2012

Exploring Cyberlearning through a NSF Lens

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AC 2012-4153: EXPLORING CYBERLEARNING THROUGH A NSF LENS

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Exploring Cyberlearning through a NSF Lens

Introduction

Phrases like "Let's Google It" and "Text Me" reflect the lifestyle of today's millennials. Though simple, they speak to an undisputed reality–the use of computing technology and high-speed communication is ubiquitous. The new opportunities that have opened up in undergraduate STEM Education can be cited in support of this fact. Cyberlearning, the use of web-based technologies to support learning, enables us to explore new ideas in a way that traditional learning may not afford. Since cyberlearning has such great potential, the study explores ways in which it might be used to promote excellence in undergraduate STEM education, and to provide the Division of Undergraduate Education (DUE) Program Officers at the National Science Foundation (NSF) with recommendations on possible directions they could take. Though originally targeted to Program Officers, STEM educators and researchers searching for new ways to use cyberlearning to improve STEM education will also benefit from these findings.

A convergent parallel mixed methods research design[7] (p. 77) was used to collect different, but complementary data to answer five research questions. 1.) How is the concept of cyberlearning described in the scholarly literature? 2.) What funding has DUE provided for cyberlearning projects over the past 10 years? 3.) What types of cyberlearning awards has DUE made over the past 10 years? 4.) What are the perceptions of cyberlearning among a subset of NSF Program Officers? 5.) Based on the quantitative and qualitative findings, what are possible directions DUE could take with its support for cyberlearning?

This study yielded many findings. In scholarly literature, cyberlearning is described using the forms in which it may appear (e.g., games, virtual environments), its purpose, attributes, and outcomes. Over the past ten years, DUE has provided approximately $100M to over 800 cyberlearning-related awards, with awards in the "Engineering" discipline receiving the largest funding. After reviewing and analyzing a statistical sample of abstracts, two observations emerged. First, the representation of cyberlearning awards varies across disciplines. Secondly, while learning management systems (e.g., Blackboard) are used most often, cyberlearning is rarely used to support learning in a real-world context or to provide a personalized learning experience. Furthermore, qualitative analysis of the responses from 18 interviews with NSF Program Officers led to interesting insights. A taxonomy of cyberlearning was developed to show that it occurs on macro-, meso-, and micro-scales (where each scale indicates the number of learners and accessible resources). Based on the quantitative and qualitative analysis, 17 recommendations were proposed.

Literature Review: "Cyberlearning" in Scholarly Literature

The term "cyberlearning" is not the only term used to describe times in which computing technology and/or high-speed computing might be used for educational purposes. Since other words that convey a similar meaning (e.g., distance education, instructional technology, virtual learning environments) are used throughout the literature, the *concept* of cyberlearning is described here. Conceptually, cyberlearning is described in the literature with: definitions, the forms in which cyberlearning may appear, its attributes, and finally, the outcomes of cyberlearning.

Definitions of Cyberlearning

To craft a working definition of cyberlearning for the purposes of this study, it is important to understand how it has been previously defined. Zia (2005), during a presentation at the National Academy of Sciences on game-based learning, defined cyberlearning using a simple formula including two essentials: Cyberlearning = Education + Cyberinfrastructure. However, definitions produced by the NSF Taskforce on Cyberlearning (2008) and the National Science Digital Library (2009) emphasize a need for the technologies to be networked; digital networks facilitate back-and-forth communications among users. Their definitions are: "the use of networked computing and communications technologies to support learning" (p.5) and "the use of network computing and technologies in support of learning," respectively. Lastly, two other definitions contributed to the working definition used for this study. Chen (2002) highlights both teaching *and* learning in the following statement: "[cyberlearning is] conceptualized as teaching and learning interactions mediated entirely through the application of state-of-the-art information and communications technologies, such as the internet and world wide web" (as cited in [10], p. 6). Additionally, Montfort (2010) took a slightly different approach and defined cyberlearning by focusing on the learner's experience. He said it is "any form of learning mediated by technology in a way that changes the learner's access to and interaction with information" (p. 2).

It is apparent that cyberlearning can be defined in many ways, and each definition emphasizes something different. Using elements of the statements just provided, the working definition of cyberlearning used for the purposes of this study is: *teaching and learning that is mediated by the use of technology and networks.*

<u>Forms of Cyberlearning</u>

Games and virtual environments are among the most easily recognizable forms of cyberlearning, but there are others. Table 1 lists the forms of cyberlearning most commonly mentioned in scholarly literature as well as a description or example. These forms of cyberlearning will be referred to throughout this report.

Form of Cyberlearning	Description/Example
Remote Access to an Authentic or Virtual Environment	Through the internet, the learner is able to conduct experiments in a remote setting; collect scientific data in a natural environment; access and analyze data that is being stored remotely **OR** The learner accesses a rich, immersive environment that simulates a real phenomena
Online Community Used Exclusively for Educational Purposes	Blogs
Learning Management System	An organized collection of modules that are independent of a course offered by an institution that allow learners to exercise and/or build skills (e.g., cognitive tutors) **OR** A resource used by the teacher to manage an aspect of their course (e.g., Blackboard, "clickers" or electronic remotes used during class)
Distance Education (Courses)	Instructor-led module(s) that learners can access remotely (e.g., distance education courses, webinars)
Repository of Interactive Resources	The National Science of Digital Libraries
Games	

Table 1

Attributes of Cyberlearning

Although the forms in which cyberlearning may appear vary, there is a consistency in scholarly literature in regards to at least five attributes of cyberlearning. Network computing and communication technology is among the most commonly mentioned attributes of cyberlearning[10,15]. The availability of and access to resources and people anytime, anywhere[2, 3] is also one of the most distinctive features of cyberlearning. The third attribute that distinguishes cyberlearning is the use of digital content that supports teaching and learning without interfering with it[10,15,16]. Furthermore, cyberlearning oftentimes occurs in a highly-interactive, rich, immersive environment[10,1]. Lastly, unlike learning that may occur in a traditional classroom, cyberlearning allows learners to have a more personalized learning experience[10,2]. Although each of these five attributes do not relate to every form of cyberlearning (see Table 1), these features are often mentioned where the concept of cyberlearning is described.

Outcomes of Cyberlearning

Cyberlearning is a viable option to use in education for a variety of reasons. The National Research Council's *How People Learn* report (NRC, 2000) includes five classes of use for information technology in K-12 education. They have been concisely summarized in another NRC report[13] (p. 4) and presented as the first five outcomes in Table 2. Although this study is meant to explore ways in which cyberlearning might improve undergraduate STEM education, these five "classes" speak directly to the outcomes of cyberlearning–regardless of utilization. Furthermore, many other reports corroborate with these outcomes[2,3,10] and include an additional outcome as well. The outcomes of cyberlearning will also be referred to throughout this report.

Outcomes of Cyberlearning
(1) Support learning in real-world contexts
(2) Connect learners to experts and communities of other learners
(3) Provide tools to enhance learning and scaffolding - such as visualization and analysis tools that enable students to utilize complex data for higher-order thinking
(4) Provide opportunities for feedback, reflection, and revision in the acquisition and construction of knowledge
(5) Expand opportunities for teacher learning, using methods such as online communities of practice and best-practice case studies
(6) Customizable, personalized learning

Table 2

Research Design

The primary goal of this study is to provide recommendations to DUE Program Officers about possible directions they may take with cyberlearning. (Now, however, the larger STEM education and research community will benefit from this knowledge as well.) In beginning to pursue this objective, it is important to determine how much funding DUE has provided to cyberlearning awards in the past and the types of awards they funded. These data were supplemented by interviews with NSF Program Officers sharing their perceptions of cyberlearning. Because of this mix of both quantitative and qualitative data in a single study, a *mixed methods research design*[6] (p. 552) was the most appropriate approach. More specifically, since quantitative and qualitative data was collected concurrently, the analysis was done separately, but the findings from both equally contributed to the recommendations made, a *convergent parallel mixed methods design*[7] (p. 180) was used.

Quantitative Methods: TUES Portfolio Analysis

Fifty keywords were used to search the NSF awards database for TUES (Transforming Undergraduate Education in STEM) active and expired awards DUE has funded over the past 10 years (the data was pulled in July 2011). Examples of keywords searched for in the titles and abstracts include: cyberlearning, educational technology, and online. 3266 awards were returned from this query. However, approximately 75% of the awards were redundant. For example, the same Principal Investigator who used the word "online" in the title of their proposal could also use the word "internet" in their abstract; in this case, this same award would be listed twice. Once the redundant awards were removed, 866 unique awards remained.

Due to time constraints, a statistical sample of awards was reviewed based on a 95% confidence level; the sample size was calculated using an online sample size calculator[8]. More specifically, a stratified random sampling strategy[17] was used to determine which awards should be reviewed. Stratification is the process of dividing the sample into homogeneous subgroups. In this case, the population was divided by award type (TUES Type-1, -2, -3) and discipline (e.g., Engineering, Mathematical Sciences). Within each subgroup, awards were randomly selected and reviewed and the number of awards reviewed was proportionate to the number of awards in the total population. Table 3 shows the sampling by Type. This sampling approach ensures that the sample was representative of the population and minimizes sampling error. All TUES Type-3 Awards were reviewed since by nature, the scale of these projects are much larger and each awards is given significantly more funding than the other TUES awards. (More details will be provided in Table 4 of the Quantitative Results section.)

Award Type	Population	Sample
TUES Type-1	601	190
TUES Type-2	234	73
TUES Type-3	31	31
Total	866	294

Table 3. Sampling of TUES Awards by Type

To review the TUES awards, I read each abstract and categorized it by Form of Cyberlearning (See Table 1) and Outcome (See Table 2) or as "Not Cyberlearning". Here is an example with the key pieces of information highlighted in red:

> *The Society for Neuroscience is establishing ERIN, Educational Resources in Neuroscience, a Web-based portal that will enable faculty who teach neuroscience to list, review, and rate materials they use in their teaching. It will help faculty share information about resources that are effective in specific undergraduate courses, as well as create a community of practice in which faculty can exchange syllabi, lab exercises, and ideas about innovative approaches to teaching and learning. Materials will be peer reviewed for scientific validity and educational merit before posting, and the listings and reviews will be freely available on the web.*

Form: Online Community Used Exclusively for Educational Purposes

Outcome: Expanding Opportunities for Teacher Learning

Lastly, data about the funding provided for each award was pulled from each of the award letters. This data was compiled to answer the research question about the amount of funding DUE has provided to cyberlearning awards over the past 10 years. All 866 awards were included in the funding analysis.

Quantitative Findings

Over the past 10 years, the Division of Undergraduate Education has provided approximately $100.6 M to 866 awards using cyberlearning keywords in their title or abstract. The awards receiving the largest funds include those Engineering or Interdisciplinary/ Multidisciplinary awards while Astronomy awards were fewest among those funded.

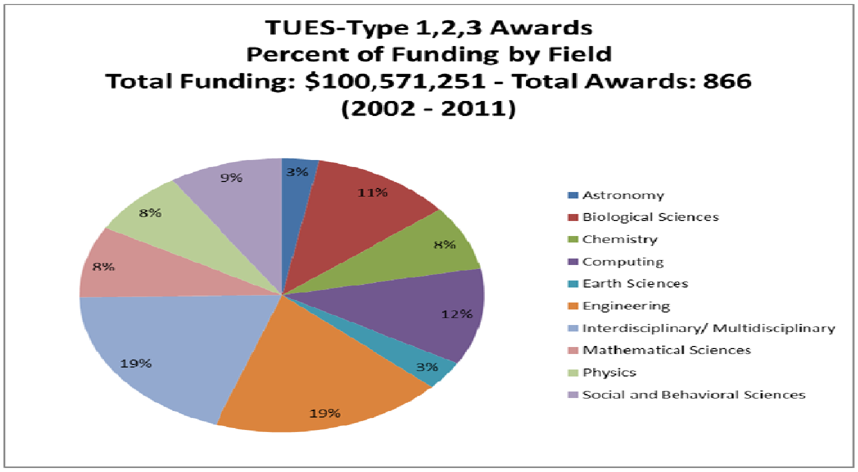


Figure 1

While Figure 1 allows us to see funding allocated to awards based on discipline, Table 4 shows how the funding is dispersed by type of TUES award. This table also shows that although there are fewer TUES Type-3 awards, the average funding per award is more than ten times the funding provided for a TUES Type 1 award! This again speaks to the scale of the award types. It is expected that the scale of projects will increase from a local to national level as the type of award changes; thus the level of funding corresponds to the cost of such endeavors.

Award Type	Total Funding	Number of Awards	Average Funding/Award
TUES Type-1	$45,558,098	601	$75,803
TUES Type-2	$29,648,018	234	$126,700
TUES Type-3	$25,365,141	31	$818,230

Table 4. Closer Look at TUES Award Types

The next few graphs provide insight about the types of cyberlearning awards DUE has made over the past 10 years (the data was pulled July 2011). Part of the reason why there were fewer cyberlearning awards in 2010 than in preceding years is because of the uncertainty associated with the year's budget situation. Figure 2 shows that among the awards reviewed (n=294), nearly half (n=149) contained forms of cyberlearning (see Table 1). Additionally, between 2005 and 2006 is when we begin to see a significant increase in the number of awards containing keywords that closely linked to cyberlearning. Lastly, one plausible explanation for the increase in awards in 2009 is due to the congressional ARRA (American Recovery and Reinvestment Act of 2009) funds NSF received.

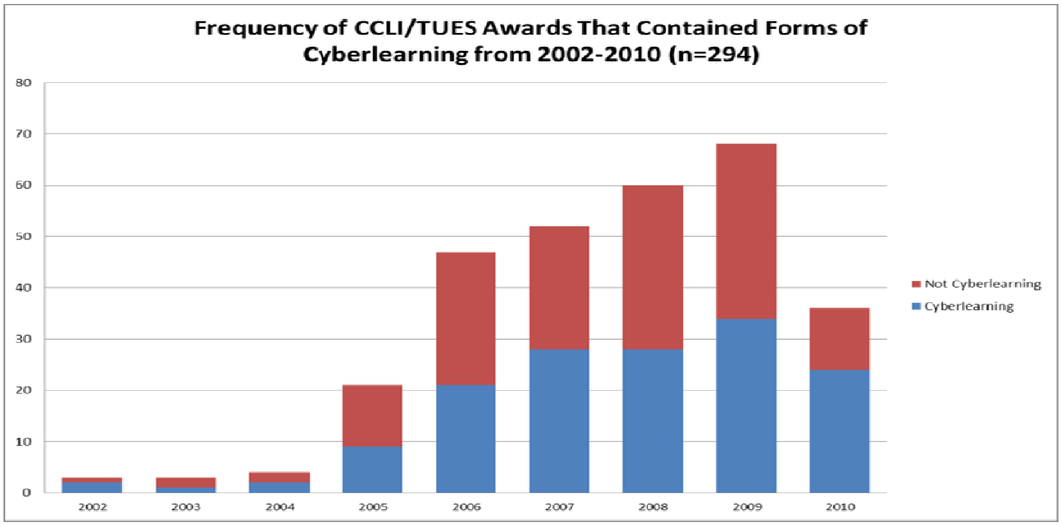


Figure 2

Of the 294 awards reviewed, approximately half of them contained Forms of Cyberlearning (see Table 1). Moreover, Figure 3 reveals which Forms of Cyberlearning are used by each discipline. Based on a quick glance, four inferences can be made. One, all disciplines have at least two forms of cyberlearning among their awards. Secondly, the representation of cyberlearning varies across disciplines, with Engineering, Computing and Interdisciplinary/ Multidisciplinary awards being the largest. Additionally, *Remote Access to an Authentic or Virtual Environment* and *Learning Management Systems* are the most common Forms of Cyberlearning. *Games* and *Repositories of Interactive Resources*, on the other hand, rarely appear among the awards. One last point might not be as obvious, but is still worth highlighting. The use of *Online Communities* is very large among certain disciplines (i.e. Mathematical Sciences, Interdisciplinary/ Multidisciplinary) and minimal to non-existent in others (e.g., Computing, Physics). Similar conclusions can be drawn about *Distance Education (Courses)* as well.

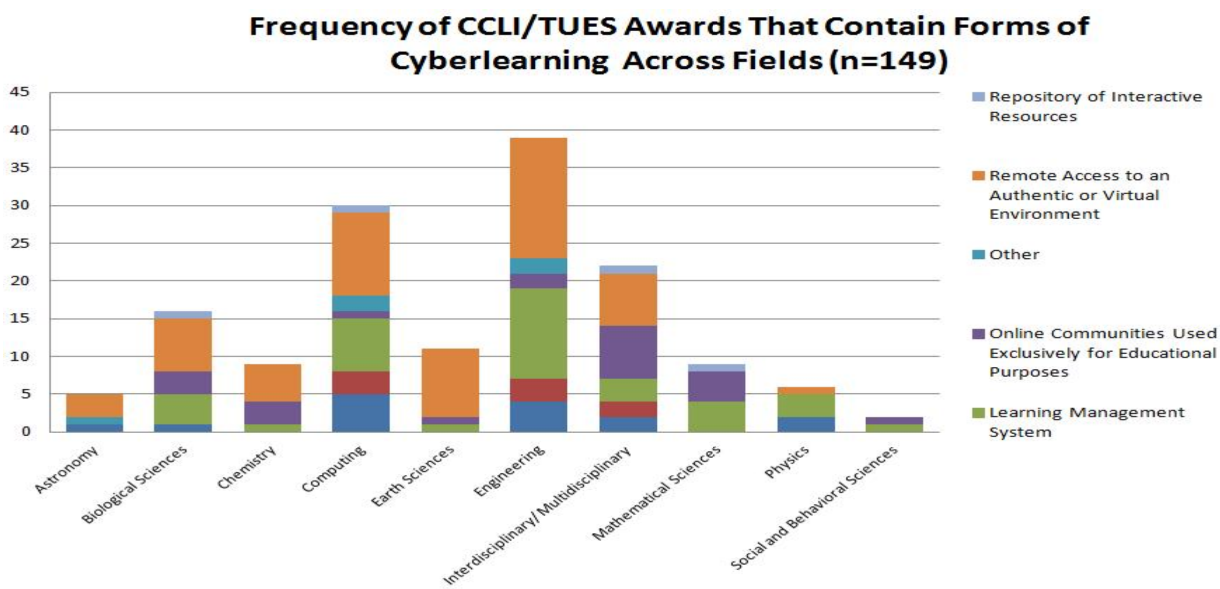


Figure 3

Figure 4 is the final graph that will be used to answer the research question about what types of cyberlearning awards has DUE made over the past 10 years. This data indicates *why* forms of cyberlearning are used; more specifically, what outcomes are most commonly achieved by using a certain form of cyberlearning. As with Figure 3, some conclusions become painstakingly obvious after one glance at Figure 4. *Learning Management Systems* is used most often to provide learners with the feedback, reflection and revision opportunities during their learning experience. What is also apparent from these data is *Remote Access to an Authentic or Virtual Environments* provide scaffolding and tools to enhance learning, such as visualizations. It is noteworthy that this form of cyberlearning also is commonly used to support learning in a real-world context (but in other forms that outcome rarely appears). Lastly, learners are rarely connecting with experts based on this data or provided with a customizable, personalized learning experience though the use of cyberlearning.

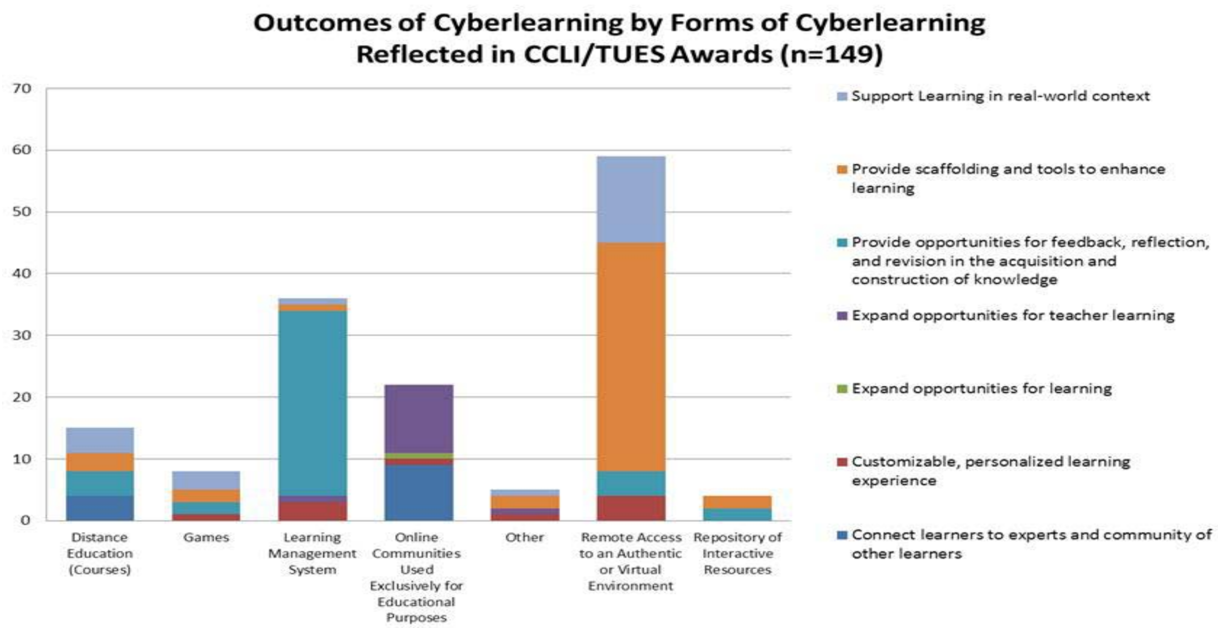


Figure 4

Summary of Quantitative Findings

A portfolio analysis of the TUES awards was conducted to answer the research questions regarding how much funding DUE has provided to cyberlearning awards over the past 10 years, and to understand the types of awards that have been funded. The findings resulting from this analysis are many. From 2002-2011, DUE spent approximately $100M on over 800 awards that use cyberlearning-related keywords. The largest amount of funding was awarded to Engineering and Interdisciplinary/ Multidisciplinary projects. A statistical sample of the awards was reviewed more closely. Based on this examination, it appears that approximately half of the awards actually contain Forms of Cyberlearning. Furthermore, among the awards that did contain Forms of Cyberlearning, the representation of the Forms varied across disciplines. *Remote Access Environments* and *Learning Management Systems* are the Forms of Cyberlearning that were used most often. However, cyberlearning is rarely used to support learning in real-world contexts or to provide learners with a personalized learning experience. These quantitative findings point to many possible directions one could take with cyberlearning. However, before suggesting recommendations, we must consider the qualitative analysis.

Qualitative Methods: Exploring NSF Program Officers' Perceptions of Cyberlearning

In order to determine the perceptions of cyberlearning among a subset of Program Officers (POs) and Division Directors, 22 people were invited via email to participate in this study. There was a follow-up personal invitation given to those who did not respond within two weeks of the email. A purposeful sampling strategy[17] was used to select POs that ranged across disciplines, years of experience at NSF, and have been (or are currently) engaged in activities that directly relate to cyberlearning or undergraduate STEM education. Eighteen POs (82%) agreed to a 30-min one-on-one interview. Table 5 shows the distribution of participants by field and years of experience at NSF.

	Years at NSF		
Field	Less than 3 yrs	3-10 yrs	Over 10 yrs
Biological Sciences	◆	◆	◆
Computing	◆ ◆		◆
Earth Sciences		◆	
Engineering	◆	◆ ◆	
Mathematical Sciences	◆		◆
Physics			◆
Social & Behavioral Sciences	◆	◆	◆

Table 5. Distribution of Interview Participants across Disciplines and NSF Tenure

The participants were asked about their academic background, research interests, and six open-ended questions. Among other things, participants were asked to: describe cyberlearning in their own words; discuss ways in which it might improve the educational experience of all learners; and provide examples of awards they had cyberlearning elements and have had compelling results. I designed the survey instrument and incorporated feedback from mentors before conducting the interviews. The interview responses were analyzed using the *Qualitative Process of Data Analysis*[6] (p. 244) which involves iteratively reading through the data and coding the texts such that recurring themes are identified and described.

Qualitative Findings

Description of Cyberlearning

During the interviews with POs, they were asked to describe cyberlearning; share the names of cyberlearning awards with compelling results; discuss ways to assess the impact of cyberlearning and in what ways they saw potential to improve the educational experience of learners.

"Learning mediated by technology" was the phrase most commonly used by participants as they began to describe cyberlearning. However, there was much more to their description than this one-liner; a taxonomy has been created to capture the breadth of responses. Figure 5 depicts the descriptions of 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.

As stated before, most participants described cyberlearning as learning mediated by technology; more specifically, the media that comes from it, since the technology may vary as widely as the media itself. Currently, the most common form of media is images; however, audio and tactile media are also viable alternatives for cyberlearning. The primary difference among participants' descriptions of cyberlearning is the lowest scale at which data can reside.

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

(1) Learner accesses data stored on a physical artifact (i.e. CD-ROM, USB Drive, handheld game, etc.).
(2) Learner accesses data stored in a remote location that is only accessible through the internet (or intranet). (Examples: online simulations, 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 systems used in a classroom)
(2) Peer-to-peer interactions between learners who exchange data over the internet (or intranet) (e.g., multiplayer games)

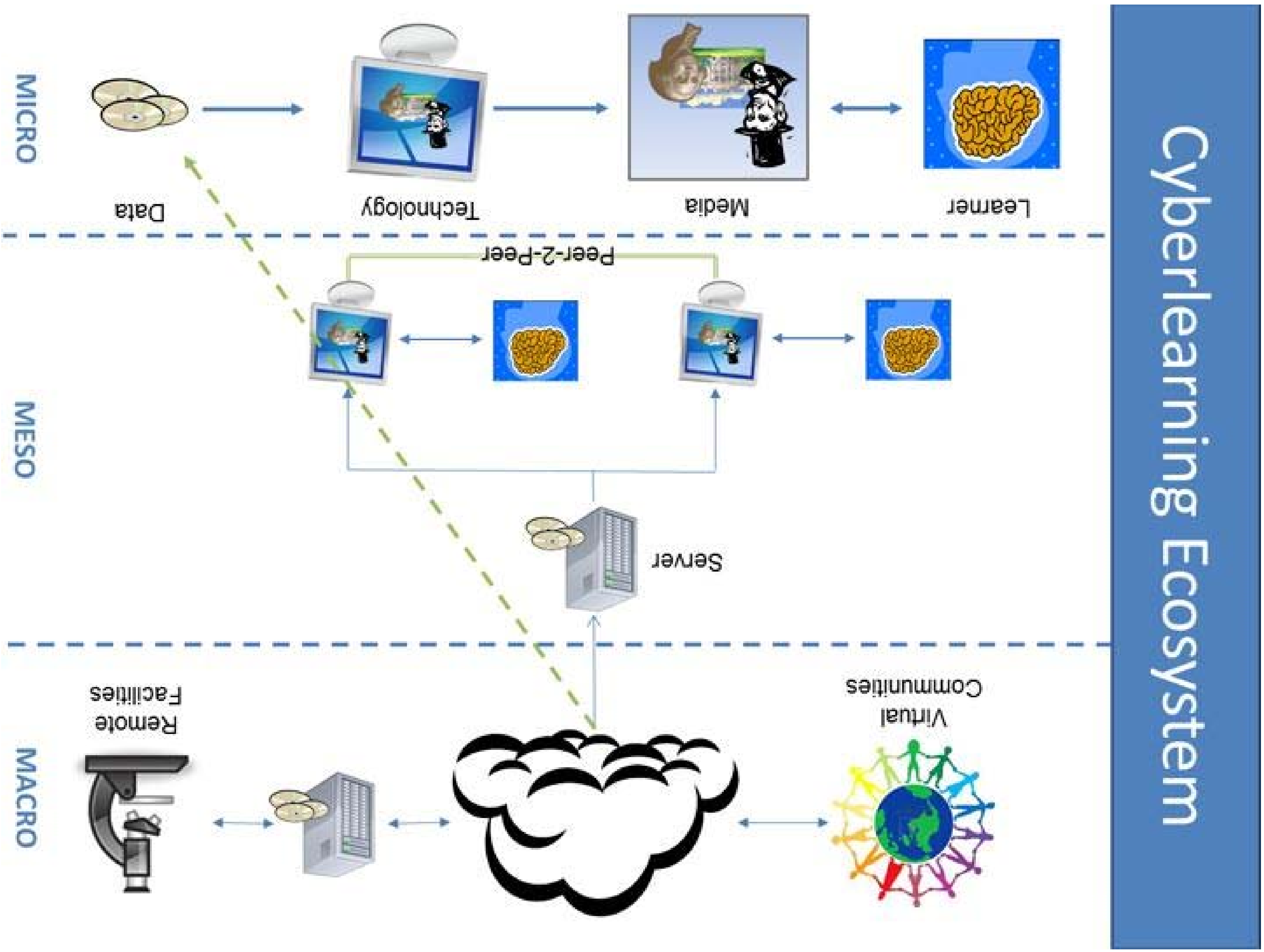
Cyberlearning at the Macro scale occurs in many ways:

Through the use of the internet, an unlimited number of learners can access other learners, vast amounts of data, and remote facilities.

Based on the participants' description and this depiction of cyberlearning as an ecosystem, the following definition of cyberlearning is proposed:

Cyberlearning is a change in the learner's thinking (e.g., understanding, interests, affect) that result from interacting with digital content.

Figure 5



Cyberlearning Ecosystem
MICRO
MESO
MACRO
Data
Technology
Media
Learner
Peer-2-Peer
Server
Remote
Facilities
Virtual
Communities

What's New?

Some participants who agree that cyberlearning can occur at the Micro level without Internet access argue that cyberlearning has existed long before now. With this in mind, one question worth answering then is: What distinguishes cyberlearning today from cyberlearning 5-10 years ago? This is a question that every generation of cyberlearning researchers will have to answer, but the answer to the question today is essentially three realities. One, there is a ubiquitous use of technology that has greater networking, and computing capabilities than ever before. Secondly, there has been a surge of "smart/intelligent" computers that can now provide intelligent responses to learners and unique responses based on the user's input. This attribute of cyberlearning facilitates a more personalized learning experience unlike what has been enabled in the past. Lastly, the prevalence of "Big Iron" is another way in which cyberlearning today differs from cyberlearning 5-10 years ago. This expression is used to describe the prevalence of supercomputers that enable high-speed computing & communication, and access to large data sets. Again, the question about the distinguishing attributes of cyberlearning today is a question that every generation of cyberlearning researchers must answer, but these are at least three attributes that distinguish today's cyberlearning experience from yesterday's.

Awards with Compelling Results

Most participants were able to name at least one Cyberlearning award that resonated with them. Among the many suggestions offered, some have either been nationally recognized by the National Academy of Sciences, widely adopted, and even commercialized! You may recognize the logos of some in Figure 6. One conclusion that can be drawn from such an array of suggestions is that cyberlearning is being used across disciplines and in some cases, having a significant impact on learning! This is consistent with the quantitative findings. It is also worth mentioning that the awards with the most compelling results are all online and widely used. Lastly, games and online simulations were the most commonly mentioned when participants were asked about cyberlearning awards with compelling results.

Figure 6. Logos of Cyberlearning Awards Mentioned during Interviews[4,9,11,18,19,20]

Assessment of Cyberlearning Awards

Interview participants were also asked about possible approaches to the impact assessment of cyberlearning. Unfortunately, most of the participants struggled to provide approaches to assessing the impact. This speaks to the need for more research in this area. However, among the few who tried, the use of a control group and experiment groups was the suggested approach. Others, however, reverted to metrics they think are most important when assessing the impact of a cyberlearning award.

Many participants said that the metrics used to assess the impact of a cyberlearning award should be based on the subject and the context (i.e., in a formal or informal environment) in which the cyberlearning occurs. Regardless of these nuances, however, *gains in students learning* was the only metric mentioned by nearly all participants. Other important cognitive measures include changes in habits of thinking and the promotion of lifelong learning. While some metrics were easily spelled out, participants also suggested that we need to open to fortuitous outcomes that may emerge as we explore the new types of learning cyberlearning affords.

Other metrics for assessing the impact of a cyberlearning award relate to the learners, the technology, and to conducting research. These metrics are packaged in the form of questions POs might ask PIs. They include: Are you reaching a diversity of learners with this development? Does this development facilitate fast feedback to the learner? Is the content accurate and easy to understand? How often are learners engaging with the resources? How widely accepted is the cyberlearning development (both in and outside the institution in which it was developed)? What gains in efficiency (in time and cost) result from this development? What were the implementation successes and disappointments? How much bandwidth/throughout is necessary to accommodate one's user population and larger populations? What innovative contribution is being made to the field? What publications resulted from this award? What is the long-term impact of the cyberlearning award?

In summary, many participants struggled with identifying approaches to assessing cyberlearning awards. However, there are many metrics that can and should be used in the process.

Issues to Consider

Before summarizing the qualitative results and making recommendations, I must share the issues that must be considered when developing cyberlearning resources. There was no interview questions related to the drawbacks of cyberlearning. However, every interview participant mentioned issues that must be mitigated as we begin to chart new courses in the cyberlearning territory.

Similar to the metrics for assessing the impact of a cyberlearning award, the issues participants mentioned related to teachers and learners, and the development and maintenance of cyberlearning resources. Protection of the learner's security and privacy was the concern is of the utmost importance. Additionally, one must consider issues of equity and the differences among learners that exist (e.g., personality, learning styles, persons that struggle with depth-perception, hand-eye coordination) when developing cyberlearning tools. It is also important to distinguish what content is better suited for a human instructor from what can be effectively taught using cyberlearning. Furthermore, now that so much data is not readily available using various cyberlearning mediums, teachers using such resources as part of their laboratories must ensure that their students are not losing an appreciation of the data collection process. Additionally, one Program Officer said, "Not everything worth knowing is online." This statement should serve as a reminder that every piece of content available has not been digitized. As a result of this, cyberlearning users should always check libraries and other traditional venues for information before assuming that content about a topic does not already exist. Lastly, issues related to correcting erroneous content (especially in digital portfolios), the cost of high-quality materials, the development of platform-specific designs and the maintenance of content and cyberlearning developments are all things that must be considered when generating new cyberlearning resources.

Summary of Qualitative Findings

To understand NSF Program Officers perceptions of cyberlearning and its potential to transform undergraduate STEM education, 18 POs were interviewed. Based on their responses, cyberlearning can be describes as changes in the learner's thinking (e.g., understanding, interest, affect) that result from interacting with digital content. Cyberlearning can occur on many scales, involving anywhere from one to many learners and/or resources at a time. Although cyberlearning has existed for quite some time, there are a few characteristics that distinguish cyberlearning today from cyberlearning ten year ago, one of which is the ubiquitous use of technology. Despite its use, there is a need for more research on how assess the impact of cyberlearning. Moreover, even though other metrics can be used for impact assessment, gains in student learning and other cognitive measures are among the most important. As we move forward in exploring the potential cyberlearning has to transform undergraduate STEM education, there are many issues, including security and privacy concerned, that must be addressed.

Recommendations

Based on the findings from the quantitative and qualitative data analysis, 17 recommendations are proposed as possible directions one could take with cyberlearning. (POs responses to the question about the potential of cyberlearning to improve the learner's educational experience are included among the recommendations.)

Similar to the *Cyberlearning Ecosystem* (See Figure 5), the recommendations (See Figure 7) have been clustered by Micro-Meso-Macro scales. In this case, however, the scales relate to the level at which the recommendation would have the greatest impact (i.e. Individual-, Local-, and Global Levels). Based on the awards reviewed during the TUES portfolio analysis, much of the work has been done at a Meso/Local-level (local to a single-institution), while little has been done at the Individual and Global Levels. For this reason, the majority of the recommendations fall into these two scales. In the interest of space, I will only elaborate on two of the macro-scale recommendations.

One of my recommendations is to encourage partnerships between majority-serving institutions and minority-serving institutions (MSIs) on future cyberlearning projects. The implicit assumption in this recommendation is that many large, majority-serving institutions have access to advanced laboratories and/or are able to create more powerful cyberlearning technologies than an MSI might. Consequently, such partnerships will enable students at MSIs to have access to cutting-edge, advanced facilities and other resources at a cost they can afford – thus improving their students' educational experience. Furthermore, majority-serving institutions would benefit from such a partnership as well because of the potential for their work to have a broader impact (which is one of the merit review criteria for all NSF proposals).

Secondly, I would encourage Principal Investigators (PIs) submitting cyberlearning proposals to identify industry partners willing to implement their successful concepts. Commercialized ideas have the potential to reach a wide audience. Furthermore, having a business structure attached to the idea helps to mitigate the issues that may extend beyond the limitations of a PI (e.g., marketing, maintenance, cost of high-quality materials).

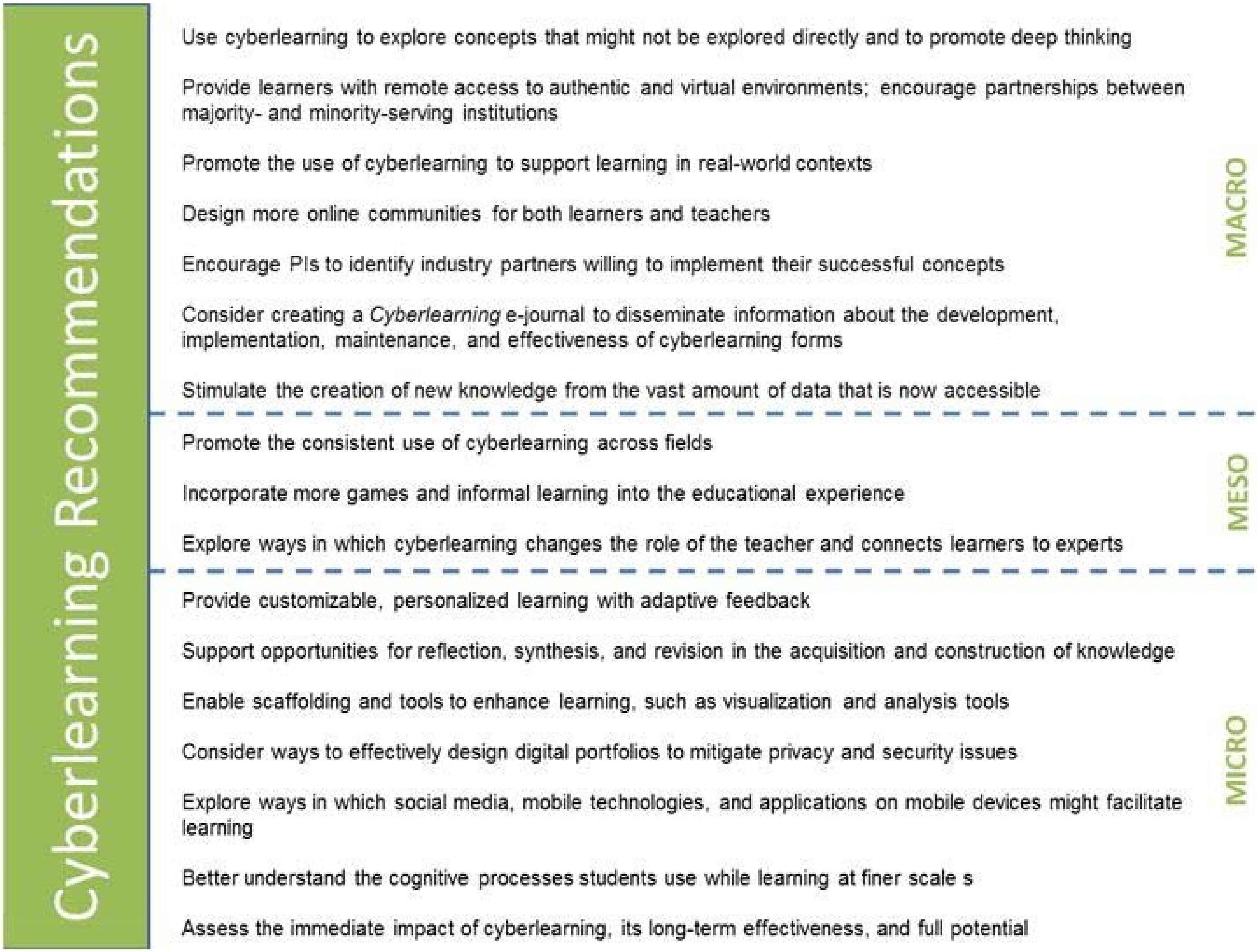

Cyberlearning Recommendations
Use cyberlearning to explore concepts that might not be explored directly and to promote deep thinking
Provide learners with remote access to authentic and virtual environments; encourage partnerships between majority- and minority-serving institutions
Promote the use of cyberlearning to support learning in real-world contexts
Design more online communities for both learners and teachers
Encourage PIs to identify industry partners willing to implement their successful concepts
Consider creating a Cyberlearning e-journal to disseminate information about the development, implementation, maintenance, and effectiveness of cyberlearning forms
Stimulate the creation of new knowledge from the vast amount of data that is now accessible
MACRO
Promote the consistent use of cyberlearning across fields
Incorporate more games and informal learning into the educational experience
Explore ways in which cyberlearning changes the role of the teacher and connects learners to experts
MESO
Provide customizable, personalized learning with adaptive feedback
Support opportunities for reflection, synthesis, and revision in the acquisition and construction of knowledge
Enable scaffolding and tools to enhance learning, such as visualization and analysis tools
Consider ways to effectively design digital portfolios to mitigate privacy and security issues
Explore ways in which social media, mobile technologies, and applications on mobile devices might facilitate learning
Better understand the cognitive processes students use while learning at finer scale s
Assess the immediate impact of cyberlearning, its long-term effectiveness, and full potential
MICRO

Figure 7

Conclusion

Cyberlearning has the potential to improve the educational experiences of all learners. Yet, its full potential has not been realized in undergraduate STEM education. The goal of this project was to explore ways in which cyberlearning might be used to promote excellence in STEM education for all students. As a result of this study, Program Officers now have a better way of organizing the layers of cyberlearning. Additionally, the findings of this study explicitly show the significant increase in the influence of cyberlearning on undergraduate STEM education. Such information has the potential to inform their selection cyberlearning projects they choose to fund in the future. Finally, this study lays the groundwork that enables them to do future explorations.

The original audience for this study was DUE Program Officers. However, STEM educators and researcher interested in using cyberlearning to improve undergraduate STEM will benefit from the findings of this study. Through the effective use of cyberlearning, students can develop expertise and work collectively to address the grand challenges of our society. Indeed cyberlearning has the potential to improve the educational experience of all learners, but we must pursue the vast opportunities that await us.

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