CYBER-ENABLED TEACHING AND LEARNING THROUGH GAME-BASED, METAPHOR ENHANCED LEARNING OBJECTS (CYGAMES)

EVALUATION REPORT: 2009-2011

Prepared for the Center for Educational Technologies (CET)
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Executive Summary

The *Cyber-Enabled Teaching and Learning Through Game-based Metaphor Enhanced Learning Objects (CyGaMEs)* is a principled approach to instructional game design and embedded assessment. The goal of the project is to facilitate and measure student intuitive understanding of science concepts through an interactive videogame environment. The project builds upon the integration of cognitive science and instructional game design to develop a robust videogame with informatics system components featuring assessment methodologies that measure and report learner growth.

Evaluation Approach

The evaluation of the project has three components: (a) a formative component to monitor project progress with annual and overall summative analyses, (b) review of intellectual merit focusing on the integrity of research and development activities, and (c) analysis of broader project impacts. The focus of this evaluation report is on activities and milestones accomplished through Year 3 of the project. Quarterly reports were analyzed to determine project progress, while data triangulation was accomplished through contact with project staff and review of "documentation trail" on the project blog, and analysis of project results. The examination of intellectual merit was informed by queries on the integrity of design and development activities, capacity for conducting the project, contribution to the body of knowledge in the field, and the development of potentially transformative tools and concepts. In turn, the examination of broader impacts focused on evidence of contributions on cyberlearning, development and promotion of infrastructure for research and education, and extent of dissemination and synergistic activities.

Evaluation Findings

Based on the review of quarterly reports of activities, audit of project documentation, and analysis of project results, the project remained on Green Status at the end of Year 3. That is, the project's proposed activities, events, or products continue to be on schedule and all milestones anticipated through Year 3 of the project plan are also on track. Based on project progress through Year 3, and taking into consideration the quality of research and development activities, level of synergistic collaboration, and extent of dissemination work, the project is meeting its goals and continues to exhibit high standards of implementation. Specifically, at the end of Year 3:

- Regarding Objective 1 associated with videogame design and development, a review of available evidence of progress confirmed that project staff was on track completing scheduled project milestones. To this end, with the implementation of some

workarounds, the project managed to resolve some performance issues upon termination of the contract with the initial developer and the game is now functional and available online for public access.

- About Objective 2 related to data collection and analysis of learning and perceptions, project staff boosted recruitment efforts to attract more players targeting public schools and science teachers, and undergraduate students through partnerships, workshops, and professional development activities, and other dissemination strategies. As a result, the project went from 152 players in 2009 to 537 in 2011. Further, the analysis of game playing has demonstrated that when playing CyGaMEs, players work toward the game goal and develop an understanding of lunar geology.

- In relation to Objective 3 targeting the refinement of analytical procedures, research on the flowometer was conducted and replicated to confirm reliability of findings showing the capacity of this assessment tool to profile game playing experience. The goal of the project is to quantify player behavior aligned with eight-flow states and identify the learning moment, and then study the interplay between the two. So far, staff has determined the point when a player's gameplay changes drastically as measured by the velocity of playing gestures such as sling shooting particles at a target (i.e., the moon) for Selene Classic. Further, an algorithm to categorize flow reports into eight flow states and intrinsic motivation for analysis has been also developed.

- About the Objective 4, concerned with the development of an informatics infrastructure, the project is also on track with the completion of related activities and milestones. Project staff continued to work on an algorithm to adapt accretion learning moment data, and are currently able to generate reports in aggregated form or to learn about the performance of individual players for basically all gameplay and assessments. This process has been automated for use by project researchers.

- Collectively, the project has clearly maximized the use of complementary internal and external intellectual capacity to meet research and development requirements and—ultimately—project goals. The use of organizational and communication structures has been instrumental in clarifying specific roles and expected contributions, sharing access to relevant data; comparing notes on pertinent design, development, and research activities, and determining progress status.

- The broader impacts of project activities align with contributions to emerging evidence that simulations advance conceptual understanding and can motivate students' interest in science learning. Project results have also established the value of embedded assessments in understanding how players experience cyberlearning. These results are significant because they align with and contribute to recent calls for conducting research and development about how embedded assessment technologies can be used to engage students in learning and assess what and how they learn.

Overall, given project progress, quality of research and development activities, and level of synergistic collaboration and dissemination, the project continues to exhibit exemplary standards of implementation.

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Understanding of Project Goals

Background

The project conceptualization emerged out of previous research and development work integrating the ideas of analogical reasoning, conceptual metaphors and structure mapping (Gentner, 1989; Hyerle, 1996; Lakoff, 1993). Analogical reasoning implies a relation between specific cases, so what is known about one case can inform the understanding about another case (Gentner, 2002). Further, analogical reasoning can be thought of as establishing relational structures between two situations, which is the basis for structural mapping theory involving the alignment between two representations of a situation of interest. In this sense, a metaphor has been suggested to be like an analogy (Gentner & Bowdle, 2008). That is, a metaphor is a unified process of understanding one situation as a function of another involving a cognitive mechanism facilitated through experiential structures connecting a source or base domain (e.g., concrete or relatively familiar) and a target domain (Lakoff & Johnson, 1980; Hurtienne & Blessing, 2007). Under these premises, the understanding of concepts implies an interface of knowledge and representations of situations, and in this context conceptual metaphors represent a framework useful for the design of multimedia instructional environments (Huertienne & Blessing, 2007).

Conceptual domains are viewed as systems of objects with distinct relations between them (Gentner, 1983). With this idea in mind, videogame environments can be thought of as systems of objects and structures of interest sharing relational connections (Bogost, 2006; Fullerton, Swain, & Hoffman, 2004). In such environments, players navigate and experience a game world through gameplay driven by an explicit goal. That is, videogames can be designed to direct players' behavior toward making progress by interacting with targeted relational structures. In this regard, the game environment becomes an analog of the targeted domain, and the goal driving the game is an analog of the targeted learning goal. Thus, playing a videogame under these conditions requires interactivity with the relational structure of the domain of interest. Through gameplay, it is expected that players would produce intuitive understandings of target concepts by establishing relational connections as they figure out how a game works.

This conceptual framework led the principal investigator (PI), Reese, to develop a design structure for specifying a target domain that could be relationally mapped to a source domain based on structure mapping principles in a videogame environment (Reese, 2007, 2008a; 2009a; Reese & Coffield, 2005). However, to study purposeful interactivity more efficiently, the PI decided to explore the integration of embedding learning and assessment within videogame environments. In 2006, this opportunity emerged when the

NASA eEducation initiative, calling for the development of videogames featuring NASA science, charged the PI's group to work on game-based research and development focusing on embedded assessment (Laughlin, Roper, & Howell, 2006; Reese, 2009a).

Based on the related emerging body of knowledge bridging analogical reasoning theory and instructional design, a single player environment called *Selene: A Lunar Construction GaME* was created to measure learnning in a game-based environment to promote viable preconceptual mental models. The project uses the double transfer paradigm involving the manipulation of a variable with a controlled environment and with random assignment at the player level (Reese, 2007, 2009a; Schwartz, Bransford, & Sears, 2005). However, the original game lacked robustness necessary for reliable educational research and thus the need to focus on meeting the Objective 1 of the CyGaMEs project: To transform an existing instructional videogame *Selene: A Lunar Construction GaME* into a robust reserach instrument.

> "The more I learned about the idea of deep learning through profound relational structures serving as the basis for structural mapping theory, I realized that the more profound the relational structure is, the better the learning would be—which is also the basis of analogical reasoning. Now, what was missing in my work was an environment that had a goal structure built into it that motivated the learner to discover the relational structure of the environment that map one domain to another and be able to gather data about the goal structure. And that's how I began to develop the CyGaME concept."
>
> *Debbie Reese, PI and Senior Researcher at the Center for Educational Technology, Wheeling Jesuit University.*

Reliable and robust games are a necessary condition for consistent playability and to generate data on learning as players transfer tasks for measurement purposes. In turn, reliable and valid data are required to generate evidence of engagement and perceived skills as users interact with the games. In this context, once *Selene* is turned into a robust game, the project will be in a position to meet Objective 2 of the CyGaMEs project: To collect GaME data representing perceptions on flow and learning. The notion of *flow* represents a useful construct for characterizing general human-computer interactions beyond navigation behavior in computer environments. The emerging understanding of flow is that of an individual engaged in a sequence of responses facilitated by interactivity with a computer environment that is focused, purposeful, and self-motivating, resulting in experiences of intrinsic interest and time-distortion during engagement. That is, when individuals reach the flow state, they become absorbed in the activity at hand to the point that awareness is completely engaged in the activity itself. Flow can be measured using data generated by a participant on perceived skill and challenge as he or she interacts with the activity of interest (Csikszentmihalyi & Csikszentmihalyi, 1988; Finneran & Zhang, 2002; Hektner, Schmidt, & Csikszentmihalyi, 2007).

Concurrently, although the body of knowledge on flow is steadily emerging, specific understandings of underlying participant's motivation, engagement, and learning needed further study in game environments. This need led to Objective 3 of the CyGaMEs

project: To develop and refine GaME methods and metrics for assessing motivation, engagement, and learning. To meet this objective, CyGaMEs proposed the development of measures and analytical techniques for the assessment of learning and player's perception of game-playing experience.

As a whole, the proposed plan was to generate more reliable data of player performance including flow, gestures, timed report, and knowledge of lunar geology. The focus on lunar formation and evolution, in the content domain of Earth and Space Science, is based on the Moon's unique record of basic geological processes of planetary birth and evolution. Its proximity allows for personal observation and makes for real connections during game playing. Further, the science of lunar formation and evolution underscores the *Selene* game (i.e., accretion, differentiation, impact cratering, volcanism, and stratigraphy) and aligns with national science education standards (National Research Council, 2007; Wood, 2003). The focus on lunar formation benefits from the direct contribution of NASA science through the work of Dr. Wood, project Co-PI. Dr. Wood has devoted his life to the study of the moon. Upon earning a doctorate in Planetary Geology, he spent 10 years as a NASA Space Scientist at the Johnson Space Center in Houston Texas. He continued his work at other venues and he is currently the Executive Director of the Center for Educational Technologies at Wheeling Jesuit University. In his view, many discoveries and understandings from planetary exploration have not been incorporated into education, and he seized the opportunity to develop a videogame targeting lunar concepts in collaboration with Dr. Reese.

> "I wanted to make a physics game, but when I presented the idea to Chuck, he proposed to build a game around the concept of the moon"
>
> *D. Reese. PI. 6/15/2011.*

> "My most continuing addiction is to the Moon, and I am lucky to have been a bit player in its scientific exploration, [and] the ability to explore it with a backyard telescope makes it much more real than anyplace else in the universe."
>
> *C. Wood, PI, in Chronicles of the New Space Age, 2006.*

In the context of planetary formation, accretion can be described as a process by which small particles collide and stick together to form larger body mass. As the larger body grows, the accretion process is enhanced by gravitational force. Billions of years ago, planet Earth collided with another planetary body and likely produced large amounts of debris into the Earth's orbit. Our moon formed from this debris through a process of accretion (Canup, 1999). Thus, understanding how the moon was formed can provide the basis for relational understanding of other planetary bodies in the solar system through an engaging videogame environment.

With access to a robust videogame (Objective 1) and reliable data (Objective 2)—based on refined assessment methods and metrics (Objective 3), the project would be in a position to achieve Objective 4: To design a prototype of a reporting system for GaME data collection and assessment within a cyber-enabled informatics infrastructure. This objective is consistent with calls in the field to develop tools capable of recording

learning over time in a way that informs a variety of stakeholders (Computing Research Association, 2005). To this end, cognitive science provides the basis for game design and the development of an informatics system featuring assessment methods to measure and report learners' growth. As portrayed by the project, unlike the game itself, the prototype informatics system is to be a proof of concept rather than a completed application (Reese, 2008b). That is, the prototype informatics system should serve as a platform for understanding why and how the concept works with evidence of methods and metrics available for further research and related applications.

Project Objectives

In the context of the research and development background outlined above, the goal of the *Cyber-Enabled Teaching and Learning Through Game-based Metaphor Enhanced Learning Objects (CyGaMEs)* project is to facilitate student intuitive understanding of science concepts through applied structure mapping and measure trajectories of learning and affect resulting from the negotiation of pragmatic constraints of an interactive videogame environment. The project builds upon the integration of analogical reasoning theory and instructional game design to develop a videogame environment featuring an informatics system with embedded assessment structures that measure and report learner growth.

Specifically, the objectives of the *CyGaME*s project are to:

1. Transform an existing instructional videogame environment, *Selene: A Lunar Construction GaME* into a robust research instrument.

2. Collect GaMEs data representing perceptions on flow and learning.

3. Develop and refine GaMEs methods and metrics for assessing motivation, engagement, and learning.

4. Integrate GaMEs data collection and assessment within a cyber-enabled informatics infrastructure

Major Project Activities/Milestones

Key administrative, programmatic, research and development, and dissemination activities are identified as major project activities and/or milestones to be accomplished in a four-year period. From the original proposal:

Year 1 Complete *Selene* design documents, hire game developers, develop the instrument to be used by WJU in the mental modeling studies, insert gameplay images (mutual alignment items) into instructional videos, Stage 1 analysis and Stage 2 design for cyber-infrastructure development, building and playtesting *Selene* level 1 beta, ongoing *Selene* data collection and analysis.

Year 2 Develop and playtest *Selene* level 2 alpha and beta, run studies using *Selene* level 1, Cyber-infrastructure Stage 2 system design and Stage 3 Rapid application development (RAD), exploratory WIU mental modeling study, ongoing *Selene* data collection and analysis, exploratory mutual alignment and scaffolding studies.

Year 3 Quality assurance testing and revision to *Selene* game, RAD development and pilot within WJU pre-service teacher studies, confirmatory WIU mental model study, ongoing *Selene* data collection and analysis, confirmatory mutual alignment and scaffolding studies.

Year 4 Final revisions to *Selene* game, level 2 functional cyber-infrastructure prototype and pilot within second WJU pre-service teacher study, ongoing *Selene* data collection and analysis, confirmatory mutual alignment and scaffolding studies.

With approval from NSF, the PI modified deadlines originally noted in the CyGaMEs proposal to accommodate the NSF award starting date and intensive Game RFP development, review, and award procedures. Within the RFP, the PI postponed all development deliverables by four months. This delay was necessary to ensure the development of the final version of the game in Years 3 and 4 of the project.

Evaluation Plan

The evaluation of the CyGaMEs project has three components: (a) a formative component to monitor project progress as it evolves over a four-year period with interim and overall summative analyses, (b) review of intellectual merit focusing on the integrity of research and development and activities, and (c) analysis of broader impacts appropriate to the nature and scope of the project and expected outcomes. The evaluation plan is driven by the following questions:

1. To what extent do project activities comply with anticipated operational timelines, strategies, and milestones?

2. What is the quality of research and development activities and products designed to improve cyberlearning?

3. What are the nature and extent of broader impacts resulting from research and development activities and project outcomes?

To address evaluation questions, a combination of methods is used in the evaluation of the CyGaMEs including review and analysis of the "documentation trail" produced as the project is implemented. Structured and open interviews/debriefings with principal investigator and key staff were started to clarify and gather deeper insights on the

conceptualization and implementation of the project. In addition, a review of project products to confirm the integrity of results was also conducted.

Access to all project data archives was available for evaluation purposes including: anonymous datasets, analysis syntaxes or descriptions, project design and requirements documents, and quarterly reports. Initially, access to project data was facilitated through the project Wiki (and/or other designated project shareware) containing all project documentation. This electronic structure was later updated into a blog with a repository of all documentation and with communication features to keep up everyone in the project up to date and clear on the nature of research and development activities. Teleconferences with project management were also conducted on a quarterly basis to debrief on project progress. In addition, follow-up, in depth interviews with senior staff are being conducted in lieu of site visits to gather further insights on the roles and contributions of project staff, and to clarify issues related to research and development activities.

Procedures

The focus of this annual evaluation report is on activities and milestones accomplished through Year 3 (June, 2011) of the project. Quarterly reports were reviewed and summarized to determine project progress. Data triangulation and clarification was conducted through direct contact with project staff via teleconferences and review of the "documentation trail". Review of project documentation was initially accomplished via the project wiki and companion site created by Second Avenue Software (SAS), the company contracted for video game development. In Year 3 of the project, project documentation was reviewed using the project blog including current and archived information.

The project timeline was divided into project categories and major milestone tasks to assess progress over time. The evaluation of design and development of the games iterations follows the different stages of development and deliverables aligned with project milestones. Likewise, research and dissemination activities were tracked against the projected timeline for related milestones. In general, progress was determined using three categories adapted from the NASA reporting system:

- Green Status: Target activities, events, or products are on schedule and all milestones in the project plan were met. Completed milestones are identified.

- Yellow Status: Most milestones in the project plan were met. Details must be provided to identify which milestones were met and not met and revised timeline and conditions for completion.

- Red Status: Many milestones in the project plan were not met. Details must be provided to identify which milestones were met and not met and revised timeline and conditions for completion.

The examination of intellectual merit was informed by emphasis identified in the NSF-REESE program solicitation around the following themes: integrity of design and development activities, capacity for conducting the project, contribution to the body of knowledge in the field, and the development of potentially transformative tools and concepts (National Science Foundation, 2009). In turn, the examination of broader impacts focused on evidence of contributions on cyberlearning, development and promotion of infrastructure for research and education, efforts to enhance the participation of underrepresented groups, and extent of dissemination and synergistic and activities (National Science Foundation, 2007).

Evaluation Findings

Based on an audit of project documentation including a review of quarterly reports and project results, it is evident the project has maintained Green Status through Year 3. Based on the revised project schedule, proposed activities, and products are on schedule and all milestones anticipated through Year 3 of the project plan are on track. Overall, at the end of Year 3, the project has complied with anticipated operational timelines and milestones associated with research, development, implementation, and dissemination activities. Regarding the quality of products designed to improve cyberlearning, the project has generated research evidence supporting the merits of the design and learning experience. Further, the project has continued to develop a consistent record of synergistic research and development activities contributing to broader impacts in the areas of videogame development, use of embedded assessments, and dissemination of results.

Based on project progress through Year 3, and taking into consideration the quality of research and development activities, level of synergistic collaboration, and extent of dissemination work, the project is on track in meeting its goals and continues to exhibit high standards of implementation.

Project Progress and Milestones

The review of project progress and milestones was driven by the following evaluation question: To what extent the project activities comply with anticipated operational timelines, strategies, and milestones? To address this question, project progress and strategies for completing milestones through Year 3 were monitored during implementation and audited at the end of the evaluation period focusing on three sets of activities: Design and development, research, and dissemination.

Design and Development Activities. Design and development activities contribute to project objectives 1 and 4. Objective 1 seeks to transform the existing instructional videogame *Selene: A Lunar Construction GaME* into a robust research instrument. In this regard, with approval from NSF, the original scope was reduced to the development of an optimized level 1 game integrated within an interactive interface containing all environment elements. In turn, Objective 4 seeks to develop a prototype for a reporting system (datamart). The purpose is to integrate CyGaMEs data collection and assessment

within a cyber-enabled informatics infrastructure as the platform for the integration of *Selene* into a science curricular unit.
Overall, based on project documentation of related activities and milestones, design and development work is on track and has been found to be on Green status. That is, target activities, events, or products are on schedule and all milestones in the project plan were met.

Regarding Objective 1 associated with videogame design and development, a review of available evidence of progress confirmed that project staff was on track completing scheduled project milestones albeit development issues encountered during through Year 3 of the project. In Year 1, the developer Second Avenue Software (SAS) was approved by NSF to subcontract for CyGAMEs and the kick-off of this collaboration was conducted on April 16, 2009. Second Avenue Software, with headquarters in Pittsford, NY, specializes in the development of interactive media for education and training and features an impressive portfolio of interactive products commensurate with the needs of the CyGAMEs project. In Year 1, the project completed Stage 1 analysis and Stage 2 design for cyber-infrastructure development and for play-testing *Selene* level 1 game. However, as the complexity of the development process increased, in Year 2 a variety of game issues were observed and brought to the attention of the developer. Some of the observed issues were significant such as defects with game performance and re-entry into the game during accretion and surface features. Given the nature of these and other issues—and the complexity of the process to resolve contractual obligations to fix game problems, the project realized it was best to: (a) terminate contractual work with game developer, and (b) develop kludges to release the version 1.2 of the game. In Year 3, with the implementation of workarounds and further quality assurance testing, the game was repaired and is available online.

Design/Development Status (Objectives 1 & 4)

Albeit a number of game development issues, the use of workarounds were successful and the game is functional and available online (Objective 1). Also, while continuing to work on an algorithm to adapt accretion learning moment data, project staff are currently able to generate reports in aggregated form or to learn about the performance of individual players for basically all gameplay and assessments (Objective 4).

Work toward Objective 4, concerned with the development of an informatics infrastructure, is also on track with the completion of related activities and milestones. In Year 1 of the project, project staff automated data reporting (e.g., participant start and completion dates and raw data) for researchers, and prepared Excel templates for case studies of flow and game-play progress (timed reports). Related work was initially slow to get started, but both planning and design activities were brought back on track during Years 2 and 3. In Year 2, an algorithm for the AccretionLM Moment of Learning analysis was translated into an appropriate programming language for the Selene game. The algorithm is used to automate detection of the accretion learning moment and allows the identification of players who have made continuous progress toward the game goal. In Year 2, the work on the reporting system prototype continued

including the development of a recruiter console. In Year 3, the initial recruiter component of the reporting system is available online permitting recruiters to generate reports of access codes for players and players' information. While continuing to work on the algorithm to adapt accretion learning moment data, the project team is currently able to generate reports in aggregated form or to learn about the performance of individual players for basically all gameplay and assessments.

Research Activities. There are two objectives associated with research activities. The first related objective (Objective 2) involves conducting research using the embedded and external assessment tools to collect GaME data representing learning and perceptions (i.e., flow). The second related objective (Objective 3) is about refining GaME methods and metrics for assessing motivation, engagement, and learning. In general, based on project documentation of research-related activities, the project has been deemed to be on Green status. That is, related activities, events, or products are on schedule and all milestones in the project plan were met. Research activities continued to progress as anticipated building upon results emerging on perceived experience, mutual alignment, and knowledge discovery; slowly building a pool of players, and continuing with the refinement of analytical procedures.

Status of Research Activities (Objectives 2-3)

Data collection and analysis of learning and perceptions continue to progress as anticipated building upon results emerging on perceived experience, mutual alignment, and knowledge discovery, and the project is slowly building a pool of players through a variety of project dissemination and recruitment strategies (Objective 2). In turn, the refinement of analytical procedures continued through Year 3 and is yielding additional insights on the use of the game assessment tools for formative evaluation purposes (Objective 3).

Regarding Objective 2 associated with *Selene* data collection and analysis of learning and perceptions, in Year 1 project staff collected data and developed case studies of perceived experience (flow) and player progress during game-play (summed timed report). In this initial stage of the project, a study was also conducted to test the effectiveness of the *flowometer,* an innovative theory-based assessment tool based upon the experience sampling method. Further, testing of applied mapping theory on *Selene* and the application of knowledge discovery techniques to analyzing Selene game-play data to evaluate interface effect independence of player demographics were also conducted in Year 1. In Year 2 data collection continued with collaborative studies at Western Illinois University, and boosted recruitment efforts to attract more players targeting public schools and science teachers, and undergraduate students through partnerships, workshops, and professional development activities, and other dissemination strategies. In Year 3, recruitment efforts continue with the assistance of the West Virginia Public Broadcasting service, Wheeling Jesuit University Institutional Advancement, Western Illinois University, and NASA education resources. As a result, the project went from 152 players in 2009 to 537 in 2011.

In relation to Objective 3 targeting the refinement of analytical procedures, related work in Year 1 was based on case studies of flow (i.e., self-reported skill and challenge) and timed reports represented by game-play data evaluated every ten seconds for player's progress toward the game goal. Studies on aggregate flow and timed report were evaluated using an experimental design based on the double transfer paradigm (Schwartz & Martin, 2004). With some variations, studies on mutual alignment (e.g., accretion) and knowledge discovery (e.g., patterns and choice performance) were also conducted in Year 1 to discern interface effect. In Year 2, in an attempt to establish the validity of claims on performance issues, the PI used timed reports and velocity gesture reports to quantitatively evaluate game performance, alignment of the game to target domain, and the implications for timed report specifications. This work provided the grounds for identifying the use of the game assessment tools for formative evaluation of the integrity of the game environment. The exploration of measures of body language/gestures using pilot videotapes was also conducted in Year 3, along with an analysis of the accretion learning moment. In addition, at the end of Year 3, the PI conducted analysis of JSON-translated player report data suggesting that on the average, players are purposefully trying to make progress toward the game goal regardless of age and gender. The PI also developed a method to automate the categorization of flow report skill and challenge data fitting the 8-channel flow model featuring different states of engagement and motivation. In Year 3, related work continued leading to the preparation of presentations and manuscripts for publication.

Dissemination Activities. Although not officially declared as part of the project objectives, dissemination is integral and expected of NSF-funded projects. In this area, the project continued to perform remarkably well drawing from the results of work related to core objectives. Through Year 3, staff and contributing partners have maintained a steady record of dissemination and based on the level of related productivity, the project has achieved Green status in this area of work. Project staff has actively disseminated the CyGaMEs approach to instructional game design and assessment through presentations, outreach activities, and scholarly publications at a number of regional, national, and international venues.

Status of Dissemination Activities

In this area, the project continued to perform remarkably well drawing from the results of work related to core objectives. Through Year 3, staff and contributing partners have maintained a steady record of dissemination and based on the level of related productivity, the project has achieved Green status in this area of work.

Through Year 3 of the project, staff and contributing partners conducted a total of 28 presentations at various national and international forums sponsored by 16 different organizations. The project targeted forums with wide reach in the field such as those provided annually by the Association for Educational Communications and Technology, the Association for Psychological Science; the Games, Learning and Society Conference, and the Lunar and Planetary Science meeting to name a few. International dissemination included presentations in Bulgaria (International Analogy Conference) and Mexico (International Meeting on Evaluation for Mid-Higher Level Education and

College Level Education). The common denominator of these major forums for dissemination is their shared interest in advancing the collective understanding of a systematic approach for instructional design and the interface with cyberlearning and game design theory.

In addition, dissemination was further channeled through outreach activities using a variety of training and development formats. Six instances of discrete outreach activities were identified through Year 3 including the following:

- Mentorship opportunities and/or presentations conducted with graduate students interested in learning about conducting, analyzing, and reporting educational research.
- Mentorship opportunities for college faculty interested in involving undergraduate students in educational research.
- Mentorship opportunities for science teachers interested in using Selene in their curriculum.
- Dissemination through the network of NASA education resources and the organization of workshops for educators.
- Mentorship opportunities for undergraduate interested in learning about conducting, analyzing, and reporting educational research through internships, research assistantships, and participation in the research experience for undergraduates (REU) program.
- Webinars for educators, researchers, and game developers.

Further, project results have been disseminated with the publication of 12 manuscripts through Year 3 of the project including a journal article, four book chapters, and six reports in conference proceedings, and a master's thesis featuring the Selene game. At the core of the publications are emerging findings on the use of structure mapping theory for designing instructional games to facilitate and assess intuitive concept knowledge in science education. All project publications and other resources are also disseminated via the project website (http://selene.cet.edu), which also provides access to the game to the general public.

Quality and Broader Impacts of Project Activities

The merits of research and development activities were examined in terms of the underlying intellectual capacity and quality of development, research, and dissemination strategies and results produced through Year 3 of the project. This examination was informed by NSF's guidelines on merit review of broader impacts of project activities (NSF, 2007).

Interdisciplinary Intellectual Capacity. The quality of project activities stems from a strong interdisciplinary and synergistic intellectual capacity supporting development, research, and dissemination work. Senior staff contributing to the project builds upon unique interdisciplinary expertise available at the Center for Educational Technologies bridging research and development expertise in instructional design and content

knowledge in lunar science. Clear roles and expected contributions have kept the project on Green status through Year 3. Dr. Debbie Reese provides the leadership and core ideas for the project drawing from complementary expertise provided by Drs. Charles Wood (scientific content) and Ben Hitt (prototype design and development), while Dr. Beverly Carter contributed to game engineering documentation through summer 2010.

Recognizing the complexity of project activities and goals, the project has been further supported with complementary expertise including contributions from 12 internal (WJU) and external parties in the areas of recruitment, project coordination, research and development, and evaluation. The contribution of Dr. Virginia Diehl, Professor of Psychology at Western Illinois University, provided evidence of the quality of the project's shared intellectual capacity as demonstrated by a research award in 2009 for a project presentation with D. Reese. In addition, the contribution of Dr. Barbara Tabachnik—provided further evidence of a strong project's intellectual capacity for conducting research and development. Dr. Tabachnick, a recipient of the Western Psychological Association's Lifetime Achievement Award, provided consulting services for statistical analysis and has been an important collaborator in the project. Moreover, 16 technicians and programmers provided further support in all areas of project work, while six undergraduate and 10 graduate students assisted in research and development activities.

Collectively, the project has clearly maximized the use of complementary internal and external intellectual capacity to meet research and development requirements and—ultimately—project goals. The use of organizational and communication structures has been instrumental in clarifying specific roles and expected contributions, sharing access to relevant data, comparing notes on pertinent design, development, and research activities, and determining progress status. This approach has facilitated the development of a strong interdisciplinary intellectual capacity underlying project work leading to broader impacts on development, research, and dissemination activities.

Development Activities. With the core intellectual capacity outlined above, the project has contributed to the enhancement of infrastructure for design and development in science education including work demonstrated in three areas: development of research-based educational materials, development of effective models for science teaching, and establishing collaborative partnerships.

Development of research-based educational materials useful in teaching. The project seeks to develop a videogame to prepare students to learn science in engaging and intuitive ways and the ability to provide instructional feedback on how well players learn science. In this regard, with the implementation of some workarounds, the project managed to resolve some performance issues upon termination of the contract with the initial developer and the game is now available to the public online. The design and development of the Selene videogame has been recognized for its engaging environment facilitating the promotion of science learning. In 2008, the Association for Educational Communications and Technology recognized the project's design and development work with an award for Outstanding Practice for Design and Development. Further, in 2009 the

Selene videogame was awarded finalist honors by the Disney Research Learning Challenge. This is a prestigious open competition seeking to identify new and creative ways to use technology to make learning engaging for children.

In addition to an engaging videogame, the project has also developed curricular materials to be used in formal and informal education. The project developed MoonGazers, which integrates Bob Crelin's Moon Gazer Wheel (http://www.bobcrelin.com/moonwheel.html) and Selene activities. A series of curricular and hands-on activities are available online for parents and educators to engage students in science learning through lunar observation and fieldwork. As such, the project is becoming a resource hub for educators and parents interested in educational materials to promote learning about the solar system's basic geological processes and with particular focus on lunar science (project materials are publicly available at http://selene.cet.edu/?page=moongazers). The usefulness of the Selene videogame and other curriculum materials have been further recognized and fully endorsed by the West Virginia Department of Education in support of science standards, adding to the evidence of broader impact in the field.

Development, adaptation or dissemination of effective models and pedagogic approaches to science teaching. The pedagogical approach to science teaching is based on the premises of personalized learning and assessment provided by gameplay. When playing the Selene game, individual players follow unique learning paths about Moon formation over time. At the core of this pedagogical approach is for players to actually experience the Moon construction and ensuing formation by creating craters and flooding them with lava. The physical play and individual discovery promote intuitive and applied learning needed to meet the game goal to build the Moon. In turn, the use of embedded assessments allows for the identification of learning patterns to determine progress toward the game goal and flow of learning. The underlying approach to the instructional game design and embedded assessments is based on analogical reasoning research, cognitive science, and game design theory. Emerging project findings suggest that embedded assessments are useful in identifying learning patterns and players' perceived experience, as well as for evaluating game performance. Thus feedback is provided to both players (i.e., students) and teachers on learning progress.

Computer simulations and videogames represent promising models to promote learning through virtual interactions and representations of natural phenomena, which may not otherwise be possible to observe in a classroom environment. Further, simulations and games can foster students' motivation to learn through challenging tasks and immediate feedback to keep them engaged as they build an understanding of learning goals via analogical reasoning. To this end, Selene's approach to science teaching and learning aligns with and supports the National Research Council's quest to establish "connections between what is known about science learning and computer gaming and simulations, the role computer gaming and simulations could play in assessing learning, and the pathways by which they could be used on a large scale" (NRC, 2011, p. 1-2).

Identification and establishment of collaboration between disciplines and institutions, among U.S. academic institutions and with international partners. Collaborative activities

have been established internally with CET and WJU units and externally with other institutions nationally and internationally. As noted above, the project integrates key intellectual capacity available at WJU and through collaborative or contractual agreements with external partners for design, development, research, and dissemination purposes. All in all, the project has established an impressive network of partners with 12 organizations including public schools, universities, research centers, and outreach agencies.

For research purposes, the project has partnered with four universities including Wheeling Jesuit University, Western Illinois University, Northwestern University, and Kent University. The collaborative work with Virginia Diehl (Western Illinois University), in particular, was productive resulting in five presentations of research results and a journal article; while work with Larry Hedges (Northwestern University) allowed the development of an algorithm to replicate hand-identification of learning in Selene. In addition, collaboration with universities has also allowed the engagement of six undergraduate and 10 graduate students in research experiences involving data collection and analysis.

To promote dissemination of project materials and/or results, the project has collaborated with NASA's eEducation Learning Environments and Research Network, Ohio County Schools (WVA), and NASA's Educator Resources Centers; and internationally with the University of Vic (Spain), and Suleyman Demirel University (Turkey). The endorsement of the project by the WVA Department of Education, as noted elsewhere, should boost potential collaboration with public schools in West Virginia and other states. Similarly, the support of NASA's outreach network provides an important platform for continued dissemination of project materials and results. On this note, it is important to recognize the international interest as demonstrated by collaborative work with the University of Vic, which spearheaded the translation of the Selene environment into Spanish and added to evidence of potential broader impacts in the field.

Research Activities. As noted earlier, research and development activities are on track through Year 3 of the project. Research activities and milestones accomplished through Year 3 of the project point to broader contributions to the advancement of discovery and understanding of science education through cyberlearning. In general, research activities are particularly relevant to recent calls for the development and evaluation of embedded assessments to measure learning within cyberlearning environments. Evidence of potential broader impacts clearly emerged in two areas: Integration of research with education activities, and partnerships with researchers and educators to develop effective means for incorporating research into learning and education.

Integration of research with education activities. Through Year 3 of the project, staff has been successful integrating research and development addressing the four underlying goals (game development, data collection, refinement of measures, report system). The Research results to date suggest broader impacts in our understanding of cyberlearning and the use of embedded assessments. Notable results have emerged from the staff's application of knowledge discovery techniques to *Selene* gameplay data suggesting that

regardless of players' background characteristics (e.g., age, grade in school, gender, race, or self-reported academic achievement), the game interface worked as expected in helping players accomplish the game goal (Reese, Diehl, & Lurquin, 2009; Reese & Hitt, 2009; Reese & Tabachnick, 2010). This suggests that the game mutual alignment tool is at play measuring change in conceptual knowledge. That is, while playing Selene learners are simultaneously engaged in creating a moon, which leads to an increased and meaningful understanding of lunar science. These emerging findings were further replicated and established that, through the use of timed reports, CyGaMEs measure learning accurately across all players (learners) (Reese et al., 2011; in press). In short, the analysis of game playing has demonstrated that when playing CyGaMEs, players work toward the game goal and develop an understanding of how lunar geology works.

Further, a significant component of CyGaMEs is the use of embedded assessments instruments to measure learning (by analyzing timed report and gestures) in the context of self-perceptions flow experience including arousal, anxiety, worry, apathy, boredom, relaxation, routine expertise, and control. Here the question is about patterns of learning as affected by the game environment. To this end, the goal was to quantify player behavior (growth in conceptual knowledge) aligned with the eight-flow states and identify the learning moment. That is, by determining the point when a player's gameplay changes drastically as measured by the velocity of playing gestures such as sling shooting particles at a target (i.e., the moon). In this regard, staff used the "flowometer" to measure changes in players' gameplay associated with flow states. The flowometer represents a useful embedded assessment of learning within instructional games for quantifying player behavior. Research on the use of the flowometer was conducted and replicated to confirm reliability of findings showing the capacity of the assessment tool to profile players' playing experience. In this regard, staff has developed components for this embedded assessment tool to automate the graphing of a player's gameplay for research purposes and provide feedback to players and other parties interested in related assessments (Reese, 2008a, 2009b; Reese & Tabachnick, 2010).

The broader impacts of research activities align with contributions to emerging evidence that simulations advance conceptual understanding and can motivate students' interest in science learning. As important, project results have established the value of embedded assessments to provide feedback to players (i.e., learners), educators, and researchers interested in understanding how players experience cyberlearning. To this end, CyGaMEs is designing an automated structure that will be available as part of the game's reporting system. As demonstrated in the project, this automated reporting system can be used as a formative and summative evaluation tool to determine whether the tool is accurately measuring learning, and whether the game environment is helping players' progress toward the learning goal (Reese, in press). The CyGaMEs reporting system already has the capacity to automate identification of the accretion learning moment and to graph patterns of players' learning. These results are significant because they align with and contribute to recent calls for conducting research and development about how embedded assessment technologies can be used to engage students in learning and assess what and how they learn (U.S. Department of Education, 2010; NRC, 2011). The potential broader

impact of CyGaMES is that its approach to embedded assessment can be generalized for use across instructional games as an integral component of a game's design.

Partnerships with researchers and educators to develop effective means of incorporating research into learning and education. Given the nature and complexity of the project, staff has sought strategic partnership with researchers and educators to test the game, collect and analyze data, and refine measures. To collect, analyze, and report studies of gameplaying, the PI collaborated with Dr. Virginia Diehl through Year 3 of the project. Dr. Diehl is Professor of Psychology at Western Illinois University. This collaborative work resulted in five presentations and a journal article. As a result of this collaboration, Reese and Diehl received an award in 2009 for best work in traditional research at the 4th Annual Western Illinois University Faculty Research Symposium.

To draw complementary expertise in the refinement of measures and embedded assessments, the PI has also partnered with Dr. Larry Hedges, Professor of Statistics at Northwestern University. Dr. Hedges is a national leader in the fields of educational statistics and evaluation. He is one of eight Board of Trustees Professors at Northwestern, the university's most distinguished academic position. He is best known for his work to develop statistical methods for meta-analysis in the social, medical, and biological sciences. Dr. Hedge's support was instrumental in developing an algorithm to replicate hand-identification of learning in Selene and resulted in an exploratory analysis of timed report data. Similarly, the PI has collaborated with Dr. Barbara Tabachnick; Professor Emeritus in the Department of Psychology at California State University at Northridge, on the analysis of data resulting from CyGaMEs embedded assessments. Dr.Tabachnick is an expert in multivariate analytical techniques and has served as advisor for the flow analysis procedure. The collaborative work with Dr. Tabachnick has already translated into a series of presentations on the validity of timed report measures.

Integration of research into learning and education was also promoted through internal collaboration at Wheeling Jesuit University with the assistance of Drs. Connie Myers and Laurie Ruberg. Working with undergraduate students, the goal of this collaborative is to use Selene as a means to help education majors develop an understanding of instructional technology. Likewise, integration of research and education has been promoted with both undergraduate and graduate students to help them develop basic understanding of the research process and data collection and analysis. This latter collaborative work was conducted with the assistance of partners at Northwestern University, Western Illinois University, Wheeling Jesuit University, and Kent State University.

Dissemination Activities. Building upon the strong intellectual capacity supporting project activities, research and development activities have produced important and interesting results. To this end, the dissemination of project information and emerging results has been outstanding. Overall, dissemination activities have included a variety of formats and the project is creating increased interest in the field as evidenced by the number of presentations, invited talks, and emerging publications.

Presentations to the broader community (e.g., radio, websites, and other related venues). Project information has been widely disseminated through the NASA portal, CET's website, and featured on West Virginia Public Broadcasting. In particular, NASA's education resource network has provided a unique opportunity for dissemination enhanced by the brand recognition of NASA as a trusted scientific institution. Two NASA's programs, NASA eEducation and NASA Educator Resource Centers have been instrumental in disseminating information about Selene and conducting workshops for educators. Another important vehicle for dissemination of project information and results is the project's website at http://cygames.cet.edu/, which provides public access to background information, testimonials, and directs to other resources associated with the Selene game (http://selene.cet.edu/).

Participation in multi- and interdisciplinary conferences, workshops, and research activities. Project information and results have been disseminated through 28 presentations to the broader community through Year 3 of the project. Dissemination venues have included regional, national, and international forums sponsored by organizations such as the Association for Education, Communication, and Technology; the Society for Research on Educational Effectiveness, Association for Psychological Science, and the Society for Information Technology and Teacher Education—to name a few. In addition, project staff, in collaboration with different partners, produced 12 publications over the first three years of the project including an article in the Journal of Educational Psychology, six book chapters, and three papers on conference proceedings. This level of dissemination through presentations in conferences and publications has been remarkable.

Presentation of research results in formats useful to policy-makers, members of Congress, and broad audiences. The CyGaMEs project was one of a few select NSF-funded projects featured on November 4, 2009 at the Senate Hart Office Building in Washington, D.C. The purpose of the event was to educate members of the Senate, their staff and other interested people about the use of technology at all levels of education, from teacher development to K-12 learning. A companion poster presentation was conducted the day before at NSF headquarters.

Conclusions

Based on the review of reports of activities, audit of project documentation, and analysis of project result, it is evident the project earned Green Status through Year 3 of implementation. That is, proposed activities, events, or products are on schedule and all milestones anticipated during this period of the project plan are on track. Overall, at the end of Year 3, it is evident that development, research, and dissemination activities are following well-developed and realistic operational timelines and strategies. In turn, the merits of project activities and products designed to improve cyberlearning are well documented and supported by sound strategies. Further, the project has continued to develop a remarkable record of synergistic activity with potentially significant broader impacts resulting from research and development activities. All in all, given project progress, quality of research and development activities, and level of synergistic

collaboration and dissemination, the project continues to exhibit exemplary standards of implementation.

Overall, across the core components of the project, there are no major areas of concern warranting a call for urgent improvement measures as design and development activities and anticipated milestones are well documented and on track. Likewise, research and dissemination activities are also on schedule, well documented, and very productive.

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