levy, Department of Education
Marcia Linn, University of California, Berkeley
Deborah F. Lockhart, National Science Foundation
Mary Lou Maher, University of North Carolina, Charlotte
Chris Makler, SRI International

Fred Martin, University of Massachusetts, Lowell	**Vitaly Shmatikov,** University of Texas, Austin
Taylor Martin, Utah State University	**Beth Simon,** University of California, San Diego
Rob Miller, MIT	**Susan Singer,** National Science Foundation
Norma Ming, Nexus Research and Policy Center	**Margaret Soltan,** George Washington University
Jack Mostow, Carnegie Mellon University	**Gerry Stahl,** Drexel University
Beth Mynatt, Georgia Tech	**Shar Steed,** Computing Research Association
Roy Pea, Stanford University	**Raluca Teodorescu,** George Washington University
Victor Piotrowski, National Science Foundation	**Loren Terveen,** University of Minnesota
Jenny Preece, University of Maryland, College Park	**Candace Thille,** Carnegie Mellon University
Jane Prey, National Science Foundation	**Tsuihsia Tseng,** Gallaudet University
Lauren Resnick, University of Pittsburgh	**Juan Vargas,** Unattached
Dawn Rickey, National Science Foundation	**Peter Vishton,** National Science Foundation
Scott Rixner, Rice University	**Gary White,** National Science Foundation
Carolyn Rose, Carnegie Mellon University	**Mark Wilson,** University of California, Berkeley
Mehran Sahami, Stanford University	**Beverly Woolf,** University of Massachusetts, Amherst
Russell Shilling, DARPA	**Lee Zia,** National Science Foundation

This page was intentionally left blank

This page was intentionally left blank

THE COMPUTING COMMUNITY CONSORTIUM

Established in 2006 through a Cooperative Agreement between the National Science Foundation (NSF) and the Computing Research Association (CRA), the CCC serves as a catalyst and enabler for the computing research community. Its goals are to unite the community to contribute to shaping the future of the field; provide leadership for the community, encouraging revolutionary, high-impact research; encourage the alignment of computing research with pressing national priorities and national challenges (many of which cross disciplines); give voice to the community, communicating to a broad audience the many ways in which advances in computing will create a brighter future; and grow new leaders for the computing research community.

www.cra.org/ccc/