Virtual World Problem-centered Challenge Evaluation

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Abstract: This paper describes the two-year implementation evaluation of a problem-based engineering design challenge held in a virtual world. The team-based challenge was designed and facilitated by an aerospace research and education institute for middle and high school student competitors in both classrooms and after-school programs across the U.S. An independent evaluation team examined participant experiences to consider the strengths of the challenge, as well as recommendations to enhance the effectiveness and efficiency of future challenges. Overall, the evaluation team found that the problem-centered design challenge offered the student competitors a unique and valuable opportunity to engage in real-life science and engineering problems with the support of advanced science, technology, and engineering resources and college-level and professional experts. Recommendations centered on needed adjustments to achieve and prepare for growth, support for teams, assessment refinement, and collaboration and other technology enhancements.

Keywords: Problem-centered instruction, virtual worlds

Over the past decade, educators have explored the learning opportunities in online three-dimensional (3D) virtual worlds. Due in a large part to the advent of the popular virtual world Second Life, the 2007 edition of the Horizon Report predicted virtual worlds would have a prominent role in the technology used to support learning, (The New Media Consortium and EDUCAUSE Learning Initiative, 2007). In that same year, others made bold predictions that 80% of active Internet users would participate in virtual worlds (Gartner, 2007). A recent search for the term *virtual world(s)* within the text of articles indexed in the ERIC database returned 262 results since 1994 from peer reviewed academic journals, suggesting a high level of interest from researchers, as well.

This paper summarizes a two year evaluation of the implementation of a team-based problem-centered design challenge in which small groups of middle and high-school students worked collaboratively as engineers and scientists to solve authentic engineering problems in both classroom and virtual world settings. The challenge was designed, developed, and implemented by an aerospace research and education institute. A stated objective of the challenge was to offer students the opportunity to engage in authentic problem-solving processes essential to careers in science, technology, engineering, and math (STEM).

The implementation evaluation, conducted by independent evaluators neither affiliated with the aerospace institute nor responsible for the design or implementation of the program, examined both the 2010-11 inaugural year of the engineering design challenge, as well as the subsequent 2011-12 implementation that incorporated the evaluators' recommendations from the 2010-11 evaluation. Conducted in two phases that followed a standard academic calendar, Phase 1 of each challenge was implemented in the fall semester, while Phase 2 was conducted in the spring term. Phase 1 offered teachers and students in both traditional classrooms and after-school programs a free inquiry-based STEM education project in which students worked in teams to design and build a prototype solution to meet the design specifications of the challenge using a recommended eight-step design process. Students were given the opportunity to extend their participation in the challenge by submitting their design prototypes for possible selection to Phase 2 of the challenge that was set in an online virtual world based on the ActiveWorlds platform (http://www.activeworlds.com/). As part of a competitive selection process at the beginning of Phase 2, teams of students were chosen by college engineering students to continue their design development under the mentorship and guidance of the college student as the team's leader. At the end of Phase 2, finalist teams with the best designs were selected to present their projects in a design assessment process that determined the winning team for each challenge.

This paper begins by examining research conducted to date on virtual worlds in education, as well as theory and research on both problem-centered and group-based instruction. This review of literature is followed by a summary of the implementation evaluation, starting with a description of the evaluation methods employed and concluding with the analysis, discussion, and conclusions of the evaluation.

Literature Review

A virtual learning environment is a multimedia online learning experience supported by virtual reality technologies that typically include the following features, (a) two or three-dimensional spatial representations, (b) multiple channels of audio, visual, and text-based channels for synchronous interaction, and (c) user immersion into the virtual environment (Mikropoulos & Natsis, 2011; Selverian & Hwang, 2003). Recent iterations of these virtual reality technologies, including the popular ActiveWorlds and Second Life applications, place users in 3D online virtual worlds with self-representations, or avatars, that allow participants to move and interact with each other and the environment (Dickey, 2005; Hew & Cheung, 2010; Wang & Lockee, 2010). The following highlights the theory and research associated with the use of virtual worlds in education, as well as relevant theory and research in problem-centered and group-based instruction.

Virtual Worlds in Education

Some suggest virtual worlds offer educators another option to support distance education (Wang & Lockee, 2010), including remote or simulation laboratories (Balamuralithara & Woods, 2009). However, many are not interested in merely replicating traditional classroom experiences, but also hope to improve the learning process by leveraging the media characteristics, or affordances, of the newest technologies to foster immersive online learning environments (Choi & Baek, 2011; Dalgarno & Lee, 2010; Dickey, 2005). As technology has evolved, educators have explored the potential of virtual worlds for the development of realistic environments for practice, the creation of 3D educational artifacts, and immersion into a virtual space that would not otherwise be accessible (Salmon, 2009). However, these same enhancements are a barrier to some learners who do not have the needed high speed Internet or technology to support access (Kirriemuir, 2010; Twining, 2010).

Research reviews on the use of virtual worlds in education suggest a lack of empirical experimental research in favor of descriptive exploratory studies that have relied on qualitative data collection, such as participant questionnaires, interviews, and observations, to examine how the virtual worlds were used (Hew & Cheung, 2010; Jarmon, Traphagan, Mayrath, & Trivedi, 2009; Wang & Lockee, 2010). In addition, research reviews suggest the majority of research has been conducted in a college setting where educators are using the virtual worlds as not only online communication spaces, but also as venues that facilitate simulations of a 3D space allowing the perception of immersion in the virtual environment through the user's avatar, as well as experiential spaces that encourage users to learn by doing (Hew & Cheung, 2010). However, while it is compelling to consider the learner interaction options afforded by the ever expanding roster of virtual reality technologies, research has long suggested no significant difference in learning outcomes based on the media used to facilitate instruction (Bernard, Abrami, Yiping Lou, & Borokhovski, 2004; Clark, 1983, 1994, 2001). These findings are supported by a recent review of research that offered little conclusive evidence of specific learning benefits from the 3D aspects of these virtual environments (Dalgarno & Lee, 2010).

Problem-centered Instruction

Following a review of instructional design theories to identify common prescriptive principles, Merrill (2002) identified the use of a *problem-centered* approach as a first principle of instruction. Problem-centered approaches are forwarded from both cognitive (Morrison & Lowther, 2010) and constructivist (Jonassen, 1999) perspectives, and are in contrast to *topic-centered* instruction in which task components are taught in isolation from a real-world problem. Problems represent the gap between a desired state and a current state, while problem solving is the process of bridging the gap that some argue is the only legitimate goal of education (Jonassen, 2011). Of the range of problem types, design problems often have no right or wrong answer (rather better or worse answers), and are considered to be of the most complex and ill-structured types to solve (Jonassen, 2000).

While reviews of problem-centered instruction offer various descriptions of methods, those described as *problem-based* approaches tend to (a) focus learning in small student groups, (b) a tutor is present as a facilitator, (c) authentic problems are presented before study of the topic, (d) the to-be-learned knowledge and skills are encountered within the problem, and (e) new information acquisition is self-directed (Gijbels, Dochy, Van den Bossche, & Segers, 2005)

Research findings on problem-based instructional methods are mixed with reviews of research suggesting limited or negative effects for recall of factual or conceptual knowledge, but significant positive effects on applications of skills and principles (Dochy, Segers, Van den Bossche, & Gijbels, 2003; Hattie, 2009). However, meta-analyses of problem-based approaches also suggest the variation in effects between knowledge and skills acquisition are significantly influenced by the assessment methods, and that the better the assessment instrument evaluates the learners' knowledge and skill application, the larger the positive effect of the problem-based approach (Dochy et al., 2003; Gijbels et al., 2005). Supporting a foundational assumption of instructional design that the conditions of learning should match the learning outcomes and the form of assessment, Jonassen (2011) argues that adequate assessment of a learner's ability to solve problems must extend beyond the learner's ability to recall information on a test, and suggests a four-pronged assessment approach that includes assessment of the learner's (a) *problem schemas*, including classifying the characteristics of the problem and the problem-solving process, (b) *problem-solving performance*, including the learner's constructed response or product compared to a rubric of desired performance, (c) *cognitive skills* required to solve the problem, including the learner's evaluation of the causal relationships among problem elements, and (d) *ability to construct arguments* in support of their solution.

Group-based Instruction

Two meta-analyses of small group, whole class, and individual learning strategies suggested that under certain conditions, instructional strategies involving small groups (two to four students) resulted in a small, but significantly positive effect on individual achievement over either whole class (Lou, Abrami, & Spence, 2000) or individual learning approaches (Lou, Abrami, & d' Apollonia, 2001). Compared to whole class instruction, the achievement effects of small group instruction were significantly larger for students of all ability levels when (a) teachers were trained in small group instruction (b) grouping was based on ability and group cohesiveness, and (c) cooperative learning (which promotes both interdependence and individual accountability within carefully designed activities) was used as the method of instruction (Lou et al., 2000). Similarly, when learning with computer technology, the effects of small group learning over individual learning with regard to individual achievement are significantly enhanced when (a) students had group work experience, (b) cooperative learning strategies were employed, (c) group size was small (pairs of students), (d) the subject was in the social sciences (versus math, science, or language arts), and (e) students were either low or high ability who appeared to benefit from receiving and giving support (Lou et al., 2001). However, even when superior group products or task outcomes were produced, no significant positive effects on individual achievement resulted when the group work (a) used no cooperative learning strategies, (b) groups were large, (c) group work used unstructured exploratory environments, or (d) the computer-based programs provided students with elaborate feedback (Lou et al., 2001).

While many forms of group-based learning exist, cooperative learning refers to a instructional approach in which learners work together in small groups and may be assessed based on the group's performance (Slavin, 1980). Studies conducted on cooperative learning suggests it is effective approach (Hattie, 2009) and often results in superior achievement gains compared to traditional classroom conditions, particularly when group goals and individual accountability are included (Slavin, 1983, 1991). Importantly, research has found that cooperative group-based learning that does not include group rewards for individual learning is no more effective in terms of learner achievement than studying independently (Slavin, 1983). Overall, these finding suggested that when working in groups, not all students may learn equally well and group task performance was not positively related to individual learning achievement in large groups with no designed cooperative strategies (Lou et al., 2001) .

Evaluation Purpose and Questions

As suggested by theory and research, while descriptive studies suggest instruction in virtual worlds encourages learning by doing, research has long suggested no significant difference in learning achievement based on the media used to facilitate instruction (Clark, 1983, 1994, 2001). Further, the results of both problem-centered and group-based instruction suggest the strategies employed affect the learning outcomes. Therefore, the purpose of this implementation evaluation was to provide decision makers with a description of what happened during the challenge, as well as an examination of the efficacy and efficiency of the challenge as a group-based and problem-centered experience. The evaluation attempted to answer the following questions. What were participation levels during the challenge implementations? Were sufficient resources and support offered to participants? What was the nature of the participants' experiences within the challenge? What was the efficiency and efficacy of the learner assessment processes?

Method

This two-year evaluation examined the implementation of a small-group problem-centered design challenge that was designed, developed, and implemented by an aerospace research and education institute for teams of middle and high-school student competitors participating in both face-to-face and virtual world settings. Independent evaluators, whose experience centered on advanced and online learning environments for education and training, conducted the evaluation. The evaluation examined two complete implementations of the challenge occurring between September 2010 and April 2012 and included an expert review of instructional materials, participant perception surveys and interviews, direct observation, and a review of challenge outcome and activity data. The following describes the participant characteristics, the evaluation design, and the document collection and analysis procedures used in this evaluation.

Participant Characteristics

During Phase 1 of the 2010-11 implementation, 693 people registered on the challenge website. Registrant groups included college students (n = 94), college professors (n = 8), high-school teachers (n = 123), high-school students (n = 378), and others (n = 90). By the end of Phase 1 of the 2010-11 design challenge, teams of four to five high-school students prepared 24 team-based submissions of potential solutions to an authentic engineering design problem under the guidance of their middle and high-school teachers or after-school coaches. During the 2011-12 implementation, the challenge also included middle-school student competitors and participation increased to over 57 teams submitting their proposed solutions in Phase 1. During each of the implementations, of the potential solutions submitted from teams in Phase 1, only 20 teams were selected to progress to Phase 2 of the challenge that was held in the virtual world. In Phase 2 of the design challenge, the student teams were no longer guided by their teachers or coaches, but were instead supported virtually by (a) challenge facilitators employed by the aerospace institute, (b) 20 college student team leaders who volunteered to mentor one team of four or five students, (c) 15 challenge assessors, including college engineering students and professors who volunteered to assess the work of the teams, and (d) five college student technology specialists who were paid to provide technology support to the teams.

Evaluation Design

The implementation evaluation was an iterative process of information gathering, sharing, analysis, and reporting, along with continuous discussion between the evaluation team and challenge implementers about what worked well and areas requiring revision. The reviewers evaluated the degree to which the instructional presentation, learner practice opportunities in the problem-centered scenario, and embedded guidance and support would affect student outcomes. In addition, the evaluators considered the overall efficiency of the instruction's implementation, including the ease with which participants were able to interact within the instructional environment.

Data Collection and Analysis

The evaluation began with an expert review of the instructional materials prior to the 2010-11 challenge implementation. The challenge evaluations were also based on surveys and interviews with participants, as well as the evaluation team's observations and document reviews from the challenge, including the design assessments of each competing team.

Expert review of materials. For the expert review, the evaluation team reviewed the instructional materials and resources embedded and linked from the challenge website. The virtual world was under development at the time of this pre-implementation review and was not included in the expert review of materials. The reviewers' evaluation focused on the instructional merits (effectiveness and efficiency) of the instruction, as well as the usability of the instructional materials presented to participants. In evaluating the instructional merits of the instruction, the reviewers considered the degree to which the instructional presentation, learner practice opportunities, and embedded guidance (or feedback) may influence student learning. In addition, the evaluators considered the overall efficiency associated with the instruction's implementation. With regard to usability, the evaluators considered the ease with which participants would be able to interact with the instructional environment, including issues of accessibility and user instructions and support.

Surveys and interviews. The purpose of the interviews and surveys was to capture participant perceptions of the challenge. At the conclusion of Phase 1 of each implementation, each school teacher or coach who participated during Phase 1 received a link to an online perception survey. A primary aim of this survey of the teachers and coaches was to understand the teachers' motivations to participate. In addition, all college student team leaders and student competitors were asked to complete an online perception survey at the conclusion of Phase 2 in each challenge implementation. All surveys were developed by the evaluation team with input from the challenge facilitator and focused on the participants' perceptions of the challenge. At the conclusion of the 2010-11 challenge implementation, interviews were conducted with three challenge evaluators who performed team assessments. In addition, frequent informal conversations were held with the challenge facilitator throughout both implementations of the challenge.

Observation and document review. The evaluators had access to both the challenge website and the virtual world. They observed the challenge implementation from the initial orientation sessions prior to the 2010-11 implementation through the final team presentations at the conclusion of the 2011-12 implementation. Observation and document reviews provided information about overall participation and the teams' outcome assessments. In addition, the evaluators reviewed correspondence between the challenge facilitator and the teams, including documents related to both challenge facilitation and team assessment. The challenge facilitator provided the evaluation team with documents related to the assessments, including the scores assigned to the challenge designs and summary comments from the challenge assessors.

Challenge Materials

As problem-centered instruction, the design challenge required the students to solve realistic science and engineering problems that were tied to national standards and focused on the students' STEM skills and knowledge. The instructional content provided teachers and students with a short list of prior knowledge expectations, as well as a roster of standards addressed in the challenge based on the National Science Education Standards, and those of the National Council of Teachers of Mathematics, the International Society for Technology in Education, and the International Technology Education Association. Educators with the motivation to engage their students in the design challenge had a wealth of resources at their disposal from the challenge website. Once registered on the website, educators and students received recommended strategies to approach a design challenge, as well as a host of documents, diagrams, and videos associated with the design problem. Original content on the website focused on the nature and structure of the problems underlying the design challenge and the recommended steps to solve those problems in the design process. However, the problem-centered challenge also required participants to seek out and access subject-matter resource materials as needed by the participants while proceeding through the steps of the design challenge. Through a variety of online tools, including the virtual world, the students tackled the real-world design scenarios using a range of technologies to support their learning. Given the requirement to access and engage in the instruction from the challenge website and virtual world, all participants needed both computer and Internet access, as well as experience using these tools. Therefore, in order to complete the challenge, participants needed to retrieve, review, and appropriately incorporate these crucial resources.

Findings

From an analysis of the data collected, the following describes the two challenge implementations. This description includes the participation levels, the resources and support adequacy, the participant experiences, and the learner assessment processes.

Participation Levels

For the 2010-11 implementation, only 24-teams completed Phase 1, below the desired 60 to 70 teams. In addition, one Phase 1 coach worked with 32 teams as part of an online after-school program. This coach had 14 teams complete Phase 1 and all were selected for Phase 2. Therefore, only 10 of the teams that completed Phase 1 advanced registration were *not* part of this online after-school program. As such, the majority of teachers and coaches who registered on the challenge website were considered *tourists* who arrived at the website to seek information about the challenge and to download available free resources, but who did not actively participate in the challenge as designed. In contrast, during the 2011-12 implementation, over 110 teams registered for Phase 1 with 57 teams submitting their work for consideration in Phase 2.

Resources and Support Adequacy

Website content. Within the post-challenge surveys, 13 teachers and coaches responded in 2010-11 and 12 responded in 2011-12. Teachers and coaches noted the value in the provided content, including the video clips of engineers and information about the design process. Several teachers and coaches added written comments to the surveys indicating that they were able to integrate the project into curriculum and that the challenge aligned to course objectives and standards. Overall, the structure of the challenge offered teachers and coaches a high degree of flexibility to incorporate the design challenge into both classroom and after-school settings, while offering outreach and professional development to educators.

Student competitor support. Student challenge competitors participated in Phase 1 of the challenge under the direction of an adult educator (either their classroom teacher or another adult coach). In Phase 2, college-level participants were recruited to fulfill the roles of team leaders, challenge assessors, and technology specialists. In both the 2010-11 and 2011-12 post-challenge surveys, over 90% of the student competitors viewed the team leaders as responsive and supportive. In addition, when asked to consider the effectiveness of the college team leaders in the challenge to guide the student competitors, one challenge assessor noted that while it was unlikely that any team leader (or challenge assessor, for that matter) would be an expert in the design specifications for the challenge problem, it could be expected that a college-level engineering student would have the necessary research skills to seek out and find the relevant background subject matter. Ultimately, the challenge assessor saw the team leader role as mobilizing, scheduling, making themselves available, and helping the student competitors properly create their virtual world spaces during Phase 2.

Challenge facilitation. In conversations with the evaluation team, the challenge facilitator noted that participants needed information regarding both the subject matter of the design problems and the administration of the challenge, as well as gentle prodding and support once the challenge was under way. While the teachers, coaches, and team leaders had the primary roles of mentoring the student competitors through either Phase 1 or Phase 2 of the challenge, the challenge facilitator acted as the overall challenge implementer during each phase. The challenge facilitator oversaw the teams' progress, offered mentoring suggestions, coordinated with the challenge assessors, facilitated guest speaker presentations, and connected teams to technology specialists. In addition, the challenge utilized a range of new technologies to connect geographically dispersed groups of participants. As such, the challenge facilitation required considerable forethought in terms of participant needs and required support.

The challenge facilitator also noted the need to be "hands on" during the Phase 2 portion of the challenge in order to coordinate the roles of the team leaders, challenge assessors, and technology specialists. Based on observations of the evaluation team, the facilitator role was crucial to the overall success of the challenge. As noted by one of the professors involved in the challenge assessment, those involved in the challenge facilitation did a "killer job" in development and implementation.

Technology support. The five paid college technology specialists were each assigned to four teams during Phase 2 of each challenge. In terms of training, not all technology specialists agreed within the survey that training for this position prepared them for the tasks they performed. One noted, "We all seemed lost … we didn't really know what we should be doing." In other written comments, the specialists indicated that they learned as they went and that the "training process never really stopped." One suggested spending time looking at the problems the students and technology had during this challenge and focusing future training on those types of problems.

In addition, survey responses from the technology specialists suggested that each team used their services used differently. While one specialist reported all that was required of a specialist was "familiarity with tech, free time, and a background with virtual worlds", all specialists felt that handling more than five or six teams would diminish the quality of service provided. Most noted the best part of working with the design teams was seeing the realization of the competitors' hard work. Yet, the specialists noted that a challenge for supporting the teams was the need to clarify periodically the specialist's limited role with the team (for example, to clarify that specialists were unable to help with the design itself). In addition, several noted they spent a lot of time explaining the use of modeling software and various modeling terms to the competitors. One specialist suggested streamlining the model building process by offering or suggesting a set of tools that are easy to use and have the required capabilities for the challenge.

Participant Experiences

Teachers and coaches. A primary purpose of the teachers and coaches survey was to understand why more teachers did not progress further within the challenge. However, only 12 of the 123 teachers and coaches who registered on the website completed at least part of the 2010-11 survey. Not surprisingly, only six of registrants who did not complete Phase 1 completed the survey. Of those, four responded that they utilized the website materials with students, but did not complete Phase 1 challenge requirements, while the other two did not use the materials with students. Of those who did not complete advanced registration, 80% responded that lack of time to devote to the project and lack of student interest were contributing factors, while 60% felt unclear of their role in the challenge.

In both the 2010-11 and 2011-12 surveys, all teachers and coaches who completed the survey agreed that the instructional goals and objectives of the challenge were clearly stated, and agreed that they would recommend the challenge to other teachers. While half of the 2010-11 respondents felt more incentives were needed to proceed to Phase 2, only one respondent in the 2011-12 survey felt more incentives were needed. In both the 2010-11 and 2011-12 surveys, approximately half of the respondents felt that no changes were needed in terms of support, while the others wanted more guidance on how to run Phase 1 and saw a need for additional instructions on the website, tutorials or webinars on how to implement the challenge, and questions and answer sessions.

While nearly 90% of responding teachers and coaches in the 2010-11 survey saw value in the provided content, such as video clips of engineers or information about the design process, only 25% of respondents to the 2011-12 survey listed this content as one of the best components of the challenge. The difference could suggest teachers repeating their participation in the challenge relied less on the provided subject matter content. However, in written comments, one respondent to the 2010-11 survey noted a problem accessing the videos due to system IT lockout at the school. In addition, most survey respondents saw benefit in the opportunity for students to work with college engineering students and engineering professionals, as well as the opportunity to participate with teams in a virtual environment with other students. Several added written comments to the perception surveys indicating that they were able to integrate the project into curriculum and that the challenge aligned to course objectives and standards.

College student team leaders. Of the 16 college team leaders who responded to the 2010-11 end of challenge survey, 80% agreed that they enjoyed working on the challenge. Written comments within this survey of the college student team leaders suggested that virtual team coordination, communication, and technical difficulties caused delays for the teams. However, within the 2011-12 end of challenge survey, only five college team leaders responded, but all agreed that they enjoyed working on the challenge, suggesting implementation improvements in support of the team leaders. Approximately half of the college student team leaders in both the 2010-11and 2011-12 surveys agreed that the team leader role and responsibilities were well defined within the challenge, while over 90% of the team leaders in both surveys agreed that their students learned a lot by participating in the challenge.

Regarding team communication, nearly all of the team leaders who responded to the 2010-11 and 2011-12 surveys reported communicating with the teams using email. Other commonly used communication tools were Google Docs and Skype. Further, email and Skype were frequently identified in the comments as the communication tools that the teams preferred to use. As a sign of the changing times, less than half of the teams in both years reported using phone voice calls.

Student competitors. In both the 2010-11 and 2011-12 post-challenge surveys of the student competitors, every respondent agreed that he or she enjoyed working on the challenge, except one student who expressed frustration working with the team's leader. In addition, surveys, interviews, and observations suggested a high level of participant engagement by most competitors during both challenge implementations. In the student competitors' post-challenge surveys, students noted that the challenge required creativity and challenged their ability to think critically and to adhere to deadlines. Student competitors listed interacting with others interested in engineering, guest speakers, applying engineering design principles to complete a project, gaining experience with 3D modeling, learning about virtual worlds, and learning about efficient collaboration as the most rewarding aspects of the participating in the challenge. Most student competitors agreed that they learned about working in a virtual environment, communicating through online tools, and the engineering design process by participating in the challenge.

Between both the 2010-2011 and the 2011-2012 post-challenge surveys, all but a few student respondents agreed that the challenge staff was responsive and supported the team's work, and written comments noted that support from the technology specialists and the challenge facilitator were especially helpful. Similarly, most student competitors agreed that the team leader was responsive and supportive and they learned a lot in the challenge, including how to work on a team. In questions about collaborating in the virtual space, several student competitors commented that they liked using the virtual world to build and create within their own spaces and that working in the virtual world offered them the chance to meet different people from across the country.

In terms of the least-liked aspects of the challenge, technical difficulties and virtual team communication and collaboration were mentioned. Further, respondents from the first implementation wrote of limitations associated with the creation, movement, orientation, and rendering of objects within the virtual world, while some commented that working in the virtual space "was glitchy", "resource intensive", and "extremely challenging". While most agreed that the technology was responsive and supported the team's work and that the team received the help and support needed to complete the challenge, other student competitors were either neutral or dissatisfied with the help and support received. A review of the written comments suggested a desire for additional support regarding both the use of modeling programs and how to import and display the developed models within the virtual world.

Challenge assessors. Feedback from the challenge assessors during their interviews was generally positive about the challenge and the challenge assessor's role and responsibilities. Overall, they felt those involved in the challenge did a good job in developing and facilitating the challenge. Yet, each offered constructive suggestions for the future, primarily geared toward guiding and supporting the challenge assessors, clarifying the team member expectations and objectives, and structuring the final synchronous presentations for team assessment. Suggestions included bringing the challenge assessors into the project earlier in the challenge. One recommended that the challenge assessors should view the teams' work products early in the timeline, which would offer greater consistency across the challenge. In addition, periodic conference calls among challenge assessors were suggested as a means to raise and answer important and frequently-asked questions.

Learner Assessments

During Phase 1 of the challenge, no formal assessment occurred and the team competitors did not receive formal feedback from challenge facilitators. Instead, only the teams selected to progress to Phase 2 received the college team leader's informal assessment of the design artifacts submitted by the teams at the end of Phase 1. All learner assessment in Phase 2 of the challenge was team based. The primary team assessments that occurred during Phase 2 portion of the challenge included both a first review (mini-assessment) and a final review of the project. The purpose of the first review (mini-assessment) of the teams was to give informal feedback to participants regarding each team's progress in the challenge based on a three-tiered rating scale (well developed, developed, or not developed). The ratings were based on the extent to which the team space was formalized and personalized, the extent to which aspects of the problem were addressed, how thoroughly the documentation was presented, how clearly the documentation supported the proposed solution, and the overall navigation and organization of the space. The challenge facilitator noted that this first review served as a wake-up call that offered the teams advice on what areas were in need of development and a reminder of the specific assessment criteria in the challenge rubric.

The purpose of the final assessment of the teams was to select the top five finalists and to select the winner of the challenge based on the finalists' presentations within synchronous sessions held in the virtual world at the end of the challenge. While only a few points separated the top finalists, the challenge assessors' comments suggest a difference in both the amount and quality of work displayed between the low scoring teams ("very little teamwork evidence", "knowledge space is lacking in content", "vague descriptions", and "I didn't have much to go on") and the high scoring teams ("team space was very thorough", "high level of detail", "organized", "very nicely thought out and presented", "Your team engaged in the design process, and "I am thoroughly impressed"). Given that the team's performance was based on their presentation, the challenge assessors noted in the post-challenge interviews that they found it difficult to assess some team's efforts due to the lack of a well-developed and sufficiently descriptive virtual world team space. One challenge assessor suggested that in future implementations the students should develop their virtual world team space as a *museum* that documents both the process and outcome of each team's design effort. However, the challenge assessors reiterated the feedback of the technology specialists, team leaders, and student competitors that the students needed a certain level of skill and knowledge both in manipulating the virtual environment and in modeling. One challenge assessor noted that gaining those skills during the challenge was likely a large cost to the teams, one that may have influenced team performance in the challenge.

During the synchronous presentation sessions at the end of Phase 2, the challenge assessors scored each team's (a) introduction, presence, and tour, (b) knowledge space, and (c) virtual models. Scores were based on an assessment rubric that focused on each team's ability to explain the designs and design process, as well as the accuracy of the 3D representations of their proposed solution. Compiled feedback from the challenge assessors suggested an assessment emphasis on the relative strength of the team's live presentation (such as delivery and timing), development of the team space (such as too much or too little detail), aspects of the models (such as uniqueness, development, and level of detail), and level of elaboration on the thought process that went into solutions. While the assessment rubric contemplated the accuracy of the proposed design solution, this aspect of the assessment accounted for less than 20% of the possible points. Further, little written commentary was provided by challenge assessors regarding design accuracy.

When asked to consider the overall performance and learning outcomes of students in the in the challenge, one challenge assessor noted during his interview that, given the nature of the challenge and the assessment parameters, the assessment centered on the quality of each team's design process and design presentation versus the quality and accuracy of the design itself, or the individual student's contribution or level of understanding. Another challenge assessor noted room for more "rigorous criticism for the students" while another suggested potential value in some form of standardized assessment. Another suggested giving teams the opportunity for peer assessment, in which students were able to analyze the work of other teams. In general, the challenge assessors found it effective to have at least three challenge assessors per team and they felt their comments during the first review assessment lead to team improvement.

Discussion

Results of this evaluation suggest the challenge offered student teams a unique opportunity to engage in authentic science and engineering problems with the support of college-level and professional experts. However, results also suggest recommendations to improve future implementations. The following summarizes the key strengths of the challenge, as well as the evaluation team's recommendations to enhance the effectiveness and efficiency of the design challenge.

Strengths

Authentic design challenge. A key strength of the challenge was the authentic science and engineering design problems. As noted during the expert review, the challenge was tied to national standards and focused on the students' skills and knowledge in science, technology, engineering, and math. Several teachers and coaches added written comments to their surveys indicating that they were able to integrate the project into curriculum and that the challenge aligned to course objectives and standards. Through a variety of online tools and virtual spaces, the students tackled real-world design scenarios using a range of new technologies to support their learning. Surveys, interviews, and observations suggested a high level of participant engagement by most student competitors.

Student competitors noted that the challenge required creativity and challenged their ability to think critically and to adhere to deadlines. Further, student competitors listed interacting with others interested in engineering, the guest speakers, applying engineering design principles to complete a project, experience with 3D modeling, learning about virtual worlds, and learning about efficient collaboration as the most rewarding aspects of the challenge. Overall, the structure of the challenge offered teachers and coaches a high degree of flexibility to incorporate the design challenge into both classroom and after-school settings while offering outreach and professional development to educators.

Access to science and engineering resources. Educators with the motivation to engage their students in the design challenge had a wealth of resources at their disposal. Once registered on the website, educators and students received recommended strategies to approach a design challenge, as well as a host of professionally produced documents, diagrams, and videos associated with the design problem. Within the surveys, teachers and coaches noted the value in the content, including the video clips of engineers and information about the design process.

College recruitment. A sufficient number of college-level participants were recruited to fulfill the roles of team leaders, challenge assessors, and technology specialists. Through word of mouth and by targeting engineering departments, recruitment of support roles was adequate for current participation levels. As noted in the surveys, the student competitors viewed the team leaders as responsive and supportive.

Recommendations

Preparing for growth. Both recruitment and support for teams are important future growth considerations. During the first challenge implementation, the recruitment of competing teams was lower than hoped (and lower in particular with teachers or coaches in a traditional school setting) with less than 10% of registered teachers completing Phase 1. A re-examination of recruitment strategies was recommended, particularly if a goal of the challenge was to support teachers and students in traditional classrooms. Recommendations included not only outreach to traditional and online high schools, but also additional support to teachers and coaches, including added clarity regarding role definitions and challenge timelines, guidance on team building, and the inclusion of Phase 1 assessment activities to incentivize the teachers and teams to commit to the challenge. In addition, as seen by the strong participation of after-school online teams, intact groups that are looking for project-based activities for their members should be targeted.

The importance of the challenge facilitator role cannot be understated in terms of both implementation success and growth of the challenge. It was recommended that the challenge facilitation role be formalized and defined. A facilitation *playbook* should be developed for future challenges that address relevant implementation topics, such as communication, support, and mentorship to challenge competitors.

In addition, the challenge implementers must more closely examine the scalability of all support roles. How many teams can be supported within the challenge as it is currently designed? How many students can each team leader mentor? How many teams can each technology member support? Future challenge planning must answer these important questions as they directly affect the efficacy and effectiveness of the challenge.

Support for support staff. Additional support was recommended for those who support the student competitors. As found during observation, surveys, and interviews, the teams often stumbled over similar hazards (often in issues related to communication and technology) and technology specialists fielded similar questions across teams. Not all of the team leaders responding to the surveys agreed that the team leader role and responsibility was well defined within the challenge. Similarly, not all technology specialists agreed that training for the position prepared them for the tasks they performed and most learned as they performed their jobs. Recommendations included the creation of guides and frequently asked question (FAQ) responses developed by prior team leaders, challenge assessors, and technology specialists to assist those in the future by addressing commonly occurring situations or problems. Periodic live meetings among support roles would also offer the opportunity to share and compare ideas and to ask questions. Further, the inclusion of live orientation for the challenge assessors (as was done for team leaders) early in the timeline would add consistency in the assessment process.

In addition, college students provided much of the mentorship, assessment, and support needs to challenge competitor. An advisory committee that includes faculty in engineering and science at a college or research center would provide additional guidance to mentors, especially in grading and assessing designs. Further, support for team leaders regarding the technical aspects of the designs could be added as part of the professional guest speaker sessions.

Assessment. While the assessment process effectively and efficiently served the purpose of comparing teams for the selection of both finalists and the winning team in the challenge, all assessment was team-based without a focus on the individual student's skill and knowledge development. In addition, no formal assessment occurred during Phase 1 of the challenge beyond the selection of Phase 2 by the team leaders. Further, the assessment placed a far greater emphasis on the design process and presentation choices of the students than the accuracy or viability of the engineering design, which may explain why one challenge assessor felt there was room for more rigorous criticism and why few student competitors ranked the level of difficulty of the challenge as high. Given that the assessment focused heavily on the team's ability to display their skills and knowledge (which was based on how well the team used the modeling software and manipulated the virtual world), it was difficult to determine whether the low scoring teams did not have the ability to develop accurate designs or if they merely had difficulty in *displaying* their designs due to problems manipulating the modeling software and their virtual world space. Recommendations included (a) incorporating individual assessment, possibly in the form of team leader and / or peer review, (b) adding a formal assessment during the Phase 1 of the challenge, (c) offering an orientation regarding the use of modeling programs and how to import and display the developed models into the virtual world, (d) refining the Phase 2 assessment rubric to emphasize the quality of the design as much as the quality of the design presentation, and (e) amending the format of the final synchronous presentation sessions to assess the teams separately over a longer period

Collaboration and technology considerations. Within the participant surveys, several respondents noted frustration over the difficulty in day-to-day collaboration and communication within the virtual teams. In addition, teams noted technical difficulties, including the creation and display of their models, which was a central requirement of the challenge. Particularly during the first implementation, teams relied heavily on communication tools outside of the provided virtual space, including email and Skype. In addition, teams sought out a variety of free or freely available modeling tools that may or may not have offered the greatest effectiveness and ease-of-use both outside and inside the virtual world. While offering the teams the flexibility and freedom to choose the tools that work for the team was important, it was recommended that team collaboration and technology considerations be addressed with team leaders at the start of the challenge, including suggestions for tools to support communication and modeling that offer the required capabilities for the challenge. The creation of a team leader guide and FAQ would also help to document what works and potential pitfalls. In addition, a mid-challenge team member assessment of the team leader and other team members helped to identify teams encountering collaboration problems.

Conclusion

As suggested by theory and research, while descriptive studies suggest instruction in virtual worlds offers an immersive online learning environment that fosters interaction and collaboration, research has long suggested no significant difference in learning achievement based on the media used to facilitate instruction. Instead, the results of both problem-centered and group -based instruction suggest the strategies employed affect learning outcomes. Therefore, the purpose of this implementation evaluation was to provide decision makers with a description of what happened during the implementations of this problem-centered challenge set in a 3D virtual world, as well as an examination of the efficacy and efficiency of the challenge as a group-based experience. Overall, the evaluation team found the strengths of the challenge included (a) the use of an authentic science and engineering design problem, (b) access to science and engineering resources and professionals, (c) effective challenge facilitation, and (d) successful recruitment of team mentors. Recommendations centered on (a) needed adjustments to both achieve and prepare for growth in team participation, (b) expanded support for team mentors and technical support, (c) refined assessment , including both individual and team-based assessment approaches, and (d) collaboration and other technology enhancements.

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