

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

FINAL EVALUATION REPORT

Prepared for the Center for Educational Technologies (CET)  
at Wheeling Jesuit University

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

## **FINAL EVALUATION REPORT**

### **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 was to facilitate and measure student intuitive understanding of science concepts through an interactive videogame environment. The project built 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 had 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. Project reports were analyzed to determine progress, while data triangulation was accomplished through contact with project staff and review of the developmental “documentation trail”, and analysis of project results.

Progress and compliance meeting anticipated project work and milestones were determined using three categories adapted from the NASA reporting system: (a) Green Status indicating full compliance, (b) Yellow Status reflecting compliance in progress, and (c) Red Status corresponding to problematic compliance. In turn, the evaluation of quality of research and development activities was informed by guidelines on the assessment of intellectual merit identified in the NSF-REESE program solicitation. Further, the examination of broader impacts focused on evidence of: Development of curricular products and materials, contributions to cyberlearning, collaborative partnerships, dissemination and outreach, and project sustainability.

### **Evaluation Findings**

Overall, based on the project timeline, proposed activities, and observed results, the project complied with anticipated operational timelines and milestones associated with each of its research and development objectives. Regarding the quality of results and products designed to improve cyberlearning, the project generated research evidence supporting the merits of the design and learning experience. Further, the project developed an outstanding record of synergistic research and development activities contributing to broader impacts in the areas of videogame development, using embedded assessments, and dissemination of results. A summary of evaluation findings is presented below around the evaluation foci.

**Efficacy of project implementation and completion.** Overall, development and research activities were on *Green Status* upon completion of the project. That is, related activities, events, or products were completed on schedule and all milestones anticipated in the project plan were met.

- **Design and development activities.** At the end of the project, the Selene has been transformed into a reliable game-based environment that can be used for research purposes to assess and report how people learn science concepts through gameplay. The game is available in English and in Spanish on the project's website. Further, the project designed, developed, and released an informatics infrastructure that provides immediate feedback to players, allows educators to assess learner performance, and permits researchers access and analyze gameplay data.
- **Research activities.** At the end of the project, activities associated with related objectives were also deemed to be on *Green Status*. That is, research activities were completed as anticipated building upon a growing pool of recruiters and players to ensure data collection, producing a data management system, conducting studies on perceived experience, mutual alignment, and knowledge discovery; and continuing with the refinement of analytical procedures. In addition, the project demonstrated how a videogame environment could be used for data collection to study players' learning during gameplay using embedded assessments and a reporting system. Using a Timed Report approach to measure gameplay and player's progress toward the game goal at 10-second intervals, the game Flowometer posts scores on skill and challenge. The use of embedded assessments allowed for the study of motivation, engagement, and learning.

**Quality of research and development work.** The quality of research and development activities was characterized by a strong conceptualization capacity leading to the transformation of the Selene game into a robust research instrument, and contributions to the shared understanding of important mediating factors in cyberlearning.

- **Design and development activities.** Two quality factors contributed to the successful completion of related activities: Conceptualization strategies and the design and development approach. The intellectual capacity behind the conceptualization of the CyGaMEs project stemmed from strong interdisciplinary and synergistic work of senior staff bridging research and development in instructional design and content knowledge in lunar science. Further, the project built upon internal and external interdisciplinary capacity for design and development. The quality of the design and development approach was also based on a focus on the integrity of design work, the project's design and development capacity, and the iterative cycle of development.
- **Research activities.** In general, research activities reflected broader contributions to the advancement of discovery and understanding of science education through cyberlearning. The quality of research activities was reviewed using two indicators: The research capacity to meet related project goals, and the nature of research outcomes. To that end, the project built upon unique interdisciplinary expertise and

collaboration with partners in the field contributing to the quality of the project's research capacity. Further, based on the nature and totality of research results, the project contributed to the shared understanding of important factors in cyberlearning through the use of embedded assessments. In addition, the project produced a reporting system that allows educators monitor player's progress and results, and project researchers access game data for research purposes.

**Broader impacts of project activities.** Project outcomes and accomplishments resulted in broader impacts on the development of research-based educational materials, contributions to research in cyberlearning, establishment of collaborative partnerships, and dissemination and outreach. The project also ensured sustainability beyond the end of grant funding support.

- **Development of research-based educational products/materials.** Three primary products were developed and delivered over the duration of the project including a bilingual version of the Selene game, an informatics infrastructure system, and curricular materials for parents and educators. The game is available in English and in Spanish on the project's website. Concurrently, project staff designed and developed a data management system, which will remain available as part of the Selene game upon completion of the project. In addition the project developed curricular and hands-on activities available online for parents and educators to engage students in science learning through lunar observation and fieldwork.
- **Contributions to research in cyberlearning.** The broader impacts of research activities align with contributions to emerging evidence that instructional video games advance conceptual understanding and can motivate students' interest in science learning. Project results also established the value of embedded assessments to provide feedback to players (i.e., learners), educators, and researchers interested in understanding how players experience cyberlearning. Project work aligns with and contributes 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).
- **Establishment of collaborative partnerships.** Collaborative activities were established internally with CET and WJU units and externally with other institutions nationally and internationally. Overall, the project established an impressive network of partners with several organizations including public schools, universities, research centers, and outreach agencies. The project also established international collaboration 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.
- **Dissemination and outreach.** Overall, in this area project staff was very productive in disseminating the results of work related to core objectives. Project staff and contributing partners collaborated in the production of a robust record of dissemination including 22 publications and numerous conference presentations and

other dissemination activities. Dissemination activities were also conducted through outreach activities using a variety of formats such as the NASA portal website, the NASA's education resource network, and the project's website which provides public access to background information, testimonials, and directs to other resources associated with the Selene game.

- **Ensuring project sustainability.** To ensure project sustainability beyond grant funding, institutional support was secured from Wheeling Jesuit University. With this agreement for institutional support, the Wheeling Jesuit University data management system will continue to provide public access to CyGaMEs data upon expiration of grant funding.

Overall, given the efficacy of project implementation and completion, quality of research and development work, and assessment of broader impacts in the field, there was consistent evidence supporting a representation of exemplary project performance.

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

## FINAL EVALUATION REPORT

### Background

The *Cyberlearning through Game-based Metaphor Enhanced Learning Objects (CyGaMEs)* project, funded by the National Science Foundation (Grant Award DRL-0814512), was initiated in September 2008 and is to close in August 2014. The initial award was granted for four years and was extended for two additional years.<sup>2</sup> The final evaluation report is based on the entire duration of the project including work completed through 2014.

As noted on the grant proposal, the CyGaMEs approach to the design of computer-mediated learning environments is based on analogical reasoning theory. That is, a metaphor can be used as a mechanism for understanding one situation as a function of another through cognitive experiential structures connecting a source or base domain (e.g., concrete or relatively familiar) and a target domain (Gentner, 1983; Holyoak, Gentner, & Kokinov, 2001). Under these premises, CyGaMEs provides a videogame environment to help people learn in a relational way through gameplay experiences making hard science concepts easier to understand building upon analogical reasoning (Reese, 2008a).

In addition to using cognitive science in its design, CyGaMEs is also based on informatics science to structure and process the communication of information during gameplay. The goal is to provide players with immediate feedback to help them learn by doing (i.e., playing) and exploring their own way to reach the game's goal. As part of this approach, CyGaMEs provides an interface for the development and refinement of analytical methods to assess and report how people learn through gameplay and for improvement of the cyberlearning environment (Reese, 2008a).

The goal of the game is to facilitate the understanding of how the Earth's moon was formed by requiring players to create their own moon including the replication of impact craters and lava flows. Through gameplay, players can develop an understanding of related science concepts catalyzed by analogical reasoning exercised as they figure out how to reach the game's goal (Reese, 2009a).

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<sup>2</sup> Additional funds for extending the project two years resulted from: (a) a renegotiated rate that discontinued service centers, while retaining the low indirect rate the project submitted with the original budget; and (b) the discontinuation of external sub-contractor company services for game development for years 3 and 4.

## Project Objectives

Specifically, the goal of the CyGaMEs project was 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. To this end, the project built upon the integration of analogical reasoning theory (Gentner, 1983) and instructional game design (Holyoak, Gentner, & Kokinov, 2001) to develop a videogame environment featuring an informatics system with embedded assessment structures that measure and report learner growth (Reese, 2009a).

The objectives of the *CyGaMEs* project were 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

Key administrative, programmatic, research and development, and dissemination activities were monitored throughout the duration of the project. A recap of major project activities is noted below for each year of the project.

- **Year 1: 2008-2009.** Completed *Selene* design documents, hired game developers, developed the instrument to be used by WJU in the mental modeling studies, and inserted gameplay images (mutual alignment items) into instructional videos. Conducted Stage 1 analysis and Stage 2 design for cyber-infrastructure development, and built and play tested *Selene* level 1 beta. *Selene* data collection and analysis were initiated as well.
- **Year 2: 2009-2010.** Continued data collection and conducted studies to investigate the effects of: (a) Assessment priming, and (b) debriefing (video instruction). Expanded collaborative research with Western Illinois University (WIU) to include player collaboration. Used WIU video data to triangulate video, gameplay, and time report data to identify learning moments.
- **Year 3: 2010-2011.** Conducted quality assurance testing and revision to *Selene* game. Continued data collection and analysis, and developed a method to automate the categorization of flow report and challenge data. Also developed a method to automate identification of learning moments using timed reports.

- **Year 4: 2011-2012.** Completed revisions to *Selene* game and continued data collection. Developed a method for quantifying learning dynamics for multidimensional and unidimensional goals, measured rate of progress for *Selene II* static goal replicated with second dataset, and also measured progress for dynamic goal.
- **Year 5: 2012-2013.** Tested and released additional game versions including *Selene*'s Spanish-language version. Conducted a discrimination pilot study and a pragmatic constraints pilot study. Designed a WJU data management system for public access to blind *Selene* data.
- **Year 6: 2013-2014.** Developed and released reporting system for players (learners) and educators containing a numeric grade book, dashboards, and in-game achievements. Also developed the CyGaMEs Gameplay Inquiry Cycle.

The recap of major project activities represents a slightly modified schedule approved by NSF to accommodate the funding starting date, review, and award procedure, and sub-contractual game development work. The major activities reported for Year 5 and 6 were possible through an extension to maximize project work and funding. Additional funds to support project work in Years 5-6 resulted from a renegotiated rate as previously noted.

### **Evaluation Plan**

The evaluation of the CyGaMEs project had three components: (a) a formative and summative component to monitor project progress with quarterly and annual analyses, (b) review of intellectual merit focusing on the integrity of research and development activities, and (c) analysis of broader impacts appropriate to the nature and scope of the project activities and outcomes. The evaluation plan was 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 was used in the evaluation of the CyGaMEs including review and analysis of the documentation produced as the project was implemented. To that end, access to all project data archives was available for evaluation purposes including: anonymous datasets, analysis syntaxes or descriptions, documentation of project design and requirements, and project reports. Initially, access to project data was facilitated through the project Wiki 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 everyone in the project up to date and clear on the nature of research and development activities. A tracking structure was further developed to document and monitor developmental work. Further, teleconferences with project management were also conducted to debrief on progress after submission of project reports throughout the duration of the project.

In addition, follow-up, in depth interviews with senior staff were conducted to gather further insights on their project roles and contributions, and to clarify issues related to research and development activities. The goal of structured and open interviews and debriefings with principal investigator and key staff was to gather multiple insights on the conceptualization, nature of design and development activities, clarify roles and contributions to the project, and understand nature and score of research work.

Further, a review of project outcomes such as manuscripts and presentation materials was conducted on a periodic basis to confirm the integrity of results. The combination of data collection strategies allowed the triangulation of evaluation information.

## **Procedures**

The final evaluation report is based on activities and milestones accomplished throughout the duration of the project. Project reports were reviewed and complementary project documentation was summarized to determine project progress. Data triangulation and clarification was conducted through direct contact with project staff via teleconferences, review of the “documentation trail,” and synthesis of interviews with project Co-PIs and other personnel. Review of project documentation was initially accomplished via the project wiki and companion site created by the company contracted for video game development. In Year 3, project documentation was reviewed using the project blog including current and archived information. Subsequently, developmental documentation was available through a tracking system describing work requirements, solution status, personnel involved, and completion progress.

The completion of major project activities was tracked and assessed over time in connection to each project objective. The evaluation of design and development of the game iterations followed 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, to address the evaluation question regarding compliance with operational timelines, strategies, and milestones, 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 are met with completed milestones identified.
- **Yellow Status:** Most milestones in the project plan were met. Details are 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 evaluation of quality of research and development activities was informed by National Science Foundation guidelines on the assessment of intellectual merit 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: Development of educational products and materials, contributions to cyberlearning, establishment of collaborative partnerships, dissemination and outreach, and efforts to ensure project sustainability (National Science Foundation, 2007).

### **Evaluation Findings**

Based on a summative review of project documentation including project reports, design and development data, and project outcomes, the results of the related analyses were organized around the three evaluation questions. Thus, evaluation findings on the extent to which the project met proposed activities and milestones are first discussed, followed by a presentation of evaluation results on the quality of project research and development activities. Finally, the assessment of broader impacts is reported to address the corresponding evaluation question.

### **Efficacy of Project Implementation and Completion**

The review of project progress and milestones was driven by the following evaluation question: To what extent did the project activities comply with anticipated operational timelines, strategies, and milestones? To address this question, project activities and milestones through Year 6 were monitored during implementation and audited at the end of the evaluation period. The report of evaluation findings on the efficacy of project implementation and completion is organized around design and development activities associated with project objectives 1 and 4, and research activities associated with objectives 2 and 3.

**Design and development activities.** Design and development activities were conducted in the project to meet Objective 1, to transform the existing instructional videogame *Selene: A Lunar Construction GaME* into a robust research instrument; and Objective 4, to integrate GaME data collection and assessment with a cyber-enabled informatics infrastructure. Overall, project activities associated with videogame design and development were on *Green Status* upon completion of the project. That is, related activities, events, or products were completed on schedule and all milestones in the project plan were met including the transformation of the existing videogame into a robust research instrument and the development of the informatics infrastructure.

***Transformation of existing videogame.*** 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 learning in a game-based environment to promote viable pre-conceptual mental models. The project used 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 research instrument.

Albeit some development issues encountered in Years 1-3, all anticipated activities and milestones were completed at the end of the project. In Year 1 the developer subcontracted for CyGaMEs began its formal collaboration with the project. The developer company specializes in the development of interactive media for education and training relevant to the requirements of the needs of the CyGaMEs project. Thus, with the assistance of the subcontractor, the project completed Stage 1 analysis and Stage 2 design of the cyber-infrastructure development and the play testing of *Selene* level 1 game. However, due to performance issues, the contractual agreement with the subcontractor was terminated in Year 2. Kludges were developed to fix game issues and release the version 1.2 of the game. Subsequently, in Year 2 of the project, with the implementation of workarounds and further quality assurance testing, the game was made available online.

In Years 4-5, the cycle of iterative design and development continued including the design and testing of additional game versions. During this period the 7.2.5 version was decompiled to allow for the development of a new version of *Selene* featuring an option for Spanish language speakers. The game's representation of density was also redesigned to improve player performance. Further, the bilingual 8.0 version of *Selene* was released upon completion of two pilot studies. Subsequently, the cycle of iterative design was completed with further design, testing, and release of additional game versions leading to version 8.0.3 upon completion of particle discrimination and pragmatic constraints pilot studies.

At the end of the project, the *Selene* game has been transformed into a reliable game-based environment that can be used for research purposes to assess and report how people learn science concepts through gameplay. The game is available in English and in Spanish on the project's website (<http://selene.cet.edu/default.aspx?page=Selene>) depending upon language players' preference (see Figure 1). The Spanish version was fully vetted by a credentialed astrophysicist (Ph.D.) with a M.S. in "English to Spanish interactive multimedia localization."

The game begins with an introduction by a lunar scientist, Charles Wood, to let players know that this is a game built around the knowledge of a scientist and science. Then, the players are provided some contextual background by watching a graphical representation of the origin of the solar system and the impact theory of the creation of the moon. The

next component of the game requires players to play and recreate the moon themselves by blasting the surface with projectiles and placing lava to replicate the lunar volcanic activity and lava flow. In this process, the game allows players to represent 4.5 billion years of geological development and learn science concepts aligned with: (a) the American Association for the Advancement of Science’s (AAAS) Atlas of Science Literacy Strand Maps (AAAS, 2001), (b) the framework for K-12 science education (Committee on Conceptual Framework for the New K-12 Science Education Standards, & National Research Council, 2011), (c) the next generation science standards (NGSS, 2013), and (d) the National Science Education Standards (National Research Council, 1995).



Figure 1. Entry page for Selene game: English (left) and Spanish (right) version.

***Development of informatics infrastructure.*** Concurrent with the transformation of *Selene* into a robust videogame, the project also sought to design a prototype of a reporting system for GaME data collection and assessment within a cyber-enabled informatics infrastructure (Objective 4). This objective is consistent with calls to develop tools capable of recording learning over time to inform a variety of stakeholders (Computing Research Association, 2005). To this end, cognitive science provided the basis for game design and the development of an informatics system featuring assessment methods to measure and report learners’ growth. Under these premises, the objective of the project was to develop a prototype for a reporting system to integrate data collection and assessment as an informatics infrastructure embedded in the game (Reese, 2008a).

Overall, based on project documentation of related activities and milestones, design and development work associated with this objective achieved Green Status upon project completion. That is, target activities, events, or products were on schedule and all milestones in the project plan were met. 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). 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 was used to automate detection of the accretion learning moment allowing 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 was released online permitting recruiters to generate reports of access codes for players and players' information.

In Year 4, project staff continued to work on the algorithm to adapt accretion learning moment data to generate reports in aggregated form or to learn about the performance of individual players for basically all gameplay and assessments. To this end, the first working version of an R solution for Learning Dynamics was developed and tested during this year. In addition, CyGaMEs Gateway and Recruiter consoles using “.Net” were redeveloped to serve as the foundation for the integrated reporting system interface and prototype. The intent at this point was to explore the integration of an SPSS server to allow data analyses and automated reporting and graphs for individual players and educators. Finally, in Years 5-6, further design and development, and testing were completed including automated weekly compilations of player log datasets. Also, SPSS syntaxes were prepared to calculate percent progress toward the dynamic goals in the Surface Features module. The final reporting system released at the end of the project features administrator and recruiter functions (see Figure 2).



Figure 2. Game dashboard showing player progress and achievements.

The administrator functions allows for the management and support of recruiters, while recruiter functions facilitates the management and support of players. As it stands, the resulting informatics infrastructure represents a reporting system that provides immediate feedback to players (formative assessment) via a game dashboard (see Figure 2). The system also generates information to generate badges and feeds a leaderboard to boost

players' motivation for continued gameplay (i.e., learning). In turn, the reporting system allows educators to assess learner performance by assessing progress toward the game's goal. As gameplay data can be downloaded for analysis, researchers can also mine *Selene* data based on specific requirements that can be translated into queries.

**Research activities.** The project had two objectives associated with research activities. Objective 2 was concerned with collecting GaME data representing learning and perceptions, while Objective 3 sought to develop and refine GaME methods and metrics for assessing motivation, engagement, and learning. At the end of the project, activities associated with objectives 2 and 3 were also deemed to be on *Green Status*. That is, anticipated research activities including data collection and studies related to the refinement of methods and metrics had been met. Research activities were completed as anticipated building upon a growing pool of recruiters and players to ensure data collection, producing a data management system, conducting studies on perceived experience, mutual alignment, and knowledge discovery; and continuing with the refinement of analytical procedures.

**Data collection and research activities.** 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, as *Selene* was gradually transformed into a robust game, concurrent activities associated with Objective 2 of the CyGaMEs project were conducted 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).

In this context, in Year 1 project staff initiated data collection and conducted 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 (Reese, 2010). 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 continued 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 2012 (Year 4), the pool of recruiters grew resulting in the registration of 767 new players. By this time, the game reached a level of players that translated into daily usage of the game. That is, the game was being used on a regular basis in classrooms around the country as part of the science curriculum. As one recruiter noted:

“[The students] are excited that they have this opportunity. All have been advised not to talk about the actual game but are comparing scores and bragging if they finish quickly. Some asked if they could work at home because they want to "win" the completion card. I know they come racing into the room to start and are very intent when playing [the game]. The kids are so engaged they seem to forget I am standing there.”

Given the steady increase in gameplay activity, the Internet bandwidth was boosted to handle the large amounts of data generated by players' usage. This strategy was critical as the CyGaMEs community of users continued to grow in 2013 to over 600 recruiters and more than 4,000 players and with summative player participation by gender roughly equivalent.

Further, in Years 5-6, the data management system was completed and turned over to the university for operation and maintenance beyond the completion of the project. As part of this process, project staff updated the automation of research protocols in the reporting system to ensure a smooth transition at the closeout of the project. In addition, a series of videos and other relevant documentation was produced to deliver most of the recruiter orientation training content.

***Methods and metrics.*** With the body of knowledge on flow steadily emerging, project staff recognized that 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 engaged in the study of measures and analytical techniques for the assessment of learning and player's perceptions of game-playing experience.

In Year 1 related work 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 (Reese et al., 2012). 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 were 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 using a nine-channel flow model featuring different states of engagement and motivation (Reese, 2012).

In 2012, project work focused on the study of game goal characteristics to boost players' motivation through reward strategies for discovery and knowledge application. Game goals model targeted learning goals to motivate, guide, and reward player discovery and application of targeted knowledge. Specifically, static and dynamic goals used in the *Selene* game were studied by analyzing a player's timed report documenting progress toward the goal every 10 seconds of gameplay. The results suggested that player achievement is consistent within time periods, with players appearing most challenged during time period 1 and achieving the greatest success in time period 3.

Subsequently, in 2013, project staff conducted a series of studies including a construct representation validation argument aligning the game with Mislevy's evidence centered design, and an examination of gameplay persistence using gameplay and demographics as predictors. Regarding the case for validity, an exploratory study was conducted to determine feasibility, followed by the cross-validation of the game approach. In general, the results quantified the relative effectiveness of game components suggesting that players spend most of their time making steady progress toward game goals. As such, the results supported the case for the game's validity argument. In the case of players' persistence, it was found that successful male and female learners playing the *Selene* game show different patterns of affect as they play. On the average, successful female players' gameplay experience tends to remain relatively stable—in a persistent state of control—across achievement levels, while successful males tend to react to the achievement of the moment. That is, as male achievement of learning goals increased, males reported increased skill and decreased challenge, and moving into a state of routine expertise. In addition, project staff also initiated the investigation of pragmatic constraints, payoff structures, and regulatory focus.

Overall, the CyGaMEs project created a robust game-based learning environment to mediate players' learning of science concepts through analogical reasoning. Concurrently, the project demonstrated how a videogame environment could be used for data collection and to study players' learning as they play the game using embedded assessments and a reporting system.



## Quality of Research and Development Activities

The quality of research and development activities were examined in terms of the underlying merits of related work and accomplishments reported throughout the duration of the project. This examination was informed by NSF's guidelines on merit review of project activities focusing on the interdisciplinary intellectual capacity and nature of research work (NSF, 2007). The analysis was driven by the evaluation question: What is the quality of research and development activities and products designed to improve cyberlearning? Thus, for the purpose of this evaluation report, the evaluative analysis was organized around two categories of project work and outcomes: (a) Design and development, and (b) research activities.

**Design and development activities.** Design and development activities were associated with two primary objectives of the project: (a) To transform the existing *Selene* game into a robust research instrument, and (b) and to create an informatics infrastructure for data collection and reporting. To this end, two quality factors contributed to the successful completion of related activities: Conceptualization strategies, and the design and development approach.

**Conceptualization capacity.** This factor aligns with the NSF's indicator of interdisciplinary intellectual capacity. In the case of this project, the intellectual capacity behind the conceptualization of the CyGaMEs project stemmed from strong interdisciplinary and synergistic work of senior staff. The Co-PIs leading the project—Drs. Debbie Reese and Charles Wood—built upon unique interdisciplinary expertise bridging research and development in instructional design and content knowledge in lunar science. Dr. Reese provided the overall leadership and core conceptualization ideas for the project drawing from prior research and related theoretical underpinnings (Reese, 2009a). Based on the premises of structured mapping and analogical reasoning she provided the conceptual basis for the development of a videogame-based environment for learning and assessment of science concepts. Dr. Reese's prior work leading to the conceptualization of CyGaMEs can be traced through her graduate studies and a series of publications on the subject (see for example Reese, 2007, 2008b; 2009a; Reese & Coffield, 2005).

In turn, the focus on lunar formation benefited from the direct contribution of NASA science through the work of Dr. Wood, who 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 (C. Wood, personal communication, December 13, 2012; Wood, 2003).

As a result of their collaboration, their conceptual plan was to transform the existing *Selene* game into an instrument to generate more reliable data of player performance while mediating learning 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 (D. Reese, personal communication, June 15, 2011; National Research Council, 2007; Wood, 2003).

This unique collaboration on the conceptualization of the videogame underscored the original quality of the project featuring Dr. Reese's application of structure mapping theory and Dr. Wood's knowledge of the formation and evolution of the Earth's moon. This collaboration also allowed the team to monitor and assess the validity and accurate representation of science concepts, and verify the reliability of the game concept throughout the design and development stages.

***Design and development.*** To transform the existing *Selene* game into a robust research instrument based on the conceptual premises noted above, the project built upon internal and external interdisciplinary capacity for design and development. Quality indicators of design and development activities were reflected on a focus on the integrity of design work, the project's design and development capacity, and the iterative cycle of development.

The focus on the integrity of the development process to create a game with accurate representations of science concepts through gameplay is exemplified with the approach for initial development. At the start of the project, a contractual agreement was established with an external developer to develop the game's infrastructure and for play testing. However, due to performance issues, the external contractual services were terminated at the end of Year 2. Subsequently, project staff decided to enhance the local capacity and implement workarounds for the game development and ensure the integrity of the game's design.

Regarding the design and development capacity, recognizing the complexity of project activities and goals, the project was supported with complementary expertise including contributions from internal (WJU) and external parties in the areas of recruitment, project coordination, research and development, and evaluation. To this end, Ben Hitt (Co-PI) contributed to prototype design and development, while Dr. Beverly Carter (Co-PI) contributed to game engineering documentation. Over the duration of the project, a cadre of graduate and undergraduate students also contributed to the project on data analysis, conducting game studies and study sessions, and programming. A team of programmers played a key role in the game development as well. Finally, additional support from international partners made the bilingual version of the game possible.

All in all, the project maximized the use of complementary internal and external intellectual capacity to meet design and development requirements. An iterative cycle of development was at the core of the design and development of the game. At the end of the project, the game development went through about a dozen iterations resulting in the deployment of the English and Spanish versions. In this process, project staff would playtest and list defects to prioritize development work. Further, to ensure shared communication and understanding of the development process, documentation of pending and completed work was characteristic of development activities. The use of organizational and communication structures was particularly 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 facilitated the design and development of the existing game and its transformation into a research instrument (R. Kosko, personal communication, May 1, 2013).

**Recognition of quality.** The design and development of the *Selene* videogame has been recognized for its engaging environment facilitating the promotion of science learning and for its promotional materials. 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 2010 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 fun and engaging for children ages 7-11.

In 2011, the Association for Educational Communications and Technology (AECT) further recognized the project quality in the form of a Best Practice Award. This was the second Best Practice Award given to the *Selene* Game by AECT. In the same year, the project was also recognized as one of 35 national of projects reflecting the recommendations of the National Research Council for STEM education. The project was recognized in the form of an invitation as a showcase presenter at the *STEM Smart: Lessons Learned from Successful Schools* hosted by NSF. Further, in 2012, the *Selene* videogame earned honorable mention in the games and apps category of the International Science & Engineering Visualization Challenge. Finally, in 2013, the Spanish version of the game received the Hispanic Graphic Design Award for P-O-P, Displays, Signs, and Exhibits by *Graphics Design USA*. *Graphics Design USA* is a news magazine for graphic designers and other creative professionals and has hosted this national contest for four decades.

**Research activities.** Research activities were associated with two project objectives: (a) To collect data on learning and perceptions, and (b) to conduct studies of motivation, engagement, and learning. In general, research activities conducted throughout the project point to broader contributions to the advancement of discovery and understanding of science education through cyberlearning. The quality of research activities was reviewed using two indicators: The research capacity to meet related project goals, and the nature of research outcomes.

***Interdisciplinary research capacity.*** Regarding research activities, the intellectual capacity underlying the design, implementation, and analytical strategies was rooted in a strong interdisciplinary and synergistic work internally and externally aligned with the NSF's indicator of interdisciplinary intellectual capacity. The Co-PIs leading the project built upon unique interdisciplinary expertise bridging research and development in instructional design and content knowledge in lunar science.

Building upon prior research, Dr. Reese led the interdisciplinary research team. She contributed to research activities by framing related work in the context of relevant theoretical premises, research design, and analysis, and report writing. In turn, Ben Hitt (Co-PI) contributed to activities bridging research and development including implementation studies. Beverly Carter (Co-PI) also contributed in that capacity through 2010. In addition, given the nature and complexity of the research agenda, project staff sought strategic partnership with researchers and educators to test the game, collect and analyze data, and refine measures. To this end, over the course of the project, staff partnered with four universities in the United States including Wheeling Jesuit University, Western Illinois University, Northwestern University, and Kent State University. Internationally, the research team collaborated with two universities, the University of Vic in Spain and the Suleyman Demirel University in Turkey. As a result of this interdisciplinary collaboration with partners at different institutions, the project was able to benefit from the engagement of graduate and undergraduate students in research experiences involving data collection and analysis.

The collaborative work with Virginia Diehl—Professor of Psychology at Western Illinois University—in particular, was very productive resulting in five presentations of research results and a journal article. Similarly, the contribution of Dr. Barbara Tabachnick as an external partner further enhanced the project's intellectual capacity for conducting research activities. Dr. Tabachnick, a recipient of the Western Psychological Association's Lifetime Achievement Award, provided consulting services for statistical analysis and became an integral and important collaborator in the project. Dr. Tabachnick is Professor Emeritus in the Department of Psychology at California State University at Northridge, and is an expert in multivariate analytical techniques. Over the duration of the project the collaborative work with Dr. Tabachnick translated into a series of presentations and publications on the validity of timed report measures.

Further, to draw complementary expertise in the refinement of measures and embedded assessments, the PI 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. Hedges'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.

Short-term consultations were also part of the interdisciplinary capacity for conducting research activities such as the assistance provided by Eric Hedberg of the Center for Advancing Research in STEM (ARC) in 2013. Related assistance was provided on the analysis of the flow power and multivariate analysis using *Selene* game data. All in all, the combination of in-house expertise and interdisciplinary collaboration with partners in the field contributed to the quality the project's research capacity.

***Nature of research results.*** This indicator of quality reflects the nature and totality of research results including contributions to data collection and reporting infrastructure for research purposes, the use of embedded assessments, and research on cyberlearning.

For research purposes, at the core of the game design is the use of embedded assessments instruments to measure learning (by analyzing timed report and gestures) in the context of self-perceptions of flow experience including flow, arousal, anxiety, worry, apathy, intrinsic motivation, boredom, routine expertise, and control. The use of embedded assessments allows the identification of patterns of learning as affected by the game environment by quantifying player behavior (growth in conceptual knowledge) aligned with nine-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. 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. As a result of this work, project staff 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, 2008b, 2009b; Reese & Tabachnick, 2010).

Building upon the use of embedded assessments and timed reports, project results contributed to the shared understanding of cyberlearning with particular emphasis on motivation, engagement, and learning. Notable results emerged from the 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). These findings were further replicated and established that, through the use of timed reports, CyGaMEs measures learning accurately across all players (learners) (Reese et al., 2012).

Project staff also developed an automated learning dynamics approach to quantify learning trajectories and achievement using standardized metrics of progress toward the goal, rate of progress, and acceleration in progress. For research purposes, standardized metrics are useful for comparisons within and between both learners and instructional games (Reese et al., 2014). The project also yielded important insights on persistence, a skill associated with academic success. The project found evidence that players' goal-seeking behavior is the strongest predictor of persistence during gameplay. That is,

patterns of goal-seeking behavior suggested that persistence might be associated with cognitive flexibility, debriefing, and feedback and effort.

In addition, in alignment with project objectives, project staff developed a reporting system infrastructure allowing the automated production of assessment reports to stakeholders. For research purposes, the reporting system provides automated weekly updates of the master and individual player logs, JSON log, and assessments. The system also provides real-time badging criteria evaluation and reporting through specific queries and data views.

Based on the nature and totality of research results, the project contributed to the shared understanding of important mediating factors in cyberlearning through the use of embedded assessments. In short, the research results stemming from project work yielded evidence that when playing CyGaMEs, players work hard toward the game goal and develop an understanding of how lunar geology works. In addition, the project produced an informatics reporting system allowing the use of the *Selene* as a research instrument for access to researches interested in cyberlearning.

***Recognition of quality.*** The nature and quality of research results produced by the CyGaMEs project were recognized through invited presentations and showcases, research awards, and alignment with calls for research on cyberlearning learning and assessment.

Recognizing the quality of project work, over the duration of the project, project staff was invited to conduct a series of presentation and showcases of research results; which reflected an appreciation in the field for the project's contributions to research on cyberlearning. A sample of invitations issued to showcase project research included presentations at the: IBM Serious Games Day, Raleigh, NC (2009), Games for Learning Institute's Design Innovation at NYU GameFest in New York (2010), and Annual Meeting of the Association for Educational Communications and Technology in Jacksonville, FL (2011). Of particular note was the invitation to showcase the project work at the STEM Smart: Lessons Learned from Successful Schools, an event hosted by the National Science Foundation. CyGaMEs was selected as one of 35 national examples of resources, programs, schools, and projects aligned to the recommendations of a National Research Council report outlining elements for successful STEM education (NRC, 2011). By participating in that event, the project was recognized for integrating research and development into a videogame-based environment.

Further, in regard to the alignment with calls for research on cyberlearning, the use of embedded assessments has been a significant project contribution to the related body of knowledge. Embedded assessments have been used in the project to measure learning by analyzing timed reports and gestures in the context of self-perception of flow experience including nine states: flow, arousal, anxiety, worry, apathy, intrinsic motivation, boredom, routine expertise, and control. The use of embedded assessments to study emotion and motivation is important as it can lead to an understanding of systematic documentation of learning as part of the design of learning environments. As a result of this work, the project produced an informatics structure to generate automated reports of

a player's game play experience. The benefits of the reporting system is that feedback can be provided immediately to students playing the videogame, to teachers interested in monitoring student understandings and performance, and to researchers interested in studying players' experiences and learning in a particular disciplinary context. Recognizing the value of this work, the project was highlighted in an issue brief focusing on improving teaching and learning through educational data mining and learning analytics published by the U.S. Department of Education's Office of Educational Technology (2012). The issue brief featured the project's work as an exemplar of integrated assessment and learning strategies with promising implications for improving teaching and learning—and related research.

Additional recognition of research work was produced in the form of awards and endorsements in the field. For example, Drs. Reese (PI) and Diehl (Co-PI) received an award in 2009 for best work in traditional research at the 4th Annual Western Illinois University Faculty Research Symposium. Subsequently, in 2010, the project was a finalist at the Disney Research Learning Challenge, a competition seeking to show that motivating interactions on computers can convey sophisticated concepts. Thus, given the appreciation for project work in the field, the alignment with calls for research on cyberlearning and assessment, there was consistent evidence indicating that the project contributed to the shared understanding of how people learn through videogame-based environments.

### **Broader Impacts of Project Activities**

The assessment of broader impacts of project activities was informed by NSF' guidelines on the merits of project impacts (NSF, 2007). The analysis was driven by the evaluation question: What are the nature and extent of broader impacts resulting from research and development activities and project outcomes? As such, project outcomes and accomplishments at the end of project were reviewed along the following indicators: (a) Development of research-based educational materials, (b) contributions to research in cyberlearning, (c) establishment of collaborative partnerships, (c) dissemination and outreach, and (e) ensuring project sustainability.

**Development of research-based educational products/materials.** Three lines of products were produced over the duration of the project including a bilingual version of the *Selene* game, an informatics infrastructure system, and curricular materials for parents and educators.

***Bilingual version of the Selene game.*** Project staff also produced and delivered a bilingual version of the *Selene* game to provide a standards-based Earth and space science videogame for Spanish/Hispanic youth. The game is available in English and in Spanish on the project's website (<http://selene.cet.edu/default.aspx?page=Selene>). Given the fact that Hispanic students now make up about 20% of all students in public schools in the United States, and that Spanish is the fourth most widely used language in the world (spoken in 44 countries), the broader impact of the game at the national and

international level is of practical significance (Fry & Gonzales, 2008; American Association of Teachers of Spanish and Portuguese, 2014).

**Informatics infrastructure system.** Concurrently, project staff designed and developed a reporting system that will remain available as part of the *Selene* game upon completion of the project. As noted earlier, the informatics infrastructure is a reporting system that provides immediate feedback to players (formative assessment) via a game dashboard and generates progress information to issue badges and feed a leaderboard to boost players' motivation for continued gameplay (i.e., learning). For educators, the system allows the assessment of learner performance by analyzing progress toward the game's goal. In turn, researchers can download gameplay data for analysis and mine game data through specific queries. Unlike typical projects resulting in a particular unidimensional product (e.g., a game), the CyGaMEs project produced an informatics structure that turned the *Selene* game into a multi-purpose instrument with broader impacts on teaching and learning (students and educators as users) and on cyberlearning research (researchers interested in related topics).

**Development of curricular materials.** In addition to an engaging videogame, the project also developed a series of outreach resources and curricular materials that can be used in formal and informal education. These curricular and hands-on activities—referred to as MoonGazers and Gameplay Inquiry Cycle—are available online at the project's website (<http://selene.cet.edu/default.aspx?page=educators>) for parents and educators to engage students in science learning through lunar observation and fieldwork.

MoonGazers is an outreach resource that packages a series of virtual, videogame-based, and hands-on activities for public access. MoonGazers resources are designed for learning about the solar system geological processes including the *Selene* game, MoonWorld (a virtual environment), and various resources involving hand-on activities. In turn, in 2013, project staff released another important resource named CyGaMEs Gameplay Inquiry Cycle. The Cycle is intended to help illustrate how educators can use the *Selene* game to maximize the students' game playing experience. Backed up by scientific credibility provided by project staff, related educational research, and alignment with science standards, 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. The development and availability of these resources for public access, which have been recognized and fully endorsed by the West Virginia Department of Education in support of science standards, provide evidence of broader impact in the field.

**Contributions to research in cyberlearning.** 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, 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).

Further, the CyGaMEs 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. 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 (Reese, 2010; 2012).

With this frame of reference, the broader impacts of research activities and results align with contributions to emerging evidence that instructional video games 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 (NRC, 2011; U.S. Department of Education, 2012). To this end, CyGaMEs designed an automated structure that is 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 game is accurately measuring learning, and whether the game environment is helping players’ progress toward the learning goal (Reese et al., 2014). The CyGaMEs reporting system 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). In general, the potential broader impact of CyGaMEs is that its approach serves as a proof of concept for using embedded assessments as an integral component of a game’s design—a concept that can be generalizable to other educational games.

**Establishment of collaborative partnerships.** Building synergistic collaboration to further expand interest in actual engagement in related research and development work is another indicator of broader impacts. To this end, collaborative activities were established internally with CET and WJU units and externally with other institutions nationally and internationally. As noted elsewhere, the project built upon internal and external collaborative structures to complement the intellectual capacity to carry on design, development, research, and dissemination work. Overall, the project established

an impressive network of partners with several organizations including public schools, universities, research centers, and outreach agencies.

For example, integration of research into learning and education was 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 was to use *Selene* as a means to help education majors develop an understanding of instructional technology. Likewise, integration of research and education was 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 several institutions such as Northwestern University, Western Illinois University, Wheeling Jesuit University, North Dakota State University, Kent State University, and the Pennsylvania State University. In turn, to promote dissemination of project materials and/or results, the project 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).

An endorsement of the project by the WVA Department of Education is another example that facilitated collaboration with public schools in West Virginia and other states. Similarly, the support of NASA's outreach network provided an important platform for continued dissemination of project materials and results. At the national level, a partnership established with the National Association for Bilingual Education (NABE) promises continued support for the promotion and use of the *Selene* game targeting Spanish-speaking students (see for example, NABE, 2013). On this note, it is also 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. To wit, the Roque de los Muchachos Observatory and Instituto de Astrofísica de Canarias has incorporated Spanish *Selene* into its astronomy outreach program in the Canary Islands (see related story at: <http://selene.cet.edu/default.aspx?page=news&id=116>).

**Dissemination and outreach.** Sharing project results with educators and researchers is another important indicator of broader project impacts in the field. Related activities included dissemination of project results through conference presentations and research articles, and outreach strategies including the provision of professional development opportunities for educators.

Regarding dissemination of project results through research articles and conference presentations, project staff and contributing partners authored 22 publications and conducted numerous conference presentations and other dissemination activities. Research articles were disseminated at noted publication outlets in the field such as the *Educational Psychology* journal, and the *British Journal of Educational Technology*. Further, presentations were conducted at national and international forums sponsored by a variety different professional organizations. To that end, the project targeted forums

with wide reach in the field such as those held 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. A list of publications and other resources resulting from project work is available at the project's website (<http://cygames.cet.edu/?page=research>).

In addition, dissemination was further channeled through outreach activities using a variety of training and development formats. Several instances of discrete outreach activities were identified throughout the project including mentorship opportunities and/or presentations conducted with undergraduate and graduate students interested in learning about conducting, analyzing, and reporting educational research through internships, research assistantships, and participation in the research experience for undergraduates (REU) program. Similarly, mentorship opportunities were also available for college faculty interested in involving undergraduate students in educational research. Further, the project offered professional development opportunities for science teachers interested in using *Selene* in their curriculum including workshops, webinars, and guest lectures over the duration of the project.

Project information was also widely disseminated through the NASA portal, CET's website, and featured on West Virginia Public Broadcasting. In particular, the NASA's education resource network 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 were 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 (<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/>).

International dissemination was also achieved during the project with presentations in Mexico and outreach activities with partners in Turkey and Spain. For example, the Partnerships for Bilingual Stem Education and Spanish Astronomy Education and Outreach in the Canary Islands are using the Spanish version of *Selene* in professional development activities. Further, in collaboration with Spaniard collaborators, an article in the Spanish magazine *Astronomía* was published in 2014 (Álvarez, Fernández, Reese, & Negrín, 2014).

Overall, in this area the project performed remarkably well drawing from the results of work related to core objectives. Project staff and contributing partners collaborated in the production of a steady record of dissemination through presentations, outreach activities,

and scholarly publications at a number of regional, national, and international venues. A highlight of related dissemination activities was the invitation to showcase the CyGaMEs project—as one of a few selected NSF-funded projects—on November 4, 2009 at the Senate Hart Office Building in Washington, D.C. to educate members of the Senate, their staff and other interested people about the use of technology at all levels of education. More recently, the quality of dissemination materials related to the Spanish version of *Selene* was also recognized with the Hispanic Graphic Design Award for P-O-P, Displays, Signs, and Exhibits by *Graphics Design USA*.

**Ensuring project sustainability.** Project sustainability beyond the funding schedule is also a critical indicator of broader impacts. In this case, the project produced a game that is available online and a system to make it work for recruiters, players, and researchers. As such, the data management system requires continued institutional support to keep the structures in operation and available to researchers. To this end, institutional support was secured from Wheeling Jesuit University to provide related support beyond the duration of the project. Thus, with this institutional support in place, the Wheeling Jesuit University data management system will provide a public repository for CyGaMEs data. All CyGaMEs' player data will remain anonymous.

Further, as part of the institutional support ensuring project sustainability, WJU agreed to give Dr. Reese (PI) access to CyGaMEs data for 5 years upon completion of the project. In this regard, to ensure a smooth transition toward a self-sustaining mode, new servers were purchased to support future project operation. In addition, project staff worked toward this transitional goal at the end of the project developing the automation of *Selene* documentation and implementation to preserve the integrity of research participants (i.e., players). Finally, as part of this transition toward sustainability, the PI agreed to continue vetting future recruiters on a volunteer basis.

## Conclusions

The evaluation of the CyGaMEs project focused on the efficacy of implementation and completion of proposed activities, the quality of research and development work, and broader impacts. Overall, regarding the efficacy of project implementation and completion—based on the project timeline, proposed activities, and observed results, the project complied with anticipated timelines and milestones associated with each objective. Specifically, all project activities associated with videogame design and development and research work were completed on schedule and all milestones anticipated in the project were met. At the end of the project, the *Selene* game has been transformed into a reliable game-based environment that can be used for research purposes to assess and report how people learn science concepts through gameplay. The game is available in English and in Spanish on the project's website. Further, project staff designed, developed, and delivered an informatics infrastructure that provides immediate feedback to players, allows educators to assess learner performance, and permits researchers access and analyze gameplay data. In turn, at the end of the project, the CyGaMEs community of users grew into a robust pool of recruiters and more than players representing almost equivalent player participation by gender.

About the quality of research and development activities, related project work was characterized by a strong conceptualization capacity leading to the transformation of the *Selene* game into a robust research instrument, and contributions to shared understanding of important mediating factors in cyberlearning. Specifically, two quality factors contributed to the successful completion of design and development activities: Conceptualization capacity, and design and development approach. The intellectual capacity behind the conceptualization of the project stemmed from strong synergistic work of senior staff bridging research and development in instructional design and content knowledge in lunar science. Further, the project built upon internal and external interdisciplinary capacity for design and development. The quality of the design and development approach was also based on a focus on the integrity of design work, the project's design and development capacity, and the iterative cycle of development. In addition, research activities reflected broader contributions to the advancement of discovery and understanding of science education through cyberlearning. All in all, based on the nature and totality of research results, the project contributed to the understanding of important factors in cyberlearning through the use of embedded assessments.

Regarding broader project impacts, three lines of products were produced over the duration of the project including a bilingual version of the *Selene* game, an informatics infrastructure system, and curricular materials for parents and educators. The game will be available in English and in Spanish on the project's website for continued public access beyond the project's closeout. Concurrently, project staff designed and developed a data management system that will remain available as part of the *Selene* game upon completion of the project. In addition the project developed curricular and hands-on activities available online for parents and educators to engage students in science learning through lunar observation and fieldwork. Further, project work aligns with and contributes 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). Also, the project established an impressive network of partners with several organizations including public schools, universities, research centers, and outreach agencies adding to evidence of potential broader impacts in the field. Moreover, the project did a remarkable job producing a robust record of dissemination including numerous publications and conference presentations. Dissemination was also conducted through outreach activities using a variety of formats such as the NASA portal website, the NASA's education resource network, and the project's website which provides public access to background information, testimonials, and directs to other resources associated with the *Selene* game. Finally, to ensure project sustainability beyond grant funding, institutional support was secured from Wheeling Jesuit University. With this agreement for institutional support, the Wheeling Jesuit University data management system will provide a public access to CyGaMEs data upon expiration of grant funding.

Thus, based on the totality of project work and outcomes, and given the efficacy of project implementation and completion, quality of research and development work, and assessment of broader impacts in the field, there was consistent evidence supporting a representation of exemplary project performance.

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