Improving Online Education Through Technology, Research, And Data

Kathryn S. McCarthy
Department of Learning Sciences, Georgia State University, Atlanta, GA

Scott A. Crossley*
Department of Applied Linguistics and ESL, Georgia State University, Atlanta, GA

Kayla Meyers
The Learning Agency, Washington, DC

Ulrich Boser
The Learning Agency, Washington, DC

Laura K. Allen, University of New Hampshire
Vinay Chaudhri, Stanford University
Kevyn Collins-Thompson, University of Michigan
Sidney D'Mello, University of Colorado Boulder
Munmun De Choudury, Georgia Institute of Technology
Kumar Garg, Schmidt Futures
Ashok Goel, Georgia Institute of Technology
Kinnis Gosha, Georgia Institute of Technology
Neil Heffernan, Worcester Polytechnic Institute
Mary Hooper, Clark Atlanta University
Elizabeth Hyman, XR Association
Daniel C. Jarratt, Infinite Campus
Deena Khalil, Howard University
Rene Kizilcec, Cornell University
Diane Litman, University of Pittsburgh
Agnes Malatinszky, CommonLit
Krista Marks, Woot Math
Danielle S. McNamara, Arizona State University
Raphael Menko, Whooos Reading
Corey Palermo, Measurement Inc.
David Porcaro
Rod D. Roscoe, Arizona State University
Steve Shapiro, Fine Tune Learning
Jim Stigler, University of California Los Angeles
KP Thai, Age of Learning, Inc.
Anne Trumbore, University of Pennsylvania
Cameron White, NewSchools Venture Fund
Rhea Wong, Quill
Diyi Yang, Georgia Institute of Technology
Marcos Zampieri, Rochester Institute of Technology

*Correspondence should be sent to scrossley@gsu.edu

Abstract

COVID-19 put online education in the spotlight and revealed the need for improving the quality of educational technologies. In the fall of 2020, more than two dozen experts from a variety of fields came together to discuss the challenges that educational technology must address in the immediate future. These experts were tasked with identifying barriers to and potential solutions for delivering high-quality and equitable online and remote education. These experts agreed that convergence and acceleration is necessary for educational technology to reach its full potential and to meet the needs of its vast and diverse body of stakeholders. Developing more effective and responsive educational technologies through the convergence of multiple fields and stakeholders can make a strong contribution to society by enhancing our ability to train the future workforce to acquire the skills they need for success. The discussions led to the identification of key topics and cross-cutting themes through which the convergence accelerator program could advance research and development of educational technologies.

This document is a summary of a U.S. National Science Foundation support workshop held in the fall of 2020 in response to the demand for educational technologies in the wake of COVID-19. Workshop attendees were tasked with identifying the critical needs, opportunities, and challenges that educational technology faces in the next few years.

BACKGROUND

The rapid growth and adoption of educational technologies for online learning increased exponentially as a result of COVID-19. Online learning is no longer a niche corner of education, but rather a public necessity. This sudden attention to educational technology has thrown into sharp relief the need for increased iterative development so that these tools can be more efficient, effective, and equitable.

Current Issues

Educational technologies largely failed to deliver on the promise to revolutionize education and learning (e.g., Reich, 2020). Indeed, some parents, teachers, and students continue to find educational technologies to be more of a hindrance and are resistant to using technology in the classroom (Beckman et al., 2019; Howard, 2013).

Conventionally, educational technology is often thought of as a vertical *landscape* of tools, with the focus on the platforms and systems themselves. Convergent and accelerated research should instead consider a broader conceptualization of a learning *ecosystem*. This ecosystem includes not only the technologies, but also the context(s) in which they are used, their interplay, and the variety of end-users and stakeholders who interact with the technology.

Educational technologies have, traditionally, focused on well-structured topics and domains (e.g., math, science, vocabulary) and have been designed to serve people learning at their own pace (e.g., MOOCs) and who are independently motivated to engage with the technology. Thus, the extant technologies tend to focus on a small subset of topics and a small subset of learners. The successful scaling *up* and scaling *out* of educational technologies requires the rapid development of technologies that span across the curriculum, across the lifespan, and across the diversity of users and stakeholders.

Currently, educational technologies tend to rely on inefficient practices. Industry-based technologies depend on quick builds and implementation, but rarely are engaged in proper evaluation and/or refinement. Instead, industry often opts to move on to the next “silver bullet” project. On the other end of the spectrum, academy-based technologies are carefully designed and developed, and success is based on large-scale randomized control trials. Although rigorous experimentation and empirical validation of approaches is critical to education and educational technologies, academy-based approaches are time and resource-intensive and by the time technologies have been built and fully-vetted, the field has often moved on.

Thus, despite its name, educational technology suffers from a lack of integration of both educational research and technological advances. Current educational technologies tend to be divorced from educational research. Commercial products tend to rely on dated methods of instruction (i.e., passive lectures, surface-level activities, linear progression, and minimal corrective feedback). For example, an analysis of MOOCs indicated that most scored poorly on instructional design and quality (Margaryan et al., 2015). In contrast, research in the Learning Sciences and the psychological and educational research on the “science of learning” suggests that meaningful, long-term learning emerges from tasks that are active and engaging and tailored to students’ individual needs and experiences (e.g., Chi & Wylie, 2014; Dunlosky et al., 2013; Glaser, 1991; Mayer, 2019; National Academies of Sciences, Engineering, and Medicine, 2018; Sawyer, 2006).

Another shortcoming of extant educational technologies is that they do not take advantage of powerful new computational approaches. In recent years, a powerful set of tools including rich computation from nascent artificial intelligence (AI) and sophisticated natural language processing (NLP) have come online. These tools have impacted fields like biology, physics, and astronomy, but their use in education lags far behind.

Finally, while convergence and collaboration are critical in the future of educational technology, there remain multiple practical and ethical obstacles. This includes how data can be shared within and across research teams while protecting the privacy of students and their families. It also pertains to how we can systematically develop, incentivize, and maintain collaborations that involve the voices and contributions of all key stakeholders.

In the past few decades, the developing fields of design-based research (Design-Based Research Collective, 2003), design-based implementation research (Fishman et al., 2013), and learning engineering have demonstrated that educational research can benefit from both empirical rigor and more rapid, iterative advancements. **In short, to keep pace with developing technology, state-of-the-art research, and the changing needs of end users, educational technologies must adopt rapid, *iterative* approaches to research and development**. Additionally, the next generation of educational technologies must, from the start, be designed to leverage the best practices and state-of-the art in education and technology and with an eye toward equity and inclusion.

With these issues in mind, the executive team brought together a panel of experts in fields related to educational technology to discuss the critical future directions for online education.

OVERVIEW

We asked the panel to take a broad lens in our consideration of online education. On one end of the spectrum, online education may refer to fully asynchronous courses designed for people around the globe. On the other end, online education may also reflect technology-supported or technology-mediated classrooms or small-group activities woven into in-person or hybrid environments. The panel was given free rein to discuss online education from K-15. Our focus was predominantly on US-based education, the panel drew from projects and research from a variety of locations. Based on the expert panel's discussions, the executive team identified both specific **topics** of interest and **cross-cutting themes** (Figure 1).

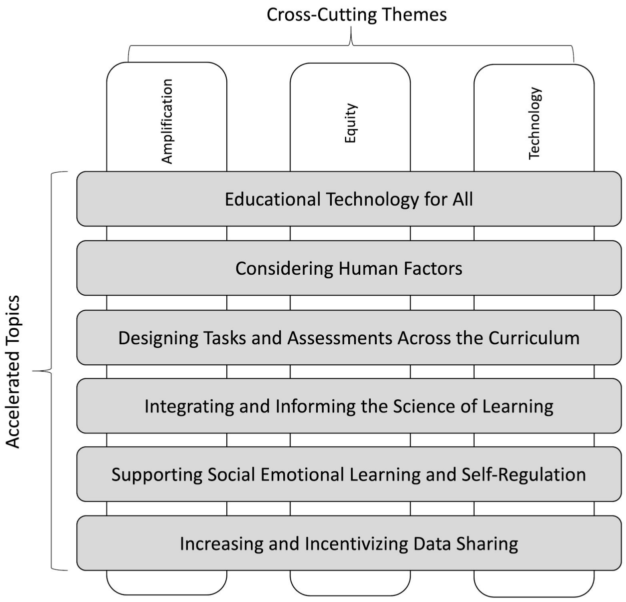

Figure 1. *Topics and Themes from Panel Discussions*

In the following sections, we provide summaries of these discussions in terms of both the issue or consideration at hand as well as recommendations for future directions.

CROSS-CUTTING THEMES

Throughout initial discussion, there were several critical ideas that emerged across discussions of a variety of topics. We categorize these as **cross-cutting themes** that must be considered in any future work in the study and development of online education, regardless of media, discipline, or target population(s).

Theme 1: Educational technology will remain of limited value if the goal is to merely substitute in-person instruction. Researchers and developers must leverage the unique affordances of technology to amplify teachers and improve education.

The pivot to emergency remote instruction in light of COVID-19 highlighted that simply moving an in-person course into an online environment is not an effective approach to learning and instruction (Hodges et al., 2020). Such approaches are not sensitive to context nor do they consider the potential benefits or affordances of technology-supported education.

Educational technologies must do more than perpetuate the status quo. They must instead consider how advances in technology can augment and improve the educational experience. This includes creating enriched environments and developing tools and methods that facilitate teachers' ability to provide high quality instruction at scale. Educational technology must center the user, which includes offering assistance to students, teachers, and parents toward overcoming initial reservations or negative experiences with the use of technology in education. Ultimately, the educational technology community must better incorporate the voices of end users throughout development and refinement.

Theme 2: Issues of equity and justice permeate all aspects of educational technology. Power imbalances can be further propagated and exacerbated by the technology itself as well as who gets to be part of the discussion that drives the research and development of that technology. Explicit attention must be given to diversity, equity, and inclusion.

Most educational technologies are reliant on some form of AI. By consequence, educational tools are susceptible to bias in the algorithms and educational technology can perpetuate and magnify these inequities (see Mayfield et al., 2019; Perry & Turner Lee, 2019). Thus, the future of educational technology requires that issues of diversity, equity, and conclusion are not an afterthought, but a critical consideration at every step of design, development, and implementation. Further, educational technology must consider not only how to avoid deepening the digital divide, but consider how technology can be agents of change and social justice.

There is a critical need to gather data sets and corpora that better reflect variations across populations. A greater diversity in the nature of data sets (e.g., dialects, cultures) can support more personalized learning that would be more culturally-relevant and responsive. Broadly, technologies must be considerate of their sociocultural context(s). This includes, but is not limited to, race, ethnicity, culture, socioeconomic status, age, sexual orientation, and disability. Further, researchers and designers must be conscientious of the intersectionality of these identities (e.g., Collins & Bilge, 2016; Crenshaw, 1991).

While the increasing use of deep learning techniques (BERT, Neural Networks) has increased the accuracy of machine learning predictions, these approaches are opaque to researchers and other stakeholders. This (1) makes it difficult to use the data to develop actionable responses to student learning and (2) raises potential concern for how these systems may perpetuate bias. Thus, equitable systems must invite researchers to look "under the hood" with the goal of identifying and addressing biases.

Finally, this equity and inclusion is not limited to the technologies themselves. There must be greater diversity across those involved in the design, development, and evaluation of these systems. Convergence must include a variety of fields of study and partnerships across industry and a variety of academic institutions, including community colleges, Minority Serving Institutions (MSIs), and Historically Black Colleges and Universities (HBCUs).

Theme 3: The future of educational technology relies on better integration of technological advances in areas of computer science.

The past decade has seen an explosion in the advancement of artificial intelligence, natural language processing, machine learning, and augmented and virtual reality. These technologies have been adopted in other scientific fields, but have yet to have broad impact in the educational technology space. These types of approaches and technologies are critical as the aims of educational technologies expand to higher order learning skills that span across a variety of disciplines. Educational technology must embrace such technology and directly consider how these advances can be used to improve the study of learning and the development of educational tools. As is evidenced below, development of NLP, CS, AI, and VR/AR/XR emerged as important solutions toward online learning.

Additionally, computer scientists with expertise in machine learning, natural language processing, and virtual reality are largely uninvolved in examining the wealth of data currently being collected through educational technology platforms. educational technology must create a talent pipeline so that researchers can take full advantage of the data that their systems provide and can use these technologies to offer state-of-the-art evaluation and support.

NEW DIRECTIONS FOR EDUCATIONAL TECHNOLOGY

Discussions among the experts identified six topics for future research and development. Each of the six topics present multiple unique lines of inquiry, but they also intersect such that each of these topics is likely to draw upon concerns from the others. For example, human factors must consider issues of emotions and self-regulation; integration of the science of learning must occur across the curriculum and across the lifespan. Thus, while these topics represent a coherent and independent track of research, they also provide opportunities for convergence across the broader spectrum of educational technology. In addition to these interactions, each of the six topics can draw upon the cross-cutting themes to strengthen their contributions to the future of educational technology.

Educational Technology for All

The majority of extant technology treats the learner as a passive recipient or consumer of information. Such approaches are at odds with best practices as indicated by work in the science of learning. Even systems that are more active and engaging still often assume an "ideal" or "average" user. However, work in aptitude-by-treatment interactions (and individual differences research more generally) suggests that targeting an assumed average often fails to meet the needs of any one individual (e.g., Connor & Morrison, 2016). This, in combination with the increasing heterogeneity of classrooms, demands that researchers and developers go beyond the question of "does it work?" to questions of *for whom* and *under what conditions.* Technologies must be sensitive and responsive to group-level differences (e.g., race, gender, culture, language) as well as individual differences (e.g., interest, skill, knowledge).

In order to meet the needs of a broader array of students, researchers must gather larger data sets in which they can examine a number of moderated and mediation relations across interventions and individual differences. In addition to diverse data sets, it will likely be beneficial to collect and tag more *context-specific* data sets so that systems can be more responsive to a greater range of users who may have different needs, experiences, and familiarity with technology (e.g., Dolan, 2016).

Sensitivity to a wide range of learners also requires educational technologies to be more intentional with how instruction and practice are delivered. Despite research that the race and gender of pedagogical agents has an effect on student outcomes (e.g., Kim & Baylor, 2016), many students do not get to see themselves represented in educational technologies in the faces or bodies of instructors, avatars, pedagogical agents, or non-player characters.

To address this issue, teams could work together to create sets of high-quality personas that provide a broad and inclusive range of colors and identities for learning environments. This may be particularly beneficial for immersive XR environments, but should also be an important consideration for any technology. This work would also allow researchers to more systematically investigate how the appearance of technology-based agents influences learning.

One major gap in the existing ecosystem of technologies is a lack of systems that are targeted toward younger (K-6) learners. While there are a variety of educational games for younger students, there are far fewer formal instruction platforms or methods of facilitating online learning for this age group. Most online education technologies have been developed for middle school through adult learners. Younger students have unique developmental needs and the switch to remote learning has been particularly challenging for the parents and teachers of young learners (e.g., Dong et al., 2020)

Due to developmental differences, elementary school students need different support than their adolescent or adult counterparts (e.g., Darling-Hammond et al., 2020). Young children are just beginning to develop their identities as learners. Educational technologies need to not only grab a child's interest, but also to begin to cultivate good habits of learning and self-efficacy. The types of technologies for younger learners must go past investigations of initial interest and novelty toward more long-term evaluation of meaningful learning as well as long-term buy-in.

Elementary students and other younger students also need great family support, but despite the critical role that family dynamics play in student development, not all parents see themselves as "part" of their child's education and see their child's success as the teacher's responsibility (e.g. Selwyn et al., 2011). Even those parents that do want to play a role in their child's education may lack the time, resources, or skills to do so (e.g., Garbe et al., 2020).

Thus, educational technologies for younger students must be sensitive to context in ways that can help draw parents into the learning process and equip them with the support they need to contribute to their child's learning. Similarly, elementary school teachers need additional support for classroom management and facilitating remote learning as their students are developing their self-regulatory skills. The students themselves, for any number of reasons, may also not receive appropriate support from their parents and teachers. Thus, research and development of educational technology must also occur for developing methods and tools for engaging students with limited adult support.

From a technology perspective, younger students also present practical challenges in the way that educational technology is "typically" done. For example, children who are not yet proficient readers and writers may require the use of speech recognition technology. However, the majority of ASR technologies are built on corpora of adult speech and are not accurate enough to understand and respond to children (Scanlon, 2020). Similarly, students' open-ended responses (summaries, short-answers) tend to systematically differ in their structure and content from adult language; thus, algorithms must be specially designed to evaluate and provide feedback for these students.

Finally, COVID-19 has also highlighted that even the best technologies are rendered ineffective if students cannot gain access to them. Black, Hispanic/Latinx, and rural students are more likely to lack the resources (e.g., a home computer or reliable internet) to maintain their schooling (Auxier & Anderson, 2020). An obvious solution would be more equitable access to the internet and technology for every student. However, devoid of large-scale systematic reform, researchers and developers must consider low-tech alternatives that allow technology-mediated learning in the face of unstable internet or unreliable access to devices. In addition, work can be done to help consider how technology could be distributed or altered to help bridge the digital divide.

Increased Consideration of Human Factors

In addition to a greater consideration of the number and types of users in the educational technology ecosystem, more attention must be paid to the specific needs and experiences of those users in relation to the technology. That is, there is a need to attend to the human factors aspect of technology and education. More specifically, as technology becomes more integrated into the classroom, rather than extramural activities, more consideration must be made to meet the needs of parents and teachers. For example, most online conferencing tools (e.g., Zoom) were not designed with classroom teaching in mind. During the pandemic, K-12 and university instructors have relied on breakout room functions to facilitate group work. However, unlike in a face-to-face classroom, indicators of student learning (student conversation, seeing students take notes, body language, etc.) are not visible when students are in virtual breakout rooms and teachers cannot readily "keep an ear" on all groups simultaneously. A tool or functionality that could analyze such cues and flag to teachers which rooms they should step into would help teachers support students in the virtual environment. These types of practical considerations to meet the needs of the classroom are critical as online education becomes more prevalent.

COVID-19 has also led to many parents taking a larger role helping their children. In addition to having to understand the technology itself, parents are also wrestling with unfamiliar pedagogy and content. Those who are less comfortable with technology or are non-native speakers may be less inclined or less able to support their children's learning. Similarly, parents may also struggle with their own misunderstandings of content or previous experiences with school (e.g., Maloney et al., 2015). Thus, researchers must explore and address how parents respond to and use educational technology. This work should explore how parents can serve as a mediator between classroom and student and how technology can support this endeavor and the social and systemic factors that influence student and parent interactions, attitudes, and experiences.

Despite their central role in the classroom, teachers are also often left out of educational technology discussions. Teachers are often mandated to use technologies and are given minimal, if any, training on how to use them. These tools are often inflexible in the sense that the teacher is limited to the topics and tasks that the system provides, and the teacher has little control over the structuring or timeline of instruction/practice within the technology. Currently, the use of technology is often compartmentalized away from "regular" instruction and thought of as supplementary or extramural. As technology becomes more integrated into moment-to-moment instruction, teachers will use the technologies for different purposes. Teacher dashboard and interfaces with educational technologies are often included as an afterthought. Research needs to consider what kinds of tools could be built or refined to help teachers do their work (e.g., find quality texts, help simplify grading, help generate individualized learning tasks/plans, behavior management). For example, research in collaboration and group dynamics can help teachers to put their students into small group arrangements that are the most likely to be effective for group problem solving and to moderate and facilitate deep discussion in unsupervised groups while the teacher makes their rounds. Thus, educational technology must better integrate teachers as design and research partners so that the technologies can support rather than hinder teachers' progress.

Expanding Educational Technology Across the Curriculum

Educational technology needs to be developed for a wide variety of disciplines and domains and to augment instruction on complex skills tailored to the needs of the 21st century workforce. There are two approaches to this. The first is to fund the research and development of educational technologies that target disciplines where acquisition metrics are more difficult to quantify (e.g., the humanities) and skills that go beyond lower-level competencies, such as critical thinking and higher-order argumentation skills. The second is to develop tools that can be flexibly applied to a number of domains.

The majority of educational technologies are designed for well-structured domains (e.g., science facts, math problems, vocabulary quizzes) and rely on repetitive practice in which responses can be quickly assessed as "correct" or "incorrect" (i.e., multiple-choice questions, numeric answers). There are far fewer technologies that target disciplines that have more ill-structured problems like reading comprehension, argumentation, communication, design, and collaboration. Disciplines that include more ill-structured problems like art, language and literature, and history pose a challenge for technology because the assessment of accuracy or quality is more nuanced than merely right or wrong.

For example, high quality argumentation requires the coordination of a number of skills that include not only the knowledge of content, but also proficiency in style, rhetoric, and argumentation schema. Instruction and practice in these domains requires activities that are, generally, more complex and time intensive, both in terms of developing activities and in the assessment, evaluation, and feedback for those activities. Large scale and domain-specific natural language corpora along with learning outcomes and individual difference measures can support the development of NLP tools for educational data mining (e.g., Word2vec spaces) and more sophisticated adaptive systems that can respond to more complex learning tasks.

Newer tools would need to rely on more open-ended data. Further, ensuring that these tools are accurate, but also fair in terms of cultural sensitivity or variations in language and dialect will be paramount. Databases can spur dramatic progress in education by leveraging the artificial intelligence that trains computers to understand text and videos. Collecting and tagging large data sets are in and of themselves valuable means of studying learning. In addition, these datasets can also catalyze "benchmark" challenges that researchers and technologists compete on, and incentivize advancements in fundamental and domain-specific fields in ways that dramatically improve education. Such datasets are key areas of convergence, bringing together the machine learning community, the education community as well as the online platforms that have become increasingly vital.

Even in well-defined domains, educators have increasingly emphasized the need to engage in more sophisticated learning activities. The sort of low-level recall and basic comprehension measures employed in many educational technologies do not reflect the kinds of critical thinking and sophisticated reasoning skills that students require to succeed across disciplines or beyond the specific curriculum. Research should consider the kinds of tools that can be built or altered to support more authentic learning tasks (e.g., problem or project-based learning, writing and composition, close reading in authentic and ecological situations). These tasks are often more collaborative than what most technology currently affords (cf. Sun et al., 2020). Convergence could yield wiki-style or discussion-board style spaces for teachers to share tools and project ideas, while students collaborate on projects and assignments. Such systems could track pre-determined metrics to observe whether students are applying critical thinking skills as they answer prompts or communicate with one another. Instead of a correct versus incorrect model, these platforms could assess whether students are progressing toward the conclusion of the lesson.

This model of learning and evaluation disrupts standard notions of training one component skill at a time, because more authentic application and critical thinking tasks require the deployment of a larger number of microskills. Working with educators and educational researchers, these tools can improve the ways in which educational technology identifies and evaluates critical outcomes and how technologies can advance the evaluation of 21st century learning skills and competencies while still meeting the current expectations from districts and state and national standards.

Beyond working with ill-structured problems spaces, educational technology tools need to develop more domain-agnostic tools and technologies that could be leveraged across a variety of disciplines and domains as compared to discipline-specific tools. The propensity for educational technology to accomplish is an empirical question that merits further exploration. Development of educational technologies that address the instructional and assessment needs of a greater variety of fields will require increased partnerships across experts in educational sciences, educational practice, and technology development. Developing automated constructive response tools that are domain agnostic or that can be more flexibly adapted to different disciplines. For example, existing automated summary evaluators (ASE) tend to focus on summary writing as a general skill rather than on the particular topic being read. Improved ASEs could be developed that better evaluate the extent to which student responses reflect deep understanding of the content and could deliver actionable feedback that supports both reading and writing skills.

Moving beyond point-and-click or fill-in-the-blank style problems also affords additional exploration into other modes of representing and studying knowledge. It would be of value to collect data sets of math handwriting or scientific drawings. These databases could be used to improve optical recognition of symbols and diagrams to assist with tutoring and could provide additional embedded assessment through examining not only what the student writes, but how (and where) the information is conveyed on the tablet or page.

Symbiosis Between Educational Technology and the Science of Learning

Research from the science of learning has shown that the tasks and activities that are most effective for learning are often counterintuitive. That is to say, the approaches that teachers and students instinctively use are often not effective. For example, teachers still strongly endorse the notion of learning styles, despite repeated evidence that teaching to preferred learning styles is, at best, ineffective and potentially harmful (MacDonald et al., 2017; Willingham et al., 2015). Similarly, students report relying heavily on study strategies such as rereading and highlighting, even though these techniques fail to support long-term or meaningful learning (Dunlosky et al., 2013; Miyatsu et al., 2018).

Thus, convergence across science of learning and educational technology can support the development of more effective ways of learning online. For example, research in applied memory suggests that repeated and interleaved practice can support more long-term and durable learning. However, students tend to avoid these types of activities on their own. By collecting and analyzing large, longitudinal datasets across a variety of contexts, researchers can develop a greater understanding of how to implement more accurate just-in-time retrieval practice activities and feedback that are sensitive to the learner's needs. Critically, educational technologies should not merely be keeping up with the state-of-the-art in the science of learning, but should be at the forefront of investigating and contributing to the body of research around how people learn. These data sets also need to inform and refine theories of learning across disciplines and contexts.

Currently, many existing tools tend to rely on tasks and activities that are not effective (i.e., passive instruction) and the linearity and modularity of these systems do not take advantage of opportunities to revisit or reintegrate content from across a course. In addition, these technologies still rely on an abundance of summative assessments, rather than engaging students in formative assessments and mining data for embedded or "stealth" evaluations (e.g., Shute, 2011) of student learning. Using data from formative activities to provide feedback to both student and instructor is not only beneficial for learning, but may also help to avoid the potential for increased academic dishonesty in online spaces when evaluations are conducted in high-stakes ways.

Educational technologies should be developed with the most recent understandings of the science of learning (e.g., NASEM, 2018) in mind. Current research suggests that learning activities should encourage and evaluate constructive learning (e.g., Chi & Wylie, 2014) and structured inquiry tasks. Such outcomes may be harder to assess. Thus, it will be important to develop automated or technology-mediated methods of evaluation and feedback that can use open-ended data to drive the system. An increased focus on leveraging linguistic and physiological data can support these efforts.

Along these same lines, there is also a need to develop higher quality means of evaluating collaborative learning and, in particular, collaborative learning within ill-structured problem spaces. Such methods of data collection and algorithm development could not only facilitate higher quality interventions, but also be used to better understand and develop theories of social interactions and socially-constructed knowledge. With the increase of parents and teachers mediating student use of educational technologies, new tools can be built to help teachers with classroom management in online spaces and to more effectively facilitate collaborative tasks and feedback.

Social Emotional Learning (SEL) and Self-Regulated Learning (SRL)

Educational technologies need to be sensitive not only to the content, but also to noncognitive components of the learning process. At present, most research tends to focus on design and usability, interest and engagement, or learning outcomes. Successful educational technologies must consider each of these in concert. On one hand, if developers attend only to issues of usability or engagement, they may develop a fun, but ineffective tool. On the other hand, if a system that is effective for learning gains is uninteresting to the user or difficult to use, then that system will have limited learning impact. Convergent research and development in educational technology must work to *triangulate* best practices across a variety of different research techniques and outcomes. Thus, a critical future direction is the development of educational technologies that gather a variety of types of data (e.g., clickstream, eye tracking, language) to develop more precise learner models and more efficient feedback that are sensitive to dynamics changes in students' emotional and metacognitive states (e.g., D'Mello & Graesser, 2012).

Social and emotional learning (SEL; Elias, 1997; Osher et al., 2016; Weissberg et al., 2003) and self-regulated learning (SRL; see Greene & Azevedo, 2007; Pintrich, 2000; Winne & Hadwin, 1998; Zimmerman, 2000) have both been identified as critical pieces of the learning process; both of these constructs are continuously being explored and redefined. In computer-based environments, affective and metacognitive/self-regulatory components are highly related to engagement and learning (e.g., Baker et al., 2010). Developing work in analytics and feedback for affective computing and self-regulated learning highlights the need to meet the student at their skill level and to provide scaffolding to keep the student on task and on track given their current state(s) (e.g., Uzir et al., 2019; Yadegaridehkordi et al., 2019). For some students, SEL/SRL support and feedback may not come from their home or their previous experiences. Thus, SEL and SRL supports can be tailored to target behavioral challenges from relatively severe behavioral issues to more mundane issues of distraction. Explicit attention to these factors in the classroom may be important to help cultivate students who are not only ready to, but also excited to learn.

Educational technologies serve as an opportunity to collect additional data about how SEL/SLR factors play a role in how students learn. In turn, a richer understanding of these factors can help to develop more effective technologies that are sensitive to more subtle differences in students' attitudes and behaviors. At present, the detection and identification of SEL is challenging. Many systems still rely on self-reported measures, which are subjective and gameable. However, there is a growing body of work exploring less invasive detection (e.g., Emerson et al., 2020; Bosch et al., 2015). Educational technology affords the opportunity to measure these behaviors in-app and at scale, which can help researchers to extrapolate more accurate information about these processes. The experts indicated that a more tractable short-term goal that would set up this area for long-term development would be targeting SRL and metacognition. SRL and metacognition are an easier set of skills to measure and track. Thus, research could focus on how to take these data and transform it into actionable feedback. Researchers could also investigate the viability of automated sociometers. Such tools could better measure collaboration and other 21st skills like cooperation and social engagement.

Initial work in these areas is promising. Additional teams can help to accelerate the speed at which we can evaluate and respond to the varying needs of instructors and students in ways that are sensitive to a wider variety of individual differences and dynamics states.

Data Sharing and Collaboration

Paramount to convergence across fields and disciplines is the need to exchange ideas and data. As a result of the current siloing of the various stakeholders interested in educational technologies, there are few infrastructures or architectures to guide best practices in data sharing and collaboration.

Educational technologies have generated immense amounts of data and increased collaboration is needed so that different teams can ask different questions. This would better allow interested parties to take full advantage of the data that educational technologies produce (e.g., Heffernan & Heffernan, 2014). In addition to analyzing the extant data, collaboration can better ensure that the technologies are testing important questions and generating the types of data that are relevant to the diverse array of stakeholders in the educational technology ecosystem.

Throughout their day, students are also using multiple forms of technology. They may log into an LMS, complete a module in a MOOC, read a web-based textbook, and then engage with an educational game. Despite each system generating a wealth of data that can help develop a rich learner model, these systems do not share data with another and even modules *within* systems are often stand-alone rather than integrative. Additionally, data tagging in education is not standardized, which presents challenges in aligning ontologies across systems. Better integration across lessons and across systems can support students making connections across topics (supporting transfer and deeper learning), helping to create a greater sense of purpose and continuity in the classroom. Combining these bodies of data can also help researchers to develop richer learner models and a deeper understanding of how students learn. Thus, an important question for educational technologies to consider is how they can support a student moving from platform to platform more seamlessly.

Although convergence and collaboration is a necessity, these new partnerships bring to the surface a number of ethical and practical concerns. How do we build systems of data and strong learner profiles while maintaining privacy? How can we leverage the power of social media and the experiences that students have outside of the classroom while respecting boundaries in and out of the classroom?

More practically, many of the existing silos among stakeholders exist because of varying expectations and incentives across fields. Educational technologies that thrive on iterative improvement need to develop sustainably -- platforms and tools tend to disappear or go stale when funding runs out or commercial systems may be hesitant to share proprietary data or approaches. In order to see iterative change and development, tools have to be developed with long-term plans and support in place to incentivize collaborations across companies and institutions.

Perhaps the most pressing of all the tasks in the future of educational technologies for online learning is the development of instrumentation and other data sharing systems and tools that maintain privacy while allowing for the creation of cross-platform learner models that can support greater adaptivity. This might include federated learning for education so that privacy data does not leave personal devices, but other opportunities should be explored.

In addition to the technologies, it would be of value for successful collaborations to document their process to put forth design pipelines and research plans. This might include documented workflows or MOU templates that ensure that different stakeholders can engage interdisciplinarily, but also come away from the project with meaningful outcomes relevant to their own professional objectives and expectations.

One means of accelerating the iterative development of online educational technologies would be the creation of a “data-processing” platform for learning engineering where data can be stored, processed, and analyzed. Similar platforms are emerging in other fields (i.e., Galaxy used for biomedical research; Blankenberg et al., 2014) to support increased collaboration and expedition of data analysis and dissemination. Convergence could also be accelerated through a social networking site for learning engineering that helps connect researchers, teachers, and administrators with learning platforms and industry partners. Such listservs exist, but they are limited in the ability to share information, collaborate, and facilitate genuine conversation.

In order to move beyond the “one and done” status quo concurrent to educational technologies, there must be explicit attention to developing a culture of continuous improvement and practical pathways for iterative collaborations. This could include tools and softwares, but also architectures and pipelines that other groups can use to engage in more efficient and effective collaboration. In this track, teams would be very broad, composed of instructional designers, researchers, and developers from both industry and academia, data scientists who can support data wrangling, experts in the education sciences (e.g., learning sciences and science of learning, educational policy), and various teacher and parent-partners.

IMPLICATIONS

The expert panel discussions highlight the need for accelerated convergence across a number of fields to solve critical issues in the future of education. While new and improved technologies are an obvious deliverable, there are a wealth of other contributions that convergence projects can bring to the advancement of STEM and learning more generally. Central to the improvement of online education is the need for multiple stakeholders to come together to address how educational technologies can be made more accessible, equitable, and efficacious. Critically, the field(s) of educational technology must develop a culture of iterative improvement as well as practical approaches to collaboration, experimentation, and refinement. By using online educational technologies as both testbed and outcomes, researchers and practitioners can improve the quality of education across contexts as well as to inform and refine theories of learning.

Figure 2. *Accelerated Framework for Improving Online Educational Technologies*

The design framework in Figure 2 is inspired by instructional design (e.g., ADDIE; see Molenda, 2003), design-based research (DBR, Barab, 2014; Puntambekar, 2018), and design-based implementation research (DBIR, Fishman et al., 2013). This design framework depends on continuous collaboration amongst a variety of stakeholders across all aspects of the educational technology cycle all existing in and/or cognizant of the socio-cultural context in which the research and development is being carried out. The cycle also implies large-scale design loops in addition to more rapid iteration. Each step in the process depends on the work done before it, but iterates that work with the goal of improving the product. For example, researchers ensure that the technologies are effectively tested and that designers are collecting the right analytics and outcomes to test how learners engage with the technology and how these interactions influence a variety of outcomes including experience (motivation, engagement, etc.) as well as short term learning gains. Designers consider input from users and educators to manipulate their experience with the technology. Such collaboration accelerates the rate of theoretically-motivated advancements and evaluations than is traditionally feasible in the lab or in industry and ensures an ongoing iterative cycle of data generation and analysis. Technologies at scale will also allow for more experimental evaluations that can meet the needs of a greater number of learners that can vary across a number of dimensions and contexts. High quality systems will lead to increased use, both in terms of the quantity of users and the quality and frequency of their interactions. This, in turn, increases the amount of data available to further mine for additional insights for future system improvement and new directions in research. While randomized control trials (RCTs) remain an important benchmark for the success of educational technologies, this approach highlights the need to consider more rapid, iterative refinements consistent with work in design-based research.

A convergence accelerator approach to educational technology would enable several key aspects not afforded in the current modus operandi. First, technologies and products would be subject to theory-driven change, where the science of learning is privileged in development toward clear learning goals. This would further allow for more rapid experimentation, where "fast fail" experiments can be run to quickly adapt technologies to improve short-term outcomes. Essential to this is an internal culture of iterative improvement toward measurable, long-term benefits that will depend on diverse teams. Thus, convergent research in educational technology will not only include those who work "in" educational technology (i.e., industry, university and non-profit research) and end-users (students, teachers, parents), but also researchers and developers who work in related domains, such as computer science, AI and machine learning, natural language processing, and virtual and augmented reality. Even beyond this, convergent teams could also include government and policymakers and experts in other relevant fields such as data ethics, child development, and those with expertise in media and marketing.

Thus, when establishing a thriving "ecosystem of educational technology," platforms would need to internalize the considerations of multiple stakeholders. This will require intentional inclusion and consideration of a number of complementary and competing outcomes including user experience and usability, personalized learning, teacher control, attention to and scaffolding for motivational and affective factors, as well as a number of various learning outcomes (e.g., immediate performance, long-term retention, deep comprehension, and the ability to transfer knowledge to new contexts).

CONCLUSIONS

The popularity of online learning has grown as policy-makers, researchers, and instructors acknowledge the need for adapting instruction in response to COVID-19. While the practice of online learning is not new, the convergence of recent developments in educational technologies, the science of learning, AI, and NLP can provide critical contributions to online learning. These collaborations will also promote high quality online instruction in varied contexts and to diverse learners who differ across a wide array of dimensions, such as skills, knowledge, and motivation.

True convergence must consider the full ecosystem of those who develop, use, and are affected by educational technology. This means that educational technology needs to be reimagined to include teachers, students, and families as co-designers and partners, rather than merely passive consumers. In order for educational technologies to fully meet their potential, teams of researchers, designers, developers, computer scientists, and educators from a variety of backgrounds and experiences must engage in long-term collaboration and iterative design. Having multiple viewpoints, goals, and expertise can support the development of technologies that can evaluate and assess learners and other end-users across a variety of dimensions and outcomes in order to provide personalized instruction and feedback that keeps students excited, engaged, and optimally learning.

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