THE EVOLUTION OF A ROCKS AND MINERALS CHALLENGE GAME DESIGN
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This design case describes design decisions and their impacts during three redesigns of an educational game called the “Rocks and Minerals Challenge.” This game was developed as a laboratory supplement for the rocks and minerals component of a university-based geology course. The game has evolved through three distinct design phases: Design 1, first designed as a challenge module in 2005; Design 2, redesigned as a game in 2012 for compatibility reasons; and Design 3, redesigned in 2015 to enhance instructional effectiveness. Following is a description of the game design factors that were implemented for each of the design phases: learning goals, levels of challenges, scaffolding, user control, feedback, and rules. The timing, rationale and impacts of these design decisions are discussed within the context of recommendations identified by existing educational game research.

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OVERVIEW
Game research has identified specific game features that are important in the design of effective educational games. There is much latitude, however, in how the designer uses these elements to accomplish a game’s goal(s) and objective(s).

Game research suggests that instructional game designers should concentrate on design challenges that meet clear learning goals (Charsky, 2010; Gunter, Kenny, & Vick, 2008; Lameras et al., 2017; Van Eck, Shute, & Rieber, 2015) and incorporate adaptive challenges that build upon prerequisite skills (Charsky, 2010; Gunter et al., 2008; Van Eck et al., 2015). Games should also be motivating (Charsky, 2010; Gunter et al., 2008; Van Eck et al., 2015), support learning through feedback and hints (Gunter et al., 2008; Lameras et al., 2017; Van Eck et al., 2015), and provide a framework of rules and choices (Gunter et al., 2008; Lameras et al., 2017).

In this design case, we discuss some of the most salient game features through an examination of the development
of a computer-based educational game for the sciences. The format and theoretical basis of the game has remained constant throughout the development of this game. The design, however, evolved based on lessons we learned during the design process and programming issues. Following, we discuss the game research and instructional design principles that served as a rationale for our design decisions.

THE RATIONALE FOR REDESIGN

Anecdotally, faculty, students, and educators at other educational institutions rated Design 1 (Figure 1) of this program highly. However, the game became non-functional when the webpages’ JavaScript stopped supporting browsers using HTML4.

Consequently, Design 2 (Figure 2) involved the transformation of its code to HTML5, which enabled the compatibility of its webpages with different browsers and a broader audience. Additionally, we improved the website’s backgrounds, reduced the number of webpages to enable easier editing, and added a summative scoring mechanism to the “Drag N Drop” Game of Level 2.

Although the visual aspects of Design 2 vastly improved with this redesign, feedback indicated that the webpages appeared cluttered and difficult to navigate, compared to the home page of Design 1, prompting the development of Design 3 (Figure 3).

Design 3 continued to use the visual elements of Design 2. However, Design 3 also adopted game elements using the more systematic, comprehensive, and diagnostic approach recommended by Ke (2009) and the Federation of American Scientists (2006).

LEARNING GOALS

Because this was a serious or educational game, our primary goal was to design an effective game that motivated students to learn geological information more effectively. Within this framework, we needed to establish clear learning goals (Killi, 2005; Dickey, 2005); a clear understanding of objectives that could facilitate the completion of these goals; and develop game features that best supported the achievement of objectives (Dondi & Moretti, 2007; Honey & Hilton, 2011). When
goals are clear, the player is more aware of what he or she is learning and how to apply the instruction (Federation of American Scientists, 2006). Goals that align the tasks of the game with intended educational outcomes (Prensky, 2011; Quellmalz, Timms, & Schneider, 2009; Wilson et al., 2009) also help prevent the inclusion of extraneous information that can distract from the learning process (Clark & Mayer, 2011) and facilitate the design of assessments that measure the effectiveness of the game (Hays, 2005; Quellmalz, et al., 2009).

The content goal established for the Rocks and Minerals Challenge (RMC) was to help students identify rocks and minerals involved in the earth’s formation through characteristics observed and tested in the laboratory. This goal helped us determine the learning objectives, instructional strategy, and design of the game at each level to facilitate the strategic scaffolding of information.

Working with a subject matter expert (SME) throughout the instructional design process is recommended for effective design, especially when establishing the goals and the need for instruction (Dick, Carey, & Carey, 2015). In addition to providing the program’s goal and objectives, our SME verified the accuracy of the RMC’s content and helped us establish standards for feedback and scoring.

LEVELS OF CHALLENGES

The completion of challenges has been the top-ranking motivation for game playing in higher education (Hainey, Connolly, Stansfield, & Boyle, 2011). Challenges in an educational game typically provide the gamer with the opportunities to acquire the skills and knowledge needed for more complex challenges (Mayer & Johnson, 2010), motivate game usage, and enhance learning potential (Wilson et al., 2009).

Good games also adjust challenges and give feedback in such a way that different players feel the game is challenging but doable and that their effort is paying off (Gee, 2005). This can be done with positive feedback in the form of hints, scores, points, prompts, and levels that help sustain engagement (Lim et al., 2013) and motivate continued game play (Jones & Issroff, 2005; Killi, 2005; Sanchez, 2011).

All three designs included challenges scaffolded in levels labeled 1, 2, 3, and 4. Level 1 is an informational resource page. Levels 2, 3, and 4 contain unique games that help students learn information needed to reach each objective. Within each level, students have access to content that is organized by geological category and subcategory. Between levels, the level of difficulty increases. That is, Level 2 of the “Drag N Drop” challenge teaches the easiest objective; Level 4’s challenge is the most difficult.

Although the organizational logic used in Design 1 and 2 was consistent, reaction to Design 2 (Figure 4) was negative. Feedback revealed that the content per page was overwhelming.

In response, we simplified the format of Design 3 (Figure 5) and organized it similar to Design 1’s home page (Figure 6), which had been very popular with users.

SCAFFOLDING

We scaffolded challenges in the RMC by introducing students to new concepts at each level, making connections between these concepts within levels, and building upon these concepts at higher levels. This logic followed the literature, which suggests that designers carefully organize challenges in a game according to levels of increasing complexity and decreasing support. Embedding the academic content in a game using this logic enables the player-learner...
Researchers suggest that scaffolding reduces the complexity of the task (Mayer, Mautone, & Prothero, 2002) and provides support during learning (O’Neil, Wainess, & Baker, 2005) by reducing the extraneous cognitive load of the learning content through design and the promotion of schemata development. Concomitantly, Clark, Tanner-Smith, and Killingsworth (2014) found that digital games using higher levels of scaffolding were associated with higher relative learning outcomes than lower levels of scaffolding.

Scaffolding also enables players to control the difficulty of gameplay, accommodating users with different levels of expertise (Bedwell, Pavlas, Heyne, Lazzara, & Salas, 2012; Gee, 2005; Sweetser & Wyeth, 2005; Van Eck et al., 2015; Wilson et al., 2009) and promoting high levels of motivation (Bedwell et al., 2012; Honey & Hilton, 2011; Killi, 2005; Wilson et al., 2009). Novices can take a long time at early levels at a lower difficulty level in order to avoid frustration, while skilled players can move through initial levels quickly, avoiding boredom (Van Eck, 2007).
The need to simplify students’ ability to control navigation within and between scaffolded levels influenced the prominent placement of our levels (Figures 4, 5, & 6) and our design of Level 1, which provided students with a summary of the content taught through all three game designs. Students who used Level 1 in Design 1 (Figure 7), however, had to search through multiple links to find alternative specimens.

In contrast, for Designs 2 (Figure 8) and 3 (Figure 9) of Level 1, we strategically placed the specimen image in the table frame of the rock/mineral (Figure 8) description to facilitate students’ retrieval of the information and reduce linking. For Design 3, we also chunked specimens by Category and Subcategory to improve the design’s pedagogical utility (Figure 9).

**USER CONTROL**

User control is an important feature of a game that refers to the amount of control a learner has over content or gameplay (Bedwell et al., 2012). Control can lead to more positive attitudes (Wilson et al., 2009) and higher cognitive outcomes (Vogel et al., 2006). User control also provides the player with the ability to influence elements within their learning environments, navigate through content, pace their progress (Wilson et al., 2009), and observe the consequences of their choices (Hainey et al., 2011). Dickey (2005) posits that choice is central to the design of gameplay through its ability

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**FIGURE 8.** Level 1 of Design 2 provided the information students should learn by Level 4 through a Rocks and Minerals summary page that gave students access to each specimen’s summary page (center page).
to both personalize the experience and affect gameplay. Choice also provides the gamer with the ability to change the level of difficulty so that the learner can make mistakes without real consequences (Sanchez, 2011) and allows users to control their exposure to information according to their level of expertise, improving learner motivation (Lameras et al., 2017).

We implemented the feature of choice, or user control, in all three designs of the RMC by providing students with multiple levels of challenges and by scaffolding the content in levels. In Designs 1 and 3, the learner was able to navigate using drop-down menus and tabs. In Design 2, the learner used tabs. Although tabs provided easier access, excessive tab use, such as that used in Design 2, appeared to overwhelm our users with information. By Design 3, the pros and cons of each method of navigation were deliberated based on the objective of the level, structure of the game, design of the page, ease of navigation, reduction of unnecessary redundancy, and the programming.
An example of changes in user control that transpired through development was the “Drag N Drop” challenge. Level 2 of Design 1 (Figure 10) provided users with two means of navigation and user control, compared to one means in Design 2 (Figure 11). In contrast, Design 3 (Figure 12) of the same level provided three means of navigation, providing users with more ways to control their gameplay.

All three designs provided access to the other pages, but Design 3 made access and control easier and more transparent.

**FEEDBACK**

According to Wouters, Van Nimwegen, Van Oostendorp, and Van Der Spek’s (2013) meta-analysis, serious games are more effective when they are accompanied by supplemental instructional methods that prompt players to articulate new knowledge and integrate it with their prior knowledge. Supportive feedback and scaffolding supplemented by hints, prompts, partial solutions, and pervasive feedback motivate learners to continue gameplay (Jones & Issroff, 2005; Killi, 2005; Sanchez, 2011), enable players to self-regulate their progress (Killi, 2005; Van Eck, 2007; Federation of American Scientists, 2006), and enhances learning (Clark & Mayer, 2011; Honey & Hilton, 2011; Hattie, 2009). Frequent feedback also allows the learner to recognize his or her achievement, anticipate the consequences of his or her actions, and adapt to the situation by applying a new strategy if needed (Sanchez, 2011).

We provided feedback in all three designs. However, the frequency, type, and degree of feedback provided in each challenge varied. Level 2 feedback was consistent in all three designs through a “Drag N Drop” challenge (Figures 10, 11 & 12), which was a memorization drill that trained students to identify rocks or minerals by name. Toward that end, images incorrectly matched to their name would return to their original location in the image table while images correctly matched remained on its name. The close linking of a learner’s action with feedback and the provision of feedback as an action instead of text enabled learners to be aware of their progress in accord with the recommendation of Liang, Lee, and Chou (2010).
In addition to this feedback, students in Design 3’s Level 2 (Figure 13) received a completion time linked to evaluative feedback since rapid response games appear to be well suited for skills that must become automated through extensive drill and practice (Clark & Mayer, 2011). The performance rubric used to provide this feedback was developed with the assistance and agreement of several SMEs. Players who received low scores were “Pebble Puppies” and encouraged to repeat the challenge. Players who received average scores were “Quarrymen” and encouraged to continue practicing. Players who received high scores were “Rock Hounds” and encouraged to challenge themselves at a higher level or attempt a similar challenge in an alternative rock or mineral category.

We provided feedback in Design 1, Level 3’s, “Mineral/Rock Identification Challenge” (Figure 14), through a drop-down word bank hint designed to support students’ efforts and a pop-up tab with the text “Good job” to reward correct answers. Design 2, Level 3’s (Figure 15), “Intermediate Challenge” added an evaluative score, a correct/incorrect text box, and the specimen’s image as a reward for correct answers in addition to the word bank hint.

We redesigned Design 3, Level 3’s (Figure 16), “Search and Find” to be more visually aesthetic. We also used a simpler pedagogical design that asked students to connect specimen images from Level 2 to characteristics, rather than the characteristics with the specimen’s name. Feedback in this design is through coloration of the buttons: red is incorrect and green is correct. Additionally, at the end of the challenge, a results page provides a score and the option for students to repeat that or an alternative challenge.

Level 4 is the most advanced level of the RMC, requiring students to apply the information learned in earlier levels. We eliminated the hints provided in Level 3 from Level 4 of Design 1 (Figure 17) but added an image of the specimen’s picture for feedback and reward for correct answers.

We also eliminated Level 3’s hints from Design 2’s Level 4 (Figure 18). However, according to users, the presentation of questions in Design 2 was overwhelming, reducing user motivation to enter this challenge. Level 4 of Design 3
of this level is a complete redesign of Design 2 that is currently in process.

RULES

According to Dondlinger’s (2007) review of educational video game design, in addition to objectives and goals, the rules of play are a significant element of effective video game design. Rules provide context to game design that can be operationalized as constraints that limit the actions a gamer can and cannot take. The flexibility of the rule structure determines the extent that learners can explore, test hypotheses, and find alternative ways of fulfilling goals. Specific, well-defined rules and guidelines also provide the player with feedback on their progress toward achieving the goals. Mayer and Johnson (2010) suggest that a rule-based environment that is responsive helps the player gain an understanding of the game.

Rules in the RMC were intrinsic to the design in that a player would be unable to complete higher-level challenges unless they had acquired the knowledge of previous challenges. We provided this rule structure to students through clear instructions and recommendations intended to help them understand the goals of each challenge.

REFLECTION AND RECOMMENDATIONS

The redesigns discussed in this paper showed the need for careful planning of the instructional design with team members before development. We developed Design 1 as a study aid for geology students before educational gameplay and mobile access was popular. The design was based on the “Learning for Use” (LfU) model (Edelson, 2001), which is a general framework developed to help web designers develop content-intensive, inquiry-based science learning activities and incorporate the principles of motivation, knowledge construction and knowledge refinement. Design 1 was popular with students, but more of a study ancillary than a game.

The predominant motivation for the redesign of Design 1 was its incompatibility with HTML5. During this reprogramming, we also incorporated more game features and upgraded our visuals to motivate increased student usage. This process took two years due to our limited funding and skeleton staff. The user reaction to Design 2 was negative. On reflection, programming decisions made in Design 2 compromised design principles.

The conflict between programming wants versus instructional design principles was also evident during Design 3.
Programmers attempted to make changes to the program, inadvertently affecting the instructional design and pedagogy. By Design 3, however, we learned to minimize these occurrences by sharing the logic of the design by posting a work plan that detailed programming activities, responsible parties, and benchmarks; and tracking progress regularly.

A side benefit of this program’s development was the growth demonstrated by our programmers, who were computer science students. The game gave them a platform to experiment, research, learn, and develop a portfolio. Corporations recruited each of these students as soon as they graduated.

**FUTURE DIRECTION**

It became evident during our literature search that there is a need for scientifically rigorous studies that identify the impact of design features on the instructional effectiveness of games and guide future design (e.g., Clark, Yates, Early, & Moulton, 2010; Deleeuw & Mayer, 2011; Hannifin & Vermillion, 2008; O’Neil & Perez, 2008; Tobias. Fletcher, Dai, & Wind, 2011). Hence, we are currently investigating the efficacy of unique game attributes implemented in Levels 2, 3, and 4 in the context of relevant theoretical constructs. Once we complete these investigations and share the results with the gaming community, we will make the RMC game available through the internet to students of geology and their instructors as an open educational resource.

**ACKNOWLEDGEMENT**

Thank you to Dr. Karen Swansen, our SME, for providing her academic expertise.

**REFERENCES**


