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A Targeted Study of Gaming and Simulation Projects in DR K-12

Community for Advancing Discovery Research in Education

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1. Introduction

In late 2009, the National Science Foundation (NSF) and the William and Flora Hewlett Foundation charged the National Research Council (NRC) with forming an ad hoc committee to examine the potential for computer games and simulations to support science education. In response, the NRC's Committee on Science Learning: Computer Games, Simulations and Education, convened a two-day workshop to review what is known about the role of computer simulation and gaming in science learning and to outline a set of priorities for future research.

The NRC committee described games and simulations as existing on a continuum and sharing many of the same characteristics. They defined simulations as models of complex systems in which users can explore the implications of modifying parameters and often allow for dynamic, as opposed to static, visualizations.[1] Simulations allow users to observe and interact with representations of phenomena that would otherwise be sensorily invisible or exist in the abstract. Scientists routinely develop and apply simulations to model and understand natural phenomena across a wide range of scales from subatomic to planetary. Games can share many of these characteristics, but unlike simulations, are often played spontaneously, in informal contexts, and primarily for entertainment. They typically feature explicit rules and goals that drive the user experience, allowing users to receive feedback about their progress and their actions to affect the state of the game.[2] The committee distinguished between games played solely for entertainment and "serious" games, which are intended (e.g., by the user, classroom teacher, or developer) to serve an additional purpose. In STEM, serious games are designed to support the learning process, and the committee focused specifically on science games that accurately modelled or simulated scientific processes, and where interactions within the game's virtual world were governed by scientific principles.[3]

In their report, the NRC committee concluded that the use of computer games and simulations had great potential to affect a variety of science learning goals, such as conceptual understanding, motivation, science process skills, science discourse and argumentation, and understanding of the nature of science. However, at the time of the report, research on the educational impact of games and simulations had not kept pace with the evolution or implementation of these products. This dearth of research made it difficult to establish a base of evidence for the effectiveness of computer games and simulations. Thus, the committee issued several recommendations targeted at improving research quality, filling gaps in the research, and creating partnerships to institutionalize research and development within the field.

The NSF's Discovery Research K-12 (DR K-12) program is one potential source of funding for the needed research on the educational effectiveness of gaming and simulations. The DR K-12 program seeks to enhance the teaching and learning of STEM in K-12 education by funding the "development, testing,

[1] Clark, D.B., Nelson, B., Sengupta, P., & D'Angelo, C. (2009). *Rethinking science learning through digital games and simulations: Genres, examples, and evidence.* Paper commissioned for the National Research Council Workshop on Gaming and Simulations, October 6-7, Washington, DC. | Plass, J.L., Homer, B.D., & Hayward, E.O. (2009). Design factors for educationally effective animations and simulations. *Journal of Computing in Higher Education, 21*, 31-61.
[2] Clark, Nelson, Sengupta & D'Angelo. (2009) | Hays, R.T. (2005). *The effectiveness of instructional games: A literature review and discussion.* (Technical Report No. 2005-004). Orlando, FL: Naval Air Warfare Center Training Systems Division.
[3] National Research Council. (2011). *Learning science through computer games and simulations. Committee on Science Learning: Computer Games, Simulations, and Education*, M. A. Honey & M L. Hilton (Eds.), Board on Science Education, Division of Behavioral and Social Sciences and Education. Washington, DC: The National Academies Press.

deployment, effectiveness, and/or scale-up of innovative resources, models, and tools"[4] in STEM areas. This work takes on many forms within the funding portfolio, including computer games and simulations. With the growing attention to these types of educational technologies, the Community for Advancing Discovery Research in Education (CADRE)[5] conducted a brief targeted study to better understand the gaming and simulation research and development work being funded within the NSF's DR K-12 program and to highlight work that may help fill the gaps identified by the NRC.

The remainder of this document describes a set of innovative projects that include a gaming or simulation component from the NSF's DR K-12 program. It begins with a description of the methodology used in this targeted study, and then describes findings related to the targeted users, educational resources developed for users, research methods, and sustainability. (See popups for more information.)

2. Methodology

CADRE annually compiles a descriptive overview of the characteristics of projects in the DR K-12 portfolio. [6] In addition, CADRE also conducts targeted studies on topics of interest to DR K-12 principal investigators (PI), the NSF, and the broader research community. The current targeted study was designed to provide insight, using selected DR K-12 projects as a set of illustrative cases, into the innovative research and development being conducted with educational games and simulations. The research questions, data, and analytic methods used in the study are described below.

2.1 Research Questions

At the time of publication, the NRC's *Learning Science Through Computer Games and Simulations*[7], reported that the evidentiary base for learning science from simulations was stronger than that of games, and overall the research on the efficacy of games to promote learning remained inconclusive, partially due to the relative newness of serious games compared to simulations. The committee recommended a research agenda for simulations and games that aimed to improve the overall quality of research as well as advance the field of research and development around games and simulations for learning. Some of the outlined approaches include:

- Examining how different contexts (i.e., formal contexts such as K-12 science classrooms or informal contexts such as after-school clubs) affect science learning
- Specifying clearly the desired learning outcomes of the game or simulation
- Assessing the potential of games and simulations to advance learning goals, including motivation, conceptual understanding, science process skills, and scientific discourse
- Applying the evidence-centered design approach to the development of assessments through games and simulations

[4] National Science Foundation. (2011). Discovery Research K-12 (DR K-12): Program Solicitation 11-588.
[5] CADRE is the resource network that was established by the NSF to support the DR K-12 community in advancing the state of research and evaluation in STEM education. Organizational partners of CADRE include Education Development Center, Inc., Abt Associates Inc., and Policy Studies Associates.
[6] The latest portfolio review can be found at
http://cadrek12.org/sites/default/files/CADRE%20YR%205%20Portfolio%20Overview%20v7_stl.pdf
[7] National Research Council. (2011). *Learning science through computer games and simulations. Committee on Science Learning: Computer Games, Simulations, and Education*, M. A. Honey & M L. Hilton (Eds.), Board on Science Education, Division of Behavioral and Social Sciences and Education. Washington, DC: The National Academies Press.

- Developing and using statistical models and machine learning approaches to make meaning from and patterns of student behavior using the large amounts of data collected through games and simulations
- Establishing alternative mechanisms for supporting large scale collaborative innovation and ongoing improvement as well as exploring systems for informing users about the quality and effectiveness of games and simulations for learning

The conceptual base for this study was guided by the NRC report along with suggestions from active DR K-12 PIs in this field. It is important to note that since the NRC's 2011 report, which provided an overview of the field prior to 2010, there have been several advancements pertaining to games and simulations research as the field continues to adapt, evolve, and advance. Recent literature reviews have found positive impacts associated with learning using computer-based and serious games, though more research is needed on the role of contextual and instructional factors. [8] The research questions guiding the analysis were:

1. What is the target audience of the gaming and simulation components of these projects?
2. How are the projects distributed across different disciplines?
3. For what contexts are these materials developed?
4. What resources and products are these projects developing?
5. What research designs and methodologies are being implemented in these projects?
    a. What outcomes are captured in these projects and how are they measured?
    b. What are the methodologies used by the projects to assess the effectiveness of the educational gaming and simulation components?
6. How are the projects addressing dissemination and sustainability?

2.2 Data

The sources of data used in this study were collected by CADRE, directly from DR K-12 PIs, for the purpose of preparing annual portfolio overviews of the DR K-12 program.[9] Each year, CADRE has asked PIs of newly funded projects to provide CADRE with their projects' proposals and responses to review panel questions. Additionally, CADRE asked PIs of existing projects funded in prior years to provide project updates in the form of annual reports, project publications, and other information about their plans, activities, and achievements. For the current study, 66 projects were originally identified from the portfolio review[10] as those involving a broader range of technologies, including educational gaming, interactive learning, and/or virtual environments. This sample was then reviewed by CADRE staff and gaming special interest group (SIG) members to identify the projects that include a significant gaming or simulation component and/or directly address gaming or simulation for K-12 STEM learning. A total of 33 projects were removed from the sample, resulting in the final set of 33 projects.

[8] Wouters, P., van Nimwegen, C., van Oostendorp, H., & van der Spek, E. D. (2013). A meta-analysis of the cognitive and motivational effects of serious games. *Journal of Educational Psychology*, *105*(2), 249.) | Connolly, T. M., Boyle, E. A., MacArthur, E., Hainey, T., & Boyle, J. M. (2012). A systematic literature review of empirical evidence on computer games and serious games. *Computers & Education*, *59*(2), 661-686.
[9] CADRE operates under a cooperative agreement (rather than a contract) with the NSF so we do not have access to the data and materials maintained by the NSF.
[10] This study included projects receiving new awards between 2007 and 2012. Three additional projects (NSF Award Nos. 1221614, 1119290, 1119383) met the inclusion criteria but are not represented in the final set due to insufficient data. Brief descriptions of these projects are included in the Appendix.

Note that, for convenience, we refer to these projects generally as "gaming" projects in the text that follows. This is not to discount the differences between games and simulations or to suggest that the same questions, priorities, and methods are guiding the research and development work being done in these areas. Rather, it reflects the fact that their comparison was beyond the scope of this report. Limited data about the projects constrained the ability to classify the projects cleanly at various points along a continuum differentiating between simulations and games.

2.3 Coding Methodology

This study drew on two types of coded data: (1) general project characteristics that were coded for the annual portfolio overview and (2) more in-depth coding conducted specifically for this study.

To generate data on general project characteristics, as part of CADRE's annual activities, the collected DR K-12 project materials were reviewed and coded by a team of CADRE researchers using a protocol designed to capture information on project attributes and characteristics as well as the DR K-12 program goals being addressed.

More comprehensive coding, specific to the research questions of this targeted study, was then conducted on the subset of gaming projects. After developing supplementary coding schemes to further characterize projects' methodologies, measured outcomes, and analysis techniques, two coders reviewed and coded the available project materials, including proposals and annual reports. After coding for the presence or absence of a particular quantitative methodology, the second level involved identifying the type of methodology used for data analysis in a project. The results are presented and elaborated in the findings section, accompanied by illustrative examples from selected projects.

2.4 Study Limitations

The materials reviewed and coded for this analysis were created by grantees for purposes other than this review. Thus, across projects, the information is reported in diverse and unsystematic ways. As a result, the level of detail reliably extracted and coded varied and was, at times, limited.

Additionally, project materials often reported on planned activities. For convenience, this report uses phrases like "projects used," but the study's data sources contained information on what projects proposed to use or discussed considering in their annual reports. While CADRE's request for additional materials included responses to NSF reviewers, annual reports, final reports, publications, and products, there were no materials beyond the proposal for 13 projects.

An additional limitation is that the insight gained through this study is limited to the set of DR K-12 projects with a gaming or simulation component, and it is unclear how representative projects funded by DR K-12 are of the larger work being conducted on educational gaming and simulations. While the findings cannot be generalized to the wider field of K-12 educational games and simulations, they do provide a snapshot of the current and recent research and development being conducted on games and simulations used in education within the DR K-12 program.

3. Findings

The NRC report's definition of games and simulations as well as its proposed research agenda described provided guidance for this study. The findings in this section, organized by research question, present descriptions of the disciplines covered, context, outcomes, data collection methods, data analysis methods, and strategies for dissemination and sustainability employed in these projects.

3.1 Disciplinary Content

While each of the STEM disciplines was targeted in the DR K-12 gaming portfolio, the major discipline addressed was science. Twenty-one out of the 33 projects focused exclusively on science, five focused exclusively on mathematics, and only two had a focus on engineering. Five projects addressed multiple disciplines as shown in Table 1.

Table 1: Major Disciplines Addressed

	Number (N=33)	Percentage
Science only	21	64
Mathematics only	5	15
Engineering only	2	6
Multi-discipline*	5	15

*Science and mathematics (2); science and social studies (1); and science, engineering, and computer science (2).

Physical Science in Elementary Grades: **The Leonardo Project: An Intelligent Cyberlearning System for Interactive Scientific Modeling in Elementary Science Education**
This project designed and implemented technologies that combined artificial intelligence in the form of intelligent tutoring systems with multimedia interfaces to support children in grades 4-5 learning science. The students used LEONARDO's intelligent virtual science notebooks to create and experiment with interactive models of physical phenomena. With this technology, students' models 'came alive' as interactive multimedia artifacts that combine animation, sound, and narration. The curricular focus was on physical and earth sciences, and the technology supported multimodal interactive scientific modeling for four curricular units: forces and motion, magnetism and electricity, landforms, and weather and climate. A central feature of this environment was PadMates, which are intelligent virtual tutors that support science learning through interactive scientific modeling.

3.2 Target Audience

While most investigated student outcomes (as described later in this report), all of the DR K-12 gaming projects engaged in research activities involving students and teachers. Even if the project materials and activities targeted students, they were accompanied by resources for teachers or professional development components. Table 2 outlines the number of gaming projects that targeted students in each grade band, with some targeting multiple grade bands. Two-thirds of the projects (66%) in the gaming portfolio targeted middle school students followed by more than a third (39%) targeting high school students. There were only two projects targeting students at the preschool level.

Gaming in Pre-K: **Next Generation Preschool Math (NGPM)**
One of two projects implementing games in pre-k, NGPM, focused on preschool classrooms in low-income communities where children currently have few opportunities to engage with coherent sequences of mathematics instruction or with interactive media. A team of learning scientists and media researchers collaborated with educational media producers to develop, test, and refine a curriculum supplement that promotes children's understanding of number (counting, comparing, and ordering) and fair sharing (equipartitioning) using self-leveling games, collaborative games, an open-ended math tool sandbox, and playground and snacktime activities.

Table 2: Grade Levels

	Number (N=33)	Percentage
Pre-kindergarten	2	6
Elementary school (K-5)	6	18
Middle school (6-8)	22	66
High school (9-12)	13	39
Other	1	6

Projects may target multiple grade bands.

3.3 Context

The DR K-12 gaming projects involved a broad range of populations and were implemented in both formal and informal settings. Table 3 describes the projects' settings in terms of whether the projects were designed and implemented in the classroom (formal school settings) or in after-school clubs, museums, or libraries (informal settings).

Table 3: Project Context

	Number (N=33)	Percentage
Formal setting	32	97
Informal setting	4	12
Other (with parents and community)	2	6

Projects may work across multiple settings.

The NRC report[11] recommended the investigation of how learning in informal contexts may be leveraged for learning in the science classroom. The following four projects implemented in informal settings.

- Leveling Up: Supporting and Measuring High School STEM Knowledge Building in Social Digital Games
- Arcadia: The Next Generation—Transforming STEM Learning Through Transmedia Games
- GeniVille: Exploring the Intersection of School and Social Media
- CyberSTEM: Making Discovery Visible Through Digital Games Conference

[11] National Research Council. (2011). *Learning science through computer games and simulations. Committee on Science Learning: Computer Games, Simulations, and Education*, M. A. Honey & M L. Hilton (Eds.), Board on Science Education, Division of Behavioral and Social Sciences and Education. Washington, DC: The National Academies Press.

Bridging Formal and Informal Contexts: **Leveling Up: Supporting and Measuring High School STEM Knowledge Building in Social Digital Games**
This project designed, developed and tested a digital gaming environment for high school students that fostered and measured science learning within alternate reality games about saving Earth's ecosystems. Players worked together to solve scientific challenges using a broad range of tools including a centralized web-based gaming site and social networking tools, along with handheld smart-phones, and an avatar-based massively multiplayer online environment (MMO). The game required players to contribute to a scientific knowledge building community; and players rated each other's contributions for their value to the communities' learning and decision-making in solving the challenge. Designers worked with high-school teachers to develop bridge activities that leveraged science learning in games for use in formal education.

3.4 Products for Teachers and Students

The portfolio of gaming projects developed a range of products as supports for its users: students and teachers. Thirty-one of the 33 projects developed products to support student learning. The student learning materials ranged from full curricula to standalone assessments. In addition, 19 of the 33 projects had professional development (PD) programs with materials for preservice and/or inservice teachers. Projects designing resources for students had PD components and/or embedded teacher training to prepare teachers to use the student resources. Many of the gaming projects incorporated more than one activity within their scope or had multiple products as part of their deliverables. Projects might have designed an assessment, for example, in addition to a PD plan for teachers. Tables 4 and 5 list the PD products and content of the PD programs that were delivered to teachers. Table 6 illustrates the kinds of student assessment materials the gaming projects created as part of their activities

Table 4: Student Learning and Teacher Professional Development Products

Student Learning Product	Number (N=31)	Percentage
Computer or internet activities and resources	31	100
Curriculum	13	42
Professional Development Product	**Number (N=19)**	**Percentage**
Stand-alone instruction, manuals, guides, or other information	15	79
One or two sessions, classes, or meetings	6	32
Full professional development course	5	26
Curricula for course	3	16
Networks or learning communities	3	16
Supervision or mentoring	2	10

Projects can develop multiple student learning and/or professional development products.

Table 5: Content of Professional Development Programs/Products

	Number (N=19)	Percentage
Student curricular frameworks	12	63
Lead specific activities	4	21
STEM content	4	21
Focus on how students learn	1	5
Modeling instructional practice	1	5

Projects' professional development programs/products can focus on multiple content categories.

Curriculum as a PD Product:
CyberSTEM: Making Discovery Visual Through Digital Games

This project developed and tested an integrated gaming platform consisting of five model games that could form the basis of integrated game-based curricula. Each game came with an associated curriculum in life sciences that teachers, museums, and other science educators can use to educate the public about cutting-edge science. The project sought to understand if participation in CyberSTEM leads to increased learning in six areas: interest in science, conceptual knowledge, scientific reasoning, reflection on knowing, participating in science, and identifying as a scientist.

Table 6: Student Assessment Products

	Number (N=12)	Percentage
Assessment in a curriculum	7	58
Stand-alone assessments	4	33
Other assessments	1	8

Games-based Student Assessments:
SAVE Science: Situated Virtual Assessments Using Virtual Environments

This collaborative research project pioneered new ways of measuring student achievement by designing and implementing an innovative model for assessment of learning in STEM. In SAVE Science, game-based assessment modules evaluated middle grade students' science content and inquiry skills. Using a database of student interactions in a virtual environment, evolving patterns of scientific understanding among students were captured and analyzed.

3.5 Project Data Collection and Analysis

3.5.1 Data Sources For Gaming Projects

The gaming projects in the DR K-12 portfolio used a diverse set of data collection instruments and methods as shown in Table 7. The data collected were both quantitative and qualitative in nature. Twenty-four of the 33 projects (73%) used student tests and assessments (e.g., pretests/posttests), while an almost equal percentage (76%) conducted interviews with students.

Sixteen projects (48%) collected survey data from students, which had items related to self-efficacy, attitudes, beliefs, etc. These survey data were quantitatively analyzed using several techniques, discussed later in this report. Eighteen projects (55%) gathered students' usage data from computer-based games for analyses. The students' assessment data were from large-scale science and/or mathematics assessments like the National Assessment of Educational Progress (NAEP) and Trends in International Mathematics and Science Study (TIMSS). These assessments are used for national and international comparisons of student academic achievement. Seventeen percent of the 24 projects collecting student test/assessment data used NAEP tests.

Table 7: Data Sources

	Number (N=33)*	Percentage
Interviews	25	76
Student tests/assessments	24	73
Observations	22	67
Computer usage	18	55
Surveys	16	48
Artifact review	7	21
Focus groups	7	21
Journal entries/diaries	5	15

Projects may collect and analyze data from multiple sources.
*For one project, there was insufficient information to identify the data source(s).

3.5.2 Outcomes Measured

Projects in the gaming portfolio researched a wide range of outcomes that could benefit the education community (see Tables 8 and 9). Twenty-nine projects (88%) included a focus on student-related outcomes, while 15 (45%) assessed teacher-related outcomes. The teacher and student outcomes are discussed in detail below.

A. Student Outcomes

Twenty-nine of the 32[12] projects (93%) in the gaming portfolio assessed the student outcomes domain. Twenty-seven of these 29 projects (84%) measured variables in the cognitive domain, such as student performance and achievement. Fifty-five percent measured psychosocial variables such as student attitudes, career interests, and motivational and emotional attributes. Projects used variables and scales that assessed students' attitudes related to science, technology, games and assessments, achievement-related beliefs, and motivational constructs including self-efficacy, goal orientation, and test anxiety and/or interest in STEM careers. Sixteen projects (55%) measured other kinds of student behavior (e.g., completion of homework, test preparation, cooperative work, attendance, and discipline violations). A listing of the instruments used by projects in the DR K-12 gaming portfolio to measure student outcomes follows Table 8.

Table 8: Student Outcomes Assessed

	Number (N=29)	Percentage
Achievement/Performance	27	93
Attitudes/Beliefs	16	55
Student behavior	16	55

Projects can address multiple student outcomes.

[12] For one project, there was insufficient information to determine the outcome(s) assessed.

Instruments Measuring Student Outcomes in DR K-12 Gaming Projects

Mathematics Topic Assessments

*Research-Based Early Math Assessment (REMA)**

Science Topic Assessments

Science Attitudes, Skills and Knowledge Survey (SASKS)
Cornell Scientific Inquiry Series
Force Concept Inventory (FCI)
Measures of Academic Progress for Science (MAPS)

Mathematics and Science Topic Assessments

*National Assessment of Educational Progress (NAEP)**
*Trends in International Mathematics and Science Study (TIMSS)**
*New Mexico Standards Based Assessment (NMSBA)**
*California Standards Test (CST)**
*New York State Regents Exam (REGENTS)**
*Pennsylvania System of School Assessments (PSSA)**
*Utah Performance Assessment System for Students (U-PASS)**

Psychosocial Assessments

Attitudes Towards Science in School Assessment (ATSSA)
Achievement Goals Questionnaire (AGQ)
Children's Self-Efficacy Scale
Early Adolescent Temperament Questionnaire Revised (EATQ-R)
Instructional Material Motivational Survey (IMMS)
Junior Metacognitive Awareness Inventory (Jr. MAI)
Motivated Strategies for Learning Questionnaire (MSLQ)
Patterns of Adaptive Learning Scales (PALS)
Self-Description Questionnaire II (SDQII)
Self-Efficacy in Technology and Science (SETS)
Sources of Science Self-Efficacy Scale (SSSE)
Strong Interest Inventory
Views about Science Survey (VASS)

*These instruments represent some of the current large scale and state-level assessment measures for science and/or math (capturing content knowledge and reasoning skills) that were used as assessments within projects.

B. Teacher Outcomes

Fifteen of the 33[13] projects in the DR K-12 gaming portfolio assessed teacher outcomes. Across this set, projects measured various teacher domains including attitudes/beliefs, classroom instruction and teacher content knowledge (both disciplinary and pedagogical). Of the projects measuring teacher outcomes, only four identified the specific instruments used to assess these variables (see below). Some instruments measure multiple constructs, for example, instructional practices, social aspects of the classroom, emotional support exhibited by the teacher, and teacher-student interactions.

Instruments Measuring Teacher Outcomes in DR K-12 Gaming Projects:

Early Mathematics Classroom Observation (EMCO)
Mathematical Knowledge for Teaching (MKT)
Principles of Scientific Inquiry-Teacher (PSI-T)
Reformed Teacher Observation Protocol (RTOP)
Stages of Concern Questionnaire (SoCQ)
Technology Use in Science Instruction (TUSI)

[13] For one project, there was insufficient information to determine the outcome(s) assessed.

Table 9: Teacher Outcomes Assessed

	Number (N=15)	Percentage
Attitudes/Beliefs	11	73
Classroom practices	8	53
Pedagogical content knowledge (PCK)	3	20
STEM content knowledge	3	20

Projects can assess multiple teacher outcomes.

Measuring Teacher Outcomes: **Cyber-enabled Learning: Digital Natives in Integrated Scientific Inquiry Classrooms**
This project investigated the professional development (PD) needed to make teachers comfortable teaching with the kinds of multi-user simulations and communication technologies that students use. The key technological resource used in the project was the Opensimulator 3D application Server (OpenSim), an open source, modular, expandable platform used to create simulated 3D spaces with customizable terrain, weather and physics. A comprehensive PD program of over 240 hours, along with follow-up, was used to determine how teachers could be supported to use information and communication technology tools effectively in classroom instruction to create meaningful learning experiences for students. The project measured various teacher domains including teacher attitudes/beliefs, classroom instruction, and pedagogical content knowledge. The PD related outcomes were measured using two instruments – the RTOP and Technology Use in Science Instruction (TUSI).

3.5.3 Analysis Techniques

With respect to the quantitative methods and techniques employed for data analyses in these projects, 79% used various statistical techniques to analyze survey and assessment data. Statistical modeling techniques include ANOVAs, ANCOVAs, multilevel modeling (MLM), structural equation modeling (SEM) and hierarchical linear modeling (HLM). Projects in the gaming portfolio also engaged techniques such as educational data mining, principal components analysis, and epistemic network analysis to construct meaning from complex game data.

Table 10: Data Analysis Techniques

	Number (N=33)*	Percentage
Statistical models (e.g., HLM, MLM, ANOVA)	26	79
Data mining	2	6
Bayesian networks	1	3
Evidence-centered design	1	3
Epistemic network analysis	1	3

Projects can utilize multiple analysis techniques.
*For four projects, there was insufficient information to identify the data analysis technique(s).

There has been a recent shift among education researchers to go beyond demonstrating significant gains on achievement test performance to understanding how to better support learning for different kinds of learners. In their report, the NRC committee highlighted the need for research on effective assessment of student learning and its use to impact learning processes.[14] They discussed how achieving the potential of simulations and games for assessment and learning would require research and development in all areas of assessment: development, implementation, and evaluation. Particularly, they emphasized the need for an evidence-centered design (ECD) approach to the development of assessments of learning through games and simulations. The ECD[15] approach involves a process in which the game-designers articulate at the outset, the competencies to be measured, the evidence that would constitute that a learner possesses those competencies, and the tasks that can be used to draw that evidence. It is worth noting that only one project, *Change Thinking for Global Science* (described below), out of the 33 projects proposed to use the ECD approach to assessment development.

Evidence-centered Design Approach: **Change Thinking for Global Science: Fostering and Evaluating Inquiry Thinking about the Ecological Impacts of Climate Change**
This project aimed to provide clear empirical information (e.g., growth spurts, growth plateaus, achievement) associated with middle and high school students' learning of complex and dynamic science related to global climate change. In addition to creating learning progressions, curricular units, and assessment instruments, the project developed and evaluated ecological simulation and modeling resources to accompany the curricular units. Their assessment design followed principles of evidence-centered design towards the creation of pretests, posttests, and embedded assessments calibrated on the same scale. Pre- and posttests were designed to evaluate students' content and inquiry reasoning over a range of complexities and contexts. Additionally, Item Response Theory (IRT) was used to create graded response models to investigate scale properties and to score student pre- and posttests in the respective measures.

3.6 Sustainability and Scalability

The research agenda proposed by the NRC committee emphasizes the need for better understandings of design features that support uptake in the marketplace, partnerships that support innovations in science education using games, and strategies for disseminating information on the quality and effectiveness of games and simulations. This section describes the ways in which gaming projects in the DR K-12 portfolio approach dissemination and sustainability. Although almost all of the projects included in this study (31) identified a plan for dissemination in the documents reviewed, the level of detail related to that plan varied, as shown in Table 11. Thirty-one projects identified vehicles for dissemination, which are described in Table 12.

[14] National Research Council. (2011). *Learning science through computer games and simulations. Committee on Science Learning: Computer Games, Simulations, and Education.* M. A. Honey & M L. Hilton (Eds.), Board on Science Education, Division of Behavioral and Social Sciences and Education. Washington, DC.
[15] U.S. Department of Education, Office of Educational Technology, Expanding Evidence Approaches for Learning in a Digital World, Washington, DC, 2013.

Table 11: Strategies for Dissemination and Sustainability

	Number (N=31)	Percentage
Identified what will be disseminated (ideas and products)	29	94
Identified dissemination partners (e.g., networks and associations, opinion leaders)	23	72
Identified potential adopter or end user	22	71
Included potential adopter or end user input in design/development/research	14	45
Addressed strategies for sustainability after the grant	5	16

Table 12: Dissemination Vehicles

	Number (N=31)	Percentage
Presentations/Poster sessions	28	90
Journal articles	27	87
Academic journals	*16*	*52*
Practitioner journals	*10*	*32*
Journals not specified	*9*	*29*
Websites	22	71
Professional networks	10	32
Workshops	10	32
Newsletters	7	23
Commercial products or publications	5	16
CDs/DVDs	4	13
Popular media	3	10
Reports (not articles or books)	3	10
Social media	3	10
Blogs	2	6
Books/Book chapters	1	3
Webinars	1	3
White or working papers	1	3

Projects can disseminate using multiple vehicles.

4. Summary

This report describes the characteristics of a subset of projects within the DR K-12 portfolio that included a gaming or simulation component. It draws on data from 33 funded projects. The summary below addresses a few of the key research questions outlined at the beginning of the report.

What populations are these projects targeting and how are they distributed across disciplines and contexts?

The gaming portfolio included projects working in pre-k through high school, with most projects working at the elementary, middle, and high school levels (18, 66, and 39% respectively). Seventy-nine percent address science topics and 21% focus on math. Thirty-one of the overall 33 projects are involved with the studies in the classroom and four of them are situated within informal contexts.

What types of educational resources were being developed and researched?

Projects in the DR K-12 gaming portfolio were developing and researching a wide variety of resources. Almost all of the projects developed products targeting students, and more than half developed resources for teachers. Slightly more than one third of the projects were designing student assessments as their products.

What are the teacher and student outcomes measured within these projects?

Both student and teacher outcomes were investigated in the research conducted across DR K-12 gaming projects. Eighty nine percent of the projects in the portfolio were researching student outcomes, nearly all of them focused on student achievement and performance, and 45% of the projects were researching teacher outcomes, with the majority looking at teacher attitudes and beliefs about their practice.

What are the prevalent methodologies and data collection techniques?

In the DR K-12 gaming portfolio, interviews (76%) and observations (67%) were common qualitative data sources while assessments and tests (73%) formed the major source of the quantitative data, followed by computer usage data (48%). A majority of projects used a mixed methods research design. Seventy-nine percent of the projects conducted research using various statistical techniques. Two projects employed data mining techniques for their data analysis, one of which used the evidence-centered design framework.

What strategies are projects using to disseminate and sustain their ideas and products?

Most projects in the DR K-12 gaming portfolio (97%) provided some level of information on their plans for dissemination, while only 16% addressed strategies for sustainability in the materials reviewed. Projects are using a variety of vehicles to disseminate their products and ideas, with the most common being presentations/posters (90%), journal articles (87%), and websites (71%).

5. Appendix: Summaries of DR K-12 Gaming Projects

Summaries are organized by the last name of the PI, which is followed by the NSF award number, project title, and a brief description.[16]

Asbell-Clarke – 1119144
Leveling Up: Supporting and Measuring High School STEM Knowledge Building in Social Digital Games
CADRE Project Profile | NSF Project Summary
This project designs, develops and tests a digital gaming environment for high school students that fosters and measures science learning within alternate reality games about saving Earth's ecosystems. Players work together to solve scientific challenges using a broad range of tools including a centralized web-based gaming site and social networking tools, along with handheld smart-phones, and an avatar-based massively multiplayer online environment. The game requires players to contribute to a scientific knowledge building community.

Asbell-Clarke – 1134919
Arcadia: The Next Generation – Transforming STEM Learning through Transmedia Games
CADRE Project Profile | NSF Project Summary
This project studies the design features of an experimental gaming environment called Arcadia: The Next Generation. Researchers are working with a group of formal and informal educators to study the connections between scientific inquiry in Arcadia and STEM learning. The project provides a dynamic and evolving place where gamers, educators, parents, and citizen scientists can come together to share, rate, and build knowledge through a variety of fun science inquiry games.

Asbell-Clarke – 1252709
FUN: A Finland US Network for Engagement and STEM Learning in Games
CADRE Project Profile | NSF Project Summary
As part of a SAVI, researchers from the U.S. and from Finland are collaborating on investigating the relationships between engagement and learning in STEM transmedia games. The project involves two intensive, five-day workshops to identify new measurement instruments to be integrated into each other's research and development work. The major research question is: To what degree learners in the two cultures respond similarly or differently to the STEM learning games?

Bulgren – 1019842
The Evidence Games: Collaborative Games Engaging Middle School Students in the Evaluation of Scientific Evidence
CADRE Project Profile | NSF Project Summary
This project develops a series of interactive on-line games and investigates the effect these games have on increasing middle school science students' and teachers' knowledge and skills of scientific argumentation. There are four areas of argumentation addressed by the games: (1) understanding a claim, (2) judging the evidence about a claim based on type and quality (objectivity, reliability or validity), (3) analyzing the reasoning applied to the claim, and (4) evaluating the claim.

[16] The projects described are at varying stages of completion, but for convenience, all summaries are written in present tense.

Campbell – 1020086
Collaborative Research: Cyber-enabled Learning: Digital Natives in Integrated Scientific Inquiry Classrooms
CADRE Project Profile | NSF Project Summary
This project explores the potential of information and communications technologies (ICT) as cognitive tools for engaging students in scientific inquiry and for enhancing teacher learning. A comprehensive professional development program of over 240 hours, along with follow-up is used to determine how teachers can be supported to use ICT tools effectively in classroom instruction to create meaningful learning experiences for students, reduce the gap between formal and informal learning, and improve student learning outcomes.

Clark – 0822370
Scaffolding Understanding by Redesigning Games for Education (SURGE)
CADRE Project Profile | NSF Project Summary
This project is focusing on the redesign of popular commercial video games to support students' understanding of Newtonian mechanics. In support of this goal, SURGE develops and implements design principles for game-based learning environments, integrating research on conceptual change, cognitive processing-based design, and socio-cognitive scripting. These enhanced games bridge the gap between student learning in non-formal game environments and the formalized knowledge structures learned in school by leveraging and integrating the strengths of each.

Clark – 1119290
Enhancing Games with Assessment and Metacognitive Emphases (EGAME)
CADRE Project Profile | NSF Project Summary
This development and research project designs, develops, and tests a digital game-based learning environment for supporting, assessing and analyzing middle school students' conceptual knowledge in learning physics, specifically Newtonian mechanics. This research integrates work from prior findings to develop a new methodology to engage students in deep learning while diagnosing and scaffolding the learning of Newtonian mechanics.

Dede – 1118530
EcoMobile: Blended Real and Virtual Immersive Experiences for Learning Complex Causality and Ecosystems Science
CADRE Project Profile | NSF Project Summary
Researchers are studying whether middle school instruction about ecosystem science can be made more engaging and effective by combining immersion experiences in virtual ecosystems with immersion experiences in real ecosystems infused with virtual resources. Project personnel are developing a set of learning resources for deployment by mobile broadband devices that provide students with virtual access to information and simulations while working in the field.

Dunleavy – 0822302
Radford Outdoor Augmented Reality (ROAR) Project: Immersive Participatory Augmented Reality Simulations for Teaching and Learning Science
CADRE Project Profile | NSF Project Summary
This project anticipates the needs of learners in 10 years by developing and testing two learning simulations that are immersive, interactive, and participatory and use augmented reality in the outdoors. Students work in teams to investigate phenomena and solve problems in a gaming environment using wireless handheld GPS units. Using a design-based, mixed-methods approach, the researchers examine the relationships among augmented reality, learning in science, socio-emotional outcomes, and the demographic characteristics of rural, underserved students.

Enyedy – 0733218
Semiotic Pivots and Activity Spaces for Elementary Science
CADRE Project Profile | NSF Project Summary
This project employs sensing technologies to help transform students' physical actions during play into a set of symbolic (computer) representations in a physics simulation and to engage the children in a developmentally appropriate and powerful form of scientific modeling. The students are in grades K–1 at UCLA's elementary school, and the intervention is based on the existing content unit on Force and Motion.

Evans – 1118571
Gateways to Algebraic Motivation, Engagement and Success (GAMES): Supporting and Assessing Fraction Proficiency with Game-Based, Mobile Applications and Devices
CADRE Project Profile | NSF Project Summary
This project is designing digital games for middle school students that will help them prepare for success in Algebra. The games are intended to help students gain a deep understanding of measurement and fraction concepts that are critical as they begin to learn algebra. The project studies students' development of fraction concepts, their engagement in the tasks, and the use of hand-held devices as a useful platform for games.

Finzer – 0918735
Data Games: Tools and Materials for Learning Data Modeling
CADRE Project Profile | NSF Project Summary
The Data Games project is developing software and curriculum materials in which data generated by students playing computer games form the raw material for mathematics classroom activities. Students play a short video game, analyze the game data, develop improved strategies, and test their strategies in another round of the game.

Hacker – 0821965
Simulation and Modeling in Technology Education (SMTE)
CADRE Project Profile | NSF Project Summary
This project develops and researches the academic potential of a hybrid instructional model that infuses computer simulations, modeling, and educational gaming into middle school technology education programs. These prototypical materials use 3-D simulations and educational gaming to support students' learning of STEM content and skills through developing solutions to design challenges.

Horwitz – 0822213
Evolution Readiness: A Modeling Approach
CADRE Project Profile | NSF Project Summary
This project uses computer-based models of interacting organisms and their environments to support a learning progression leading to an appreciation of the theory of evolution and evidence that supports it. The project has created a research-based curriculum centered on progressively complex models that exhibit emergent behavior. The project will help improve the teaching of complex scientific topics and provide a reliable means of directly assessing students' conceptual understanding and inquiry skills.

Horwitz – 1238625
GeniVille: Exploring the Intersection of School and Social Media
CADRE Project Profile | NSF Project Summary
This project examines the design principles by which computer-based science learning experiences for students designed for classroom use can be integrated into virtual worlds that leverage students' learning of science in an informal and collaborative online environment. GeniVille is the integration of Geniverse, an education based game that develops middle school students' understanding of genetics with Whyville,

an educational virtual word in which students can engage in a wide variety of science activities and games.

Johnson-Glenberg – 1020367
Embodied STEM Learning Across Technology-based Learning Environments
CADRE Project Profile | NSF Project Summary
This project conducts interdisciplinary research to advance understanding of embodied learning as it applies to STEM topics across a range of current technology-based learning environments (e.g., desktop simulations, interactive whiteboards, and 3D interactive environments). The project has two central research questions: How are student knowledge gains impacted by the degree of embodied learning and to what extent do the affordances of different technology-based learning environments constrain or support embodied learning for STEM topics?

Kafai – 1238172
Transforming STEM Competitions into Collaboratives: Developing eCrafting Collabs for Learning with Electronic Textiles
CADRE Project Profile | NSF Project Summary
This project supports the development of technological fluency and understanding of STEM concepts through the implementation of design collaboratives that use eCrafting Collabs as the medium within which to work with middle and high school students, parents and the community. They examine how youth at ages 10-16 and families in schools, clubs, museums and community groups learn together how to create e-textile artifacts that incorporate embedded computers, sensors and actuators.

Ketelhut – 0822308
SAVE Science: Situated Assessment using Virtual Environments for Science Content and Inquiry
CADRE Project Profile | NSF Project Summary
The SAVE Science project is creating an innovative system using immersive virtual environments for evaluating learning in science, consistent with research- and policy-based recommendations for science learning focused around the big ideas of science content and inquiry for middle school years. Motivation for this comes not only from best practices as outlined in the National Science Education Standards and AAAS' Project 2061, but also from the declining interest and confidence of today's student in science.

Klopfer – 1019228
DRK12-Biograph: Graphical Programming for Constructing Complex Systems Understanding in Biology
CADRE Project Profile | NSF Project Summary
This project investigates how complex systems concepts supported by innovative curricular resources, technology applications and a comprehensive research and development structure can assist student learning in the domain of biology by providing a unifying theme across scales of time and space. The project seeks to address four areas of critical need in STEM education: biological sciences, complex systems, computational modeling, and equal access for all.

Kulm – 1020132
Preservice Teachers Knowledge for Teaching Algebra for Equity in the Middle Grades
CADRE Project Profile | NSF Project Summary
This project is using Second Life and other technology to structure carefully planned learning experiences for pre-service teachers. Virtual technologies are used to provide pre-service teachers practice in presenting and assessing problem solving activities in a virtual classroom with diverse populations. Researchers hypothesize that technology enriched strategies have the potential to deepen pre-service teachers' understanding and effectiveness in teaching emerging algebra concepts to diverse student populations.

Lester – 0822200
Developing Science Problem-Solving Skills and Engagement Through Intelligent Game-Based Learning Environments
CADRE Project Profile | NSF Project Summary
The project draws upon intelligent tutoring and narrative-centered learning technologies to produce a suite of intelligent game-based learning environments for upper elementary school science students. The games explicitly model student knowledge and problem solving and dynamically customize feedback, advice, and explanation as appropriate. Unlike its predecessor, the platform is multi-user so it can support collaboration; offer dynamically generated feedback, advice, and explanation; and provide a pedagogical dashboard that generates student progress reports.

Lester – 1020229
The Leonardo Project: An Intelligent Cyberlearning System for Interactive Scientific Modeling in Elementary Science Education
CADRE Project Profile | NSF Project Summary
This project designs and implements technologies that combine artificial intelligence in the form of intelligent tutoring systems with multimedia interfaces (i.e., an electronic science notebook and virtual labs) to support children in grades 4-5 learning science. The students use LEONARDO's intelligent virtual science notebooks to create and experiment with interactive models of physical phenomena.

Lewis Presser – 1119118
Next Generation Preschool Math
CADRE Project Profile | NSF Project Summary
This project is developing, testing, and refining a curriculum supplement (a hands-on technology) that (1) promotes children's' understanding of number (counting, comparing, and ordering) and fair sharing (equipartitioning); (2) uses interactive media on an emerging handheld platform (touch screen tablets), integrating new multi-touch activities with existing hands-on activities; (3) enhances opportunities for learning with interactive media through shared use with adult guides and peers; and (4) provides professional and technical support materials for preschool educators.

Millar – 1119383
CyberSTEM: Making Discovery Visible through Digital Games
CADRE Project Profile | NSF Project Summary
CyberSTEM is developing and testing an integrated digital gaming network that spans homes, schools, and informal learning settings, offering a suite of digital games based on cutting-edge discoveries in the life sciences. The project asks if participation in CyberSTEM leads to increased learning in six areas: interest in science, conceptual knowledge, scientific reasoning, reflection on knowing, participating in science, and identifying as a scientist. The target audience includes youth in grades 6-9.

Mokros – 0733264
The GENIQUEST (GENomics Inquiry through QUantitative Trait Loci Exploration with SAIL Technology): Bringing STEM Data to High School Classrooms
CADRE Project Profile | NSF Project Summary
This project is developing and testing a website, software application, and supplemental instructional materials that use publicly accessible genomics data to foster scientific inquiry among high schools students. Outcomes for students and teachers include developing knowledge, skills, and understandings related to genetic inheritance; data investigation and analysis; the process of scientific inquiry; and collaboration.

Pedersen – 0628264
Engaging Middle School Students in Student-directed Inquiry through Virtual Environments for Learning
CADRE Project Profile | NSF Project Summary
This project is developing five web-based modules for middle school science that engage students in student-directed inquiry and provide teachers with professional development in facilitating this inquiry. These modules immerse students in virtual environments for learning (VELs) where they take on the role of scientists engaged in a complex task. The virtual settings presented in the VELs support students in designing and carrying out their own investigations.

Perkins – 1020362
Expanding PhET Interactive Science Simulations to Grades 4-8: A Research-based Approach
CADRE Project Profile | NSF Project Summary
Colorado's PhET project and Stanford's AAALab are developing and studying learning from interactive simulations designed for middle school science classrooms. Products include 35 interactive sims with related support materials freely available from the PhET website; new technologies to collect real-time data on student use of sims; and guidelines for the development and use of sims for this age population. The team will also publish research on how students learn from sims.

Quellmalz – 0733345
Calipers II: Using Simulations to Assess Complex Science Learning
CADRE Project Profile | NSF Project Summary
This project is pioneering simulation-based assessments of model-based science learning and inquiry practices for middle school physical and life science systems. The assessment suites include curriculum-embedded, formative assessments that provide immediate, individualized feedback and graduated coaching with supporting reflection activities as well as summative end-of-unit benchmark assessments. The project is documenting the instructional benefits, feasibility, utility, and technical quality of the assessments with over 7,000 students and 80 teachers in four states.

Quellmalz – 1221614
SimScientists Assessments: Physical Science Links
CADRE Project Profile | NSF Project Summary
The goal of this project is to develop and validate a middle school physical science assessment strand composed of four suites of simulation-based assessments for integrating into balanced (use of multiple measures), large-scale accountability science testing systems. It builds on the design templates, technical infrastructure, and evidence of the technical quality, feasibility, and instructional utility of the NSF-funded Calipers II project. The evaluation plan addresses both formative and summative aspects.

Reichsman – 0918642
The NextBio Project: A Student Collaboratory for Biology Cyberlearning
CADRE Project Profile | NSF Project Summary
This project addresses biology teachers and students at the high school level, responding to the exponential increases occurring in biology knowledge today and the need for students to understand the experimental basis behind biology concepts. The project studies the feasibility of engaging students in an environment where they can learn firsthand how science knowledge develops in the fields of bioinformatics and DNA science by performing collaborative, simulated experiments to solve open-ended problems.

Shaffer – 0918409
AutoMentor: Virtual Mentoring and Assessment in Computer Games for STEM Learning
CADRE Project Profile | NSF Project Summary
This project is developing a system for producing automated professional mentoring while students play computer games based on STEM professions. The project explores a specific hypothesis about STEM mentoring: A sociocultural model as the basis of an automated tutoring system can provide a computational model of participation in a community of practice, which produces effective professional feedback from non-player characters in a STEM learning game.

Songer – 0918590
Change Thinking for Global Science: Fostering and Evaluating Inquiry Thinking About the Ecological Impacts of Climate Change
CADRE Project Profile | NSF Project Summary
This project draws from the expertise of a fully collaborative educator-scientist team to create learning progressions, curricular units and assessment instruments towards large scale research on the teaching and learning of climate change and impacts by 7-12th graders in primarily under-resourced schools. Products include eight week curricular units, IPCC-compliant simplified future scenarios, an online interface with guided predictive distribution modeling, and research results.

Squire – 0746348
Scientific Role-Playing Games for 21st-Century Citizenship
CADRE Project Profile | NSF Project Summary
This project investigates the potential of online role-playing games for scientific literacy through the iterative design and research of Saving Lake Wingra, an online role-playing game around a controversial development project in an urban area. Saving Lake Wingra positions players as ecologists, department of natural resources officials, or journalists investigating a rash of health problems at a local lake, and then creating and debating solutions.

Squire – 1258679
CyberSTEM: Making Discovery Visible Through Digital Games Conference
CADRE Project Profile | NSF Project Summary
This workshop addresses the need to connect a range of experts involved in game development and research to develop and disseminate best practices. The workshop will also establish a network hub where educators and developers can find tools for implementing game-based curricula. The project will bring together approximately 100 early contributors, including researchers, teachers, game designers and publishers, to inform the next phases of research, development, and production in the field of games and learning.

Wiburg – 0918794
Math Snacks: Addressing Gaps in Conceptual Mathematics Understanding with Innovative Media
CADRE Project Profile | NSF Project Summary
This project is developing and evaluating effectiveness of 15 - 20 short computer mediated animations and games that are designed to: (1) increase students' conceptual understanding in especially problematic topics of middle grades mathematics; and (2) increase students' mathematics process skills with a focus on capabilities to think and talk mathematically.

Xie – 0918449
Enhancing Engineering Education with Computational Thinking
CADRE Project Profile | NSF Project Summary
This project investigates the educational value of computer technologies for learning engineering. The project engages high school students to design, build, and evaluate an energy-efficient model house with the aid of computer simulation and design tools.