Key Aspects of Cyberlearning Resources with Compelling Results

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Abstract

The positive outcomes of existing cyberlearning resources, like Scratch, PhET, and the Mobile Studio, hint at the promise cyberlearning holds for facilitating the development of 21st century skills. While National Science Foundation (NSF) Program Officers (POs) are interested in continuing to support cyberlearning research and developments that promote excellence in undergraduate science, technology, engineering, and mathematics (STEM) education, there is a need to understand elements of existing resources that have already achieved positive outcomes. An exploratory sequential mixed methods research design[1] was used to explore this topic. Of the 1,000 NSF-funded projects POs have highlighted in the *NSF Highlights* over the past 10 years, nearly100 were cyberlearning awards. After applying selection criteria to identify awards with compelling results to serve as exemplars, one-hour interviews were conducted with the developers of 15 cyberlearning resources to garner insights on their approaches to development, implementation, and dissemination. This paper includes insights about the larger population of cyberlearning resources, as well as some of the key aspects of cyberlearning exemplars. Such insight are not only helpful to POs interested in supporting future cyberlearning research, but also to future developers of cyberlearning resources.

Introduction

Thanks to resources like Scratch, PhET, and the Mobile Studio, cyberlearning is facilitating the development of 21st century skills. With these tools, learners are creating and sharing interactive media, manipulating computer simulations to understand physics in the world around them, and tweeting classmates about the fascinating outputs generated by their personalized circuit boards. This is just a subset of the infinite possibilities cyberlearning affords; and NSF Program Officers in the Division of Undergraduate Education (DUE) are interested in exploring more. Such interest was the impetus for this study.

The NSF Taskforce on Cyberlearning defined cyberlearning as "the use of networked computing and communications technologies to support learning" (p.10)[2]. The positive outcomes of existing cyberlearning resources point to its promise to support DUE's mission of promoting excellence in undergraduate STEM education for all students. As part of moving forward, however, there is a need to understand elements of the existing NSF-funded resources that have already achieved positive outcomes. Thus, the purpose of this study is to identify and highlight key elements of existing cyberlearning resources with compelling results. An explanatory sequential mixed methods research design[1] was used to address the follow research questions:

1. How many cyberlearning resources have been highlighted among NSF reports over the past 10 years? Where do they fit within a cyberlearning taxonomy? What are the emerging opportunities?
2. What are some of the keys aspects of a subset of cyberlearning resources with compelling results?

Since this research builds directly on prior work[3], a brief summary of the previous study will be presented first. This will be followed by a more detailed explanation of the methods, and finally the results and discussion.

Prior Work

The mission of the Division of Undergraduate Education (DUE) is to promote excellence in undergraduate STEM education for all students. To help fulfill this mission, DUE Program Officers needed to better understand how technology –particularly the technologies emphasized in the original definition of "cyberlearning"[2]– could provide more equitable educational opportunities for all learners. In summer 2011, a study was completed to begin this process in a formal way by synthesizing current practitioners' and experts' views of what cyberlearning is, how it is currently utilized and how it might impact undergraduate STEM education in the future.

A convergent parallel mixed methods research design[1] was used to complete four main tasks. Initially, a literature review was conducted to acquire a conceptual understanding of cyberlearning. Secondly, there was an analysis of how much funding DUE has provided to support cyberlearning awards over the past 10 years, and to determine what types of cyberlearning awards have been funded. Third, 18 NSF Program Officers shared their perspectives on cyberlearning during one hour interviews. A synthesis of their perspectives resulted in the creation of a taxonomy, and a list of cyberlearning resources that have had a significant impact on STEM education (among other things). Finally, the findings from the quantitative and qualitative analysis informed recommendations of possible directions DUE could take with cyberlearning. The findings of this study were shared with DUE Program Officers (POs) and have been published for the benefit of the larger STEM education community[3].

Using the cyberlearning projects cited during interviews with POs as an impetus, another study was proposed to explore how cyberlearning networks are best implemented and spread. This is what led to the focus on cyberlearning resources with compelling results. The research findings presented in this article about key aspects of such cyberlearning resources are one piece of this larger study. In addition to contributing to the motivation for this study, there are two other direct links from the prior study to the present study. One, some of the cyberlearning resources cited during interviews are included among those mentioned in this article. (See the methods section for details about the selection criteria.) Secondly, a synthesis of the interview responses led to the development of a taxonomy that shows how cyberlearning can occur on three scales: a macro-, meso-, and micro-scales. As the prefixes might suggest, each scale indicates an increase in the number of learners involved in the experience and the number of accessible resources[3]. This taxonomy was used in this study to obtain a broader perspective of the large population of cyberlearning resources cited in NSF reports over the past 10 years.

Methodology

In this study, different but complementary types of data were collected and analyzed. Since the initial quantitative results of this study were used to purposefully sample during the qualitative phase, an explanatory sequential mixed methods research design[1] was used to answer the proposed research questions. The primary point of interface for mixing the two strands was in the data collection; the qualitative strand of data collection and analysis was prioritized. The purpose for adding the qualitative strand was to enhance our understanding of the quantitative results. Methods associated with each strand will be discussed next.

Quantitative Methods

Multiple sources were used to generate a population of cyberlearning resources with compelling results. The majority came from three lists of NSF awards: cyberlearning awards cited in *NSF Annual Reports*[4]; and the cyberlearning projects among the DUE and Division of Research on Learning in Formal and Informal Settings (DRL) awards within the *NSF Highlights*. *NSF Highlights* is a source of information about NSF investments in discovery, learning, and infrastructure stored on the NSF intranet. Each highlight is a summary of the funded project of interest, along with its transformative results and positive outcomes. The contents of the website are organized by year, NSF directorate, and NSF division. Awards included in this project were first funding between 2002-2012. Cyberlearning examples mentioned during interviews with POs during the summer 2011 study that were not among the three lists were also included. A few non-NSF-funded cyberlearning resources were also added. The purpose for doing so was to include examples of recent technologies that are having a impact on higher education (e.g., MOOCs). In sum, the population of cyberlearning resources included approximately 120 unique awards.

Determining which awards to include in the population were based upon the fitness of the award's deliverables with two working definitions of cyberlearning, and the six common forms in which it appears[3]. The two definitions of cyberlearning used in this study stem from the prior research and from NSF. They are: "changes in the learner's thinking (i.e. understanding, interests, efficacy) that result from interacting with digital content" (p.10)[3]; and "the use of networked computing and communications technology to support learning" (p.10)[2]. Both definitions were used in an attempt to capture cyberlearning resources with and without a network connection that NSF has supported since 2002. The six forms of cyberlearning of interest in this study are: distance education courses, serious games, virtual environments, digital repositories, online communities exclusively used for education purposes, and learning management systems. In short, if the project deliverable mentioned in the highlights did not represent one of these six forms or did not fit within the scope of the working definitions, it was not added to the population of cyberlearning resources.

Information about each award was used in two ways. One, each cyberlearning resource was mapped to the cyberlearning taxonomy created in the previous study. Essentially, the schema depicts cyberlearning as an ecosystem with three scales: "Micro", "Meso", and "Macro". As the Micro-Meso-Macro prefixes suggests an increase, each scale of the *Cyberlearning Ecosystem* indicates the number of learners involved in the experience and the number of accessible resources.

Cyberlearning at the Micro-scale occurs in at least two ways:

(1) Learner accesses media stored on a physical artifact (e.g., CD-ROM, handheld game).
(2) Learner accesses media stored in a remote location that is only accessible through the Internet (or intranet) (e.g., intelligent tutoring systems).

Cyberlearning at the Meso-scale occurs in at least two ways:

(1) Two or more learners can be part of the same educational experience and send/receive data to/from a server, but this experience does not require an Internet connection (e.g., clicker response system).
(2) Peer-to-peer interactions between learners who exchange data over the Internet (or intranet) (e.g., multiplayer games).

Cyberlearning at the Macro-scale occurs in many ways:
Through the use of the Internet, an unlimited number of learners can access other learners, vast amounts of data, and remote facilities anytime, any place.

In addition to mapping each award to the taxonomy, various details about each award were also recorded. Such data includes: the year(s) in which it was highlighted by DUE, DRL, and/or NSF; the discipline associated which the cyberlearning project; and the number of nodes associated with it when searched for in IKNEER. Interactive Knowledge Networks for Engineering Education Research (IKNEER)[5] is an online tool used for visualizing networks of collaborations among researchers, and sometimes projects. Each node represents network members. IKNEER information was used as a mechanism for quantitatively gauging networks forming around the cyberlearning resources and their Principal Investigators (PI) since understanding how cyberlearning networks form and spread was the focus of the larger study. These details were used in the qualitative phase of the study.

Qualitative Methods

Once the population of cyberlearning projects was complete, a purposeful sampling strategy[6] was used to identify a subset of cyberlearning projects to serve as exemplars and to be explored in-depth. Criterion used to determine the overall makeup of the sample of exemplars were:

- Sample represented a wide representation of disciplines
- Sample included the six main forms of cyberlearning
- Sample represented all scales of the cyberlearning taxonomy
- Cyberlearning projects mentioned during interviews with POs were prioritized
- Cyberlearning projects highlighted multiple years were prioritized
- Cyberlearning projects with over 150 nodes in its IKNEER network were prioritized

Seventeen awards were selected as cyberlearning exemplars. The PIs on 15 out of 17 projects (88% response rate) agreed to participate in a 30-60 minute phone interview. The cyberlearning projects highlighted in this study are: Alice, Carnegie Learning's Cognitive Tutors, CodeLab, Coursera, Epistemic Games, FirstGlance in Jmol, Mobile Studio, Molecular Workbench, On the Cutting Edge, Physics Education Technology (PhET), Scratch, SimCalc, TeachEngineering, Web-based Inquiry Science Environment (WISE), and Wolfquest.

Everett Roger's[7] *Diffusion of Innovation* theory was used to frame the development of protocol questions to help explore how cyberlearning networks develop and spread. In preparation for the semi-structured interviews, the proposal documents for each award, and annual/final reports were reviewed to obtain a general understanding of each project and some of its outcomes. During the interviews, participants shared insights on how their cyberlearning resource was designed, implemented, disseminated, and scaled-up. PIs were also asked about their perspectives on cyberlearning, in general. After transcribing the interviews, the researcher iteratively read through the data and coding the texts such that recurring themes are identified and described. More specifically, the texts were analyzed on two levels: one, to understand and summarize significant details about the exemplary cyberlearning resource itself; and secondly, to identify themes across participants' responses and cyberlearning resources to inform implications for future developers and NSF Program Officers. For validation purposes, interview participants engaged in member checking (p.208)[8] by provided feedback on the accuracy of their respective project summaries. Their input was incorporated into the final draft of each project summary. A synthesis of all responses shed light on each award, and on how cyberlearning networks develop and spread. While much of the qualitative results related to how cyberlearning networks develop and spread will not be presented in this publication, insights regarding the key aspects of these cyberlearning resources and implications for future developers will be described here.

Results

The first set of research questions relate to the number of cyberlearning awards NSF has highlighted over the past 10 years, how they map to a cyberlearning taxonomy, and some of the emerging opportunities. The population of cyberlearning resources included 118 cyberlearning awards, 90 of which came from the *NSF Highlights*, beginning in 2002. The others came from final reports, annual reports, and suggestions from NSF Program Officers. Figure 1 shows the distribution of the awards over the 10-year period. The years map to the year in which it was highlighted or included in one of the NSF reports.

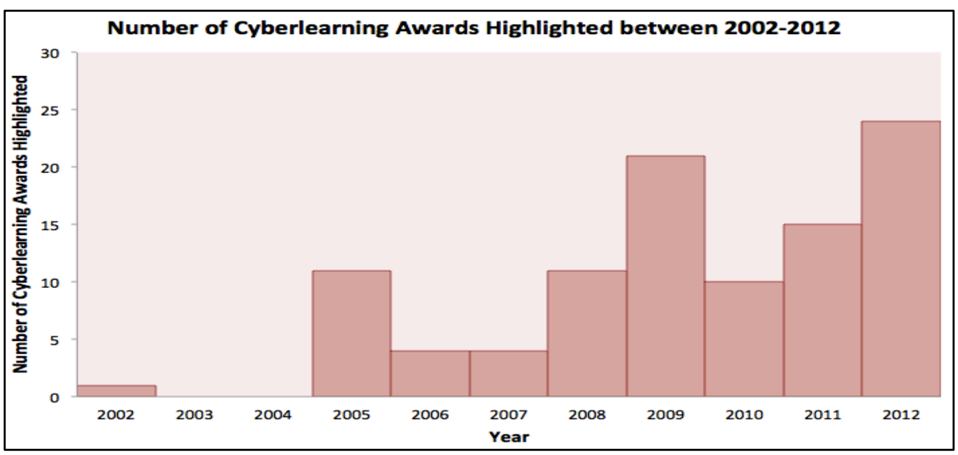


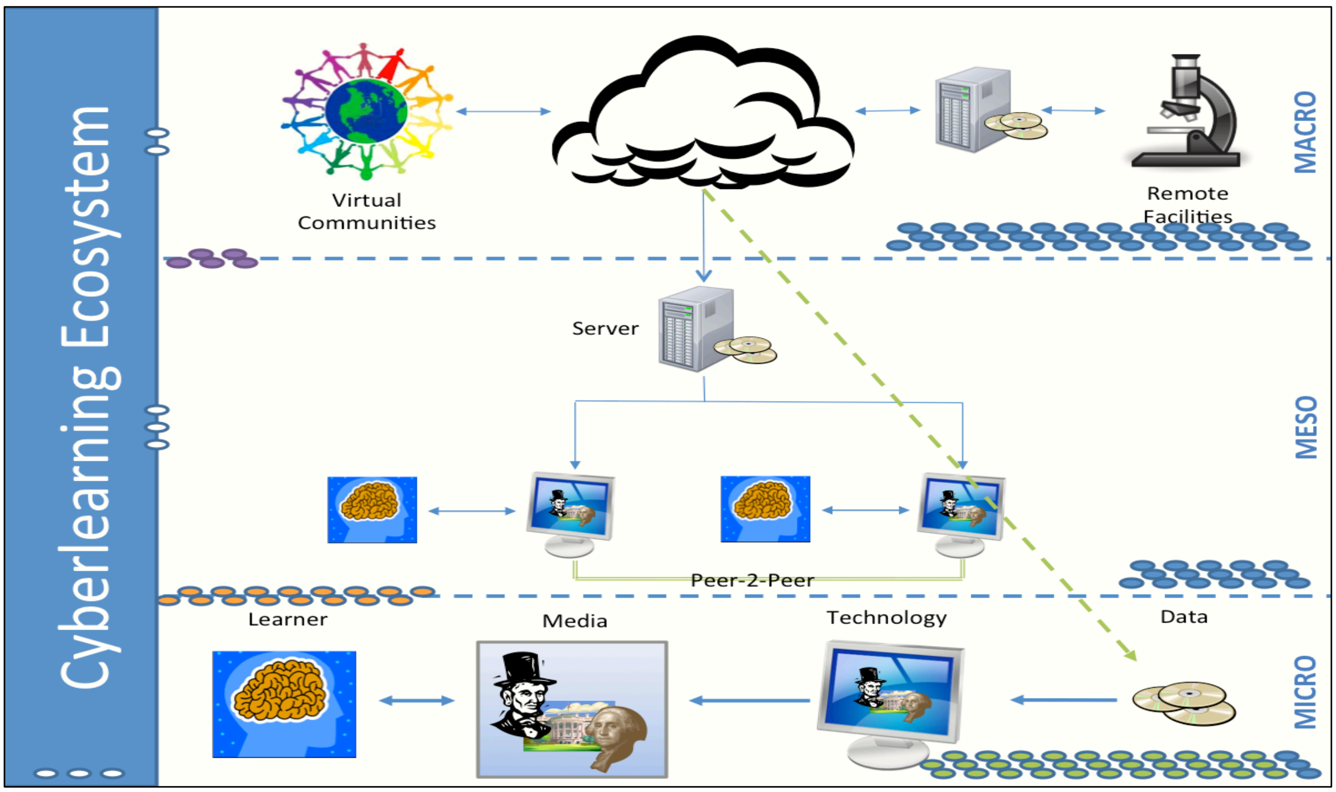
Figure 1 – Number of Cyberlearning Awards Highlighted between 2002-2012

Among the first observations to note is that before 2005 only one cyberlearning award was highlighted. On the contrary, cyberlearning awards have been highlighted every year since then –with a relatively increasing trend– and the largest spikes in 2009 and 2012. This brings to light one of the parallels between these results and the quantitative results of preceding study[3]. In both studies, 2005 was the beginning of an increase in the awards of interests. Similarly, there was also a spike in the number of awards in 2009. As in the previous study, one plausible explanation for this increase is due to the congressional ARRA (American Recovery and Reinvestment Act of 2009) funds NSF received.

Figure 2 is a mapping the 118 awards to the *Cyberlearning Ecosystem*, the cyberlearning taxonomy created during the prior study[3]. This mapping provides one snapshot of the current cyberlearning landscape, and also suggests some emerging opportunities. At first glance, it is easy to see that there are just as many projects that fit distinctly into one scale (i.e., blue circles) as those that cross boundaries. This speaks to both the complexity of the highlighted projects, and to a limitation of the taxonomy. One example of an award that represents the interplay between boundaries is "UT3" (UToledo. UTeach. Utouch the Future); it is represented by a purple circle on the macro/meso-scale line. UT3 is a professional development program for second career science and math teachers who are Noyce Scholars (recipients of the Robert Noyce Scholarship for STEM Professionals). Once the Noyce Scholars' pre-service training ends, workshop participants can continue to receive support through an online learning community. So, although projects containing online communities are typically classified as Macro-scale project, the exclusivity of the community qualifies it for Meso-scale project as well. This is just one example of how the projects may fall into more than one scale of the taxonomy.

There is another noteworthy connection between these results and the results of the prior work. According to the previous analysis, the majority of the cyberlearning awards funding by DUE's Transforming Undergraduate Education in STEM (TUES) program were at the institutional and/or individual course level (Meso-scale)[3]. However, according to this data, NSF staff tends to highlight cyberlearning projects that fit into the Macro-scale more often than at Meso-scale (37 vs. 16 awards). Additionally, Micro-scale cyberlearning developments that did not include an Internet connection (e.g., media stored data on a CD-ROM) were the least highlighted (3 awards), while the number of those that did (32 awards) is comparable to the number of other Macro-scale projects. Though preliminary this finding, this hints at the value of integrating an online component into the development of the cyberlearning resource, and its potential to be perceived as a transformative agent in STEM education.

The blue circles represent the awards that cleanly fit into one of the three scales, the largest of which are macro-scale cyberlearning projects. Among the 37 awards that fit this classification, digital repositories accounted for nearly half of them, and online communities designed for those who share a similar interest and/or want to exchange resources (e.g., educators, bird watchers) were also common. Furthermore, the number of MOOCs (Massive Online Open Courses) (among the green circles), which attract hundreds of thousands of learners all over the world, is increasing. MOOCs are one venue for allowing vast amounts of learners to personalize their experience, to connect with experts in their field no matter where they are in the world, and to engage in lifelong learning[9, 10]. Thus, MOOCS offers an unprecedented opportunity to think critically about the nature and structure of higher education, and about ways to promote resources that have the potential to drastically improve the educational experiences of those who, before now, may not have had access to such materials. Outside of the digital repositories, online communities, and MOOCs within this classification, there were very few instances of learners remotely sensing and collecting real-time data, accessing and analyzing large data sets, or engaging in learning through multi-player serious games.



LEGEND	Macro/Micro	Macro/Meso
Distinctly Macro, Meso, or Micro	Meso/Mico	Research Involving Cyberlearning Context

Figure 2 – Mapping Cyberlearning Awards in *NSF Highlights* to Taxonomy

These are just a few examples of the emerging opportunities for cyberlearning at the Macro-scale.

Cyberlearning awards in the Meso-scale were the second largest group of highlighted projects. Most of the awards in this subset include resources used in one classroom and/or by one instructor. Rarely were there examples of partnerships between corresponding faculty at departments in other institutions, implementing cyberlearning developments or modules, and studying its effectiveness in varying contexts. Unfortunately, none of the awards among the highlights were designed specifically for collaborative learning, and only two projects included the development of resources with tactile media to assist blind students with learning mathematics and science. Though few, they call attention to the need for more cyberlearning research that improves the educational experiences of STEM learning disabilities and promote collaborative learning.

Finally, the majority of the awards highlighted included the development of an actual cyberlearning resource (represented by the white circles in the banner). Said differently, few of them focus solely on studying a phenomenon in a cyberlearning context, or mining large data sets gathered during cyberlearning to understand how people learn. In fact, there was only one instance of a cyberlearning tools designed specifically for analyzing large data sets. These examples present another rich source of research possibilities for cyberlearning researcher. There is a need for more research that results from mining data captured from the human-computer interactions that occur during cyberlearning. Such research could advance the science of learning, and improve our understanding of STEM learning in both cyberlearning contexts and in other settings (National Research Council, 2001).

In summary, 90 of the 118 awards in this study's population were those mentioned among the last 10 years of *NSF Highlights*. Awards are spread across all three scales of the *Cyberlearning Ecosystem* taxonomy, and many cross and/or fall outside of the boundaries. Though limited in scope, this population of awards provides one snapshot of the current cyberlearning landscape, while also revealing some of the future possibilities. Now that the analysis of the cyberlearning population has been discussed, key aspects of the most compelling cyberlearning resources will be presented.

Fifteen cyberlearning awards were studied in-depth, 14 of which were NSF-funded. Again, the names of the cyberlearning resources are: Alice, Carnegie Learning's Cognitive Tutors, CodeLab, Coursera, Epistemic Games, FirstGlance in Jmol, Mobile Studio, Molecular Workbench, On the Cutting Edge, Physics Education Technology (PhET), Scratch, SimCalc, TeachEngineering, Web-based Inquiry Science Environment (WISE), and Wolfquest. These resources represented a variety of STEM disciplines, and the major six forms of cyberlearning. Three of the 15 were mentioned during the interviews that were conducted as part of the prior work. The table below provides details about the disciplines and target audience(s) associated with each of the cyberlearning resources. After the table, there will be brief descriptions of the key aspects of each resource. This will include the name of the resource, a one-line description of it, some of the most compelling results, at least one factor that led to the positive outcomes achieved, and a link to find the resource online.

Cyberlearning Resource	Discipline								Target Audience				
	Biological Sciences	Chemistry	Computing	Earth Science	Engineering	Mathematical Sciences	Physics	Social & Behavioral Sciences	Students	Faculty	K-12	Higher Education	MOOC
Alice			✓						✓		✓	✓	
Carnegie Learning's Cognitive Tutors						✓			✓		✓		
CodeLab			✓									✓	
Coursera	✓		✓	✓	✓	✓	✓	✓	✓			✓	✓
Epistemic Games								✓	✓		✓	✓	
Jmol	✓	✓							✓	✓		✓	
Mobile Studio					✓				✓			✓	
Molecular Workbench	✓	✓											
On the Cutting Edge				✓						✓		✓	
Physics Education Technology (PhET)						✓	✓		✓	✓	✓	✓	
Scratch			✓						✓				
SimCalc						✓			✓		✓		
TeachEngineering					✓					✓	✓		
Web-based Inquiry Science Environment (WISE)	✓	✓		✓			✓		✓	✓	✓	✓	
Wolfquest								✓	✓		✓	✓	

Table 1 – Cyberlearning Resources With Compelling Results

Alice is a program visualization tool for teaching novices how to do object-oriented programming. To date, there are over 3500 teachers who use Alice to teach undergraduate Computer Science courses, and 8-10 textbooks on Alice have been written. One of the key factors that led to such outcomes was keenly listening to the need and questions of potential adopters during the initial stages of development. Link: http://www.alice.org/

Carnegie Learning's Cognitive Tutors provided an applied test of the ACT-R theory of human cognition[11], and was the first algebra tutor designed to address the social context of using technology in high school classrooms. The cognitive tutors have been used in over 3,000 schools, and a plethora of foundations have invested in its growth and commercialization. One key decision that led to such positive outcomes is building the cognitive tutors around a cognitive theory and basing future decisions upon empirical data. Link: http://www.carnegielearning.com/

CodeLab is a web-based programming education service that was first designed to help undergraduate computer science (CS) students learn the content taught in introductory CS classes. It was created in response to a need to address the low attrition rates in CS1 to CS2 courses. CodeLab is unique in that was commercialized at the same time at which the NSF grant was awarded in 2000 and is still used in CS classrooms across the country. The team's emphasis on commercialization as part of their sustainability model was a key factor that led to the positive outcomes CodeLab has achieved. Link: http://www.turingscraft.com/

Coursera is a social entrepreneurship company that allows the best universities to take the best courses from their best instructors and offer it to everyone around the world so that everyone has access to the best education. Stanford, Princeton, and Columbia University are among the growing list of leading institutions partnering with Coursera. Since Fall 2011, when the first 3 Stanford courses were offered, 950,000 students around the world have become Courserians – 65% of which are outside the U.S. Partnering with leading institutions, and including technology, business, and pedagogy experts in the endeavor are key factors that have led to outcomes Coursera has achieved. Link: https://www.coursera.org

Epistemic Games are educational games designed to help players learn to think like professionals (e.g., engineers, urban planners, journalist). The game are currently being offered to K-12 students nationwide through collaborations with the Massachusetts Audobon Society, as well as first-year engineering programs at several universities. One of the most compelling aspects of the game is its ability to quantify changes in the learner's "epistemic frame", that is their skills, knowledge, values, and ways of making decisions in a professional field. Link: http://edgaps.org/gaps/

Jmol is a free, open source tool that is used by students, educators, and researchers who want to see and understand 3-D protein structures, but do not have the expertise of a structural biologist. It has been cited in over 100 papers and is used by tens of thousands of educators, students, and researchers worldwide. The decision to make Jmol open source, that is, owned and managed by its community of users, has been crucial to its permanence over the past 12 years. Link: http://jmol.sourceforge.net/, http://firstglance.jmol.org

Mobile Studio is a portable circuit board designed for Electrical Engineering (EE) students to gain a practical understanding of fundamental EE concepts by "tinkering" anytime, any place. Over the past decade, Mobile Studio boards have been integrated into both EE courses, and Circuits courses for non-majors, and at institutions within the US and around the world in countries (e.g., Ethiopia, the Philippines). Key aspects of the Mobile Studio are its low cost, size, and flexibility in how it can be integrated into a course. Link: http://mobilestudio.rpi.edu/

Molecular Workbench is an online environment for making models based on interactions of molecules and photons, and is useful for teaching and learning. Although it is hard to know the full extent of Molecular Workbench's impact, the developers do know it has been downloaded over 800,000 times. Ensuring that the science concepts were right is one of the key aspects of this resource. Link: http://mw.concord.org/modeler/

On the Cutting Edge combines real and virtual professional development for geoscience faculty, and allows them to learn the state-of-the-art research on teaching and how to use it in their classes. The compilation of materials has grown from that which was used in five workshops to a collection of resources on over 45 topics, and is used by faculty both in and outside the geoscience community. One key factor that led to the outcomes achieved was the development of a website with a powerful search engine. Link: http://serc.carleton.edu/NAGTWorkshops/index.html

Physics Education Technology (PhET) Interactive Simulations was founded by 2001 Physics Noble Prize Winner, Carl Wieman, and are designed to show how physics is relevant and helps explain the world around us. PhET simulations are downloaded 35,000,000 times/year, have been translated into 67 languages, and are used by educators and researchers worldwide. Key aspects of PhET are its low barriers to adoption. For example, the developers ensure that the simulations are designed to work on all software platforms and are easy to download. Link: http://phet.colorado.edu/

Scratch is an online community that actively engages young people in learning how to program through creating and sharing interactive media (e.g., stories, games). Since its launch in 2007, 1.1 million users are registered members of Scratch, and 2.7 million projects have been shared among members. Key aspects of Scratch include linking to young learners' interest and the important ideas they should learn. Link: http://scratch.mit.edu/

The vision of **SimCalc** developers is to democratize the learning of important mathematics by integrating visualization technologies, curricular materials and professional development. Through partnerships, SimCalc has expanded from Texas to middle schools in Florida, and schools in England. As you might assume, developing partnership with credible people and organizations is one the keys aspects of SimCalc. Link: http://math.sri.com/, http://www.kaputcenter.umassd.edu/projects/simcalc/

TeachEngineering is a searchable, standards-based digital library containing over 1,100 K-12 engineering curricula activities for teachers. To date, up to 90,000 unique users access the *TeachEngineering* curriculum monthly. Continuously alignment with the ever-changing 24 million cross-state science, technology, and engineering standards is one of the key aspects of this cyberlearning resource. Link: http://www.teachengineering.org/

Web-based Inquiry Science Environment (WISE) is a powerful online platform that guides learners, collects real-time data, provides visualizations, generates automated mentoring, and offers various tools for teachers (including grading tools and an authoring system). Currently, over 30,000 students and 3800 teachers around the world use the latest version of WISE, and thousands of others use previous versions.
The leadership of a strong interdisciplinary team is one of the primary factors that have led to the positive outcomes WISE has achieved. Link: http://WISE.Berkeley.edu

Wolfquest is a 3-D simulation game that allows players to learn about wolf life by joining a pack and living in the Yellowstone National Park. Wolfquest has been downloaded more than 1 Million times in over 200 countries. The game is currently maintained by the Minnesota Zoo, and is freely available online. One of the key aspects of Wolfquest was the selection of charismatic animal that would capture the interest of their target audience. Link: www.wolfquest.org

Discussion

While there is value in understanding key aspects of each cyberlearning resource in isolation, there is just as much to learn from looking across resources. Consequently, this section includes such insights, but with an emphasis on what these resources reveal about the design, implementation, and sustainability of cyberlearning resources.

One of the most salient themes related to the conceptualization of a cyberlearning resource is the emphasis of research-based approach to design. Specific activities associated with this approach to design might include, but are not limited to: building around a theoretical frameworks, grounding decisions in design research, and basing future modifications on empirical evidence. In addition to a design supported by research, it is also important to ensure that the content is accurate, and is an authentic representation of the phenomena of interest. Oftentimes, this can be fostered by the use of a strong interdisciplinary design team. Lastly, it is important to design resources that make understanding the concepts of a domain more accessible; allow learners to see the practical significance of the content being presented; and strike a healthy balance between being both educational and fun (this is especially important for young learners).

In addition to perspectives on conceptualization and design, the highlighted cyberlearning resources provide one key insight to consider during implementation as well. It is important to listen to the feedback, concerns, and input of both potential adopters and existing users. This is especially important during the early phases of implementation. This does not necessitate a compromise on every design choice to accommodate every new suggestion. However, this does mean that developers should be confident about their core idea(s) –for example, a theoretical framework or target audience- and be open to modifying details that are not related to the team's core idea(s) to ensure that the resource meets the needs of the users.

Lastly, the highlighted awards illuminate one key idea as it relates to sustainability: begin planning for long-term sustainability early. Although coming up with a plan for long-term sustainability is one of the developers' biggest struggles, many are overcoming these challenges and generating plans that promote success. Some of these plans include commercialization. Others involve seeking support from foundations and other sponsors. Moreover, some of the cyberlearning resources are sustained by developing partnerships, or by integrating the resource into the design of a long-standing course. These are just a few of many ways to approach planning for the long-term sustainability of a cyberlearning resource.

Conclusion

The positive outcomes that have resulted from existing cyberlearning resources are promoting excellence in undergraduate STEM education, and this is a work that Program Officers (POs) at the National Science Foundation are interested in continuing to support. As part of moving forward, however, there was a need to understand elements of the existing NSF-funded resources that have already achieved positive outcomes. This study was conducted in response to the need. An exploratory sequential mixed methods research design[1] was used to identify and highlight key elements of existing cyberlearning resources with compelling results.

This findings of this paper included insights about a subset of cyberlearning resources NSF had funded over the past 10 years, as well as some of the key aspects of cyberlearning exemplars and implications for those who plan to take on similar endeavors. The hope is that the findings of this study were not only helpful to those interested in supporting future cyberlearning research, but also to future developers of cyberlearning resources.

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