MINER TROUBLES: A GAMIFIED MATCHING-TO-SAMPLE

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Gamification is a powerful technique for improving engagement and learning, which has been applied in many contexts, including education. In behavior analysis, a procedure that has also driven several applications in educational settings is Matching-to-Sample, especially in the context of the Stimulus Equivalence paradigm. Considering the potential benefits of the interaction between both fields, this study describes a gamified Matching-to-Sample (MTS) software called "Miner Troubles". The program shares the same characteristics of the typical MTS, but it was adapted to provide a game-like experience, which was defined based on conventional gamification elements. The software serves as an example of a possible interaction between concepts from behavior analysis and gamification and discusses how it can be further developed and evaluated.

Keywords: matching-to-sample; gamification; stimulus equivalence

Games have become a significant part of many people's lives. In the United States, 65% of the population plays video games at least one hour a week, and globally, at least 87% of 16-24 years old population plays video games (Entertainment Software Association, 2023; We Are Social et al., 2023), leading some authors to refer to this generation as the "gamer generation" (Deterding, 2014). While research on game playing has often focused on the negative effects of game-play, such as game addiction, which can impact up to 15% of the youth population (Humayya et al., 2022; Karaca et al., 2020), some studies have shown that playing video games can actually improve various cognitive skills, particularly when the games are based on learning principles and research evidence (Mayer et al., 2019).

Considering the significant amount of time spent on games and their characteristic to capture attention, the utilization of game designs in non-game contexts – what has been known as gamification – has emerged as a potential path to engage people in various tasks (Deterding et al., 2011). In line with this perspective, numerous studies have been conducted, with a particular focus on education (de Sousa Borges et al., 2014). For instance, a bibliometric survey of gamification research in education revealed a significant increase, from fewer than 50 papers before 2012 to over 500 papers in 2019, involving researchers from 100 different countries (Swacha, 2021).

In addition to the quantity of published papers, several studies have examined the impact of gamification in applied contexts. A meta-analysis investigating the effects of gamification on learning found a positive effect on various outcomes, including cognition, performance, and engagement (Sailer & Homner, 2020). Furthermore, a literature review indicated that gamification applied to educational contexts can have a positive impact on academic performance and motivation (Manzano-León et al., 2021).

Given the observed positive outcomes, the utilization of game-based procedures or gamification has been considered as a potential area for exploration, description, and integration within behavior analysis (Morford et al., 2014).

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The authors propose that the intersection between behavior analysis and gamification can be mutually beneficial, expanding the toolkit available to behavior analysts for behavior interventions and fostering collaboration in explaining and exploring behavior analysis concepts for gamification researchers.

This intersection has already begun in various research subjects, including: delay discounting (Young & Howatt, 2024; Young & McCoy, 2015), the use of common resources (Camargo & Haydu, 2016; de Oliveira et al., 2023), healthcare interventions (Vaidya & Armshaw, 2021), increasing accuracy of data entry (Parry-Cruwys & MacDonald, 2021), do-say correspondence (Alves et al., 2024), reading and writing instruction (de Souza et al., 2017; de Souza et al., 2018; Nascimento et al., 2012; Tripiana-Barbosa & de Souza, 2015), mathematics instruction (de Souza et al., 2023), developing gamified interventions for children with autism (Silva et al., 2024), and procedures for human operant research (Helvey et al., 2023). However, there is scope for further development, considering the advancements made by both games/gamification and behavior analysis over the past decade. It is noteworthy that psychology researchers (including behavior analysts), have published relatively fewer papers on gamification compared to other fields such as Social Sciences, Engineering, and Medicine (Swacha, 2021). This is peculiar considering the use of psychological terminology and concepts by gamification researchers (Morford et al., 2014).

A procedure extensively used in behavioral research, particularly in educational applications, that can be readily adapted to a game format, is the Matching-to-Sample (MTS). While there is a wide range of manipulable variables in MTS (Arntzen, 2012), the core procedure always involves a series of discrete trials. Each trial begins with the presentation of a sample stimulus, followed by the presentation of two or more comparison stimuli, which are selected by the participant (by pointing to, touching, or clicking on the stimulus using a mouse). For each sample stimulus, one of the comparison stimuli is designated as correct, and its choice is reinforced. This establishes a relationship between each sample stimulus and its corresponding comparison stimulus. As an example, when a sample stimulus (e.g., A1) is presented with two comparison stimuli (e.g., B1 and B2), choosing only one of the comparison stimulus (B1) results in reinforcement. But when another sample stimulus is presented (e.g., A2), choosing only the other comparison stimulus (B2) is reinforced.

The MTS procedure has been used for a long time and in many contexts to establish identity matching and to train and test for different repertoires (Anderson & Colombo, 2022; Hively, 1962). However, in behavior analysis, the MTS procedure is most associated with the paradigm of equivalence relations, as proposed by Sidman and Tailby (1982). According to Sidman, a conditional discrimination training procedure (as the MTS) is a contingency that might generate equivalence relations (Sidman, 2000). For example, when training AB and BC (two relations), the learner may correctly exhibit the relations BA, CB, AC, and CA (four novel relations) without the need for explicit training for each one individually (Pilgrim, 2020; Sidman, 1994). This potential to faster teaching, by expanding the number of relations beyond the ones explicitly taught, has prompted numerous studies examining the applicability of the stimulus equivalence paradigm on different populations and with various subjects, what have originated what is referred to as Equivalence-Based Instruction (de Rose et al., 1992; Fienup et al., 2011; Fienup & Brodsky, 2020; Matos & D'Oliveira, 1992; Pilgrim, 2019; see also Rocha e Silva & Ferster, 1966, for an example of using matching to sample to generate new relations before the equivalence paradigm had been formulated).

Despite the substantial number of papers demonstrating the effectiveness of EBI (Brodsky & Fienup, 2018), few papers compared EBI with more traditional teaching procedures. As one example, Lovett et al (2011) compared the satisfaction levels of lecture videos and EBI using a social validity test. The participants rated the lecture video slightly higher than EBI when considering if they would prefer that type of instruction over traditional instructions, but there were no differences when considering all items of the social validity test. The authors discussed that the preference data indicated that participants equally preferred passive (lectures) and active (EBI) learning, and that EBI might be less preferable than a lecture video. Similar results were found in other experiments, although differences in the procedures and social validity tests difficult a proper comparison (Augland et al., 2020; Ferman et al., 2020). While the preference of EBI over other teaching procedures is still a question that requires more experiments, none of the studies mentioned the hypothesis that EBI can be perceived as less appealing than traditional lectures, due to experimental tasks (including MTS trials) being described by participants as "simple and repetitive, and often described by the participant as boring or uninteresting" (Pilgrim, 1998, p.23).

The gamification of the MTS procedure offers a potential avenue to test motivational aspects in experimental research and EBI, while preserving the key characteristics and effectiveness of the conventional procedure. But the initial step towards exploring this research agenda is the development of a gamified MTS software (e.g., de Souza et al., 2018). Therefore, the objective of this paper is to describe the software "Miner Troubles", providing an example of the potential interaction between behavior analysis and gamification, and tracing future paths of research. The software program is presented based on the incorporation of gamification elements and it's MTS characteristics.

Development of a Gamified MTS (Miner Troubles)

Equipment and software

Miner Troubles was developed utilizing the UPBGE software (version 0.3 alpha), an open-source game engine specifically designed for 3D games. The programming code was written in Python language (version 3.9.6), which is compatible with UPBGE. The variables and conditions within the game were manipulated using a Python script reader. The physical structure and design of the game were created using the UPBGE program.

Story and Instructions

The procedure begins by presenting the story of the main character, the participant's objectives, and providing general instructions on the screen:

> "Miner works in a mine and sells diamonds. One day, when he was digging, Miner fell into a hole and, when looked around, realized that he had fallen into Namdis tomb, famous for being an old maze. To get out of it, Miner needs to learn which doors he may or may not open. Your task is to help Miner to get out of the tomb and collect all the diamonds you can find. Your total number of diamonds is on the right-upper corner of the screen. To pass each phase, you must open 12 correct doors consecutively (the total number is in the left-upper corner of the screen). Use the keyboard arrows to move Miner and the spacebar to open the selected door."

The software scenery was designed as a close, dark, and abandoned space to create an environment without distracting stimuli. The primary source of illumination in the game is Miner's lantern, which allows the participant to clearly see only one stimulus at a time (see Figure 1d). The doors, walls, floor, and overall scenarios remain consistent across trials, with the only changes occurring in the abstract stimuli used for the training and testing procedures. The use of a single spot illumination, the repetition of the same scenery without variations and the place in which the game story takes place were intentional choices to help participants focus on the task of learning stimulus relations, rather than being distracted by irrelevant variables (such as door color and room shape).

Experimental Task and Game Structure

All training and testing trials take place within the same virtual space in the game, which consists of two rooms: The Sample Room and the Comparison Room, connected by corridors. At the start of the game, Miner is located in the Sample Room (the participant is unaware of the room names). The Sample Room contains a door with a single stimulus displayed on it (the sample stimulus; see Figure 1a). Upon opening the door, the participant must traverse the corridor between the Sample Room and the Comparison Room (the character is controlled using the keyboard arrows and the 'space' key to open the door). Therefore, the procedure is a Delayed Matching-to-Sample (DMTS; what means that the sample stimulus is removed from the screen when the comparison stimuli are presented) and the time it takes for the

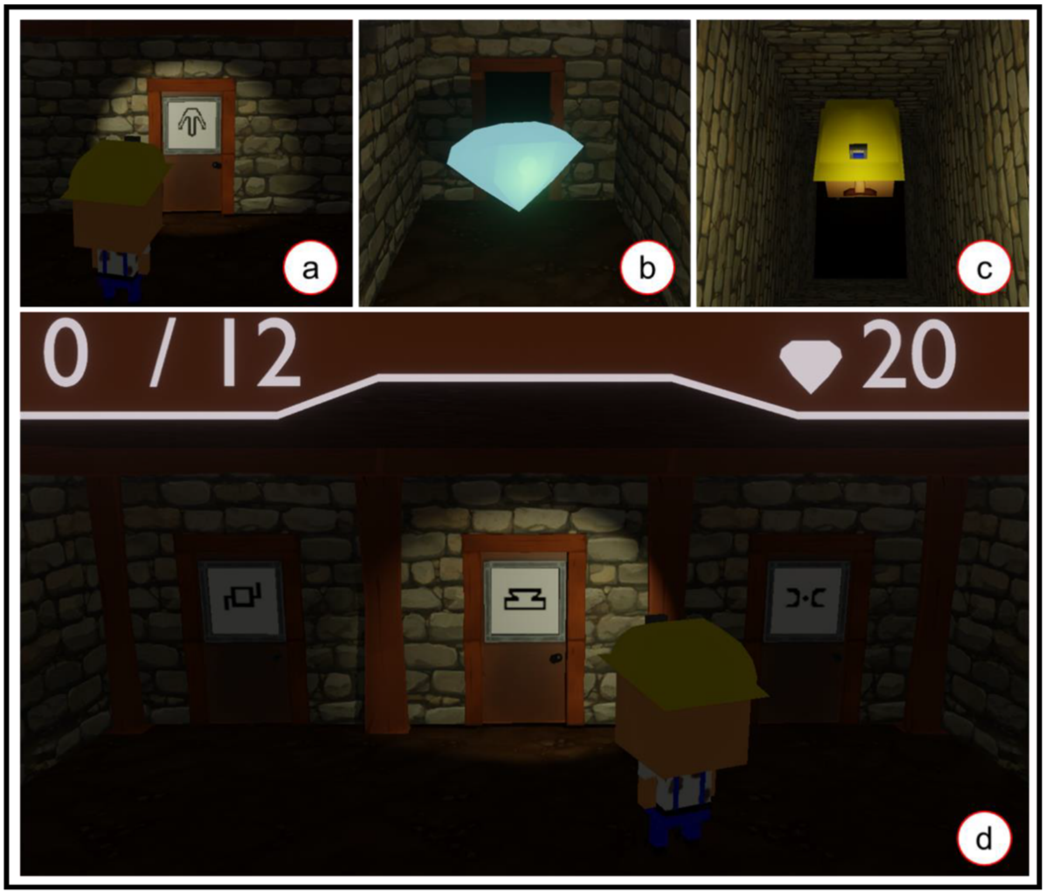

Figure 1. Images from the first version of Miner Troubles game: (a) Sample door with the sample stimulus; (b) consequence for correct responses; (c) consequence for incorrect responses; (d) comparison doors with comparison stimuli; the numbers above the doors indicate trials (completed/programmed) and collected diamonds.

participant to cross the corridor is approximately 3.5 seconds[1].

In the Comparison Room, three doors are present, each displaying a different comparison stimulus (Figure 1d). The participant must choose one door to open, and only one door can be opened. During training trials, selecting the correct door leads Miner to a corridor containing a diamond (see Figure 1b). The participant can then proceed through this corridor, reaching an open door that grants access to the next Sample Room. If the participant chooses the door with a stimulus that is not related to the sample, the corridor has no diamonds, and Miner falls into a pit (see Figure 1c). After falling, the participant loses one diamond and the consecutive correct response counter is reset, so the participant needs to do 12 consecutive correct trials to end the block, independent of how many correct trials they had done before. After falling, Miner is taken back to the Sample Room (trials are presented randomly, so the trial following a correct or incorrect comparison stimulus selection vary).

In testing blocks, no programmed differential consequences, such as diamonds or pits, are presented, and after selecting a comparison stimulus, Miner proceeds through the corridor to the next Sample Room. At the end of each training or testing block, Miner arrives at a resting room with a mining cart on a rail. In this room, the following instruction is presented:

1 A new version of the software was developed, in which crossing from Sample Room to Comparison Room was automatized and it takes approximately 2.5 seconds.

"This is a resting room if you need to pause. When you feel ready to continue, just press the spacebar close to the mining cart. Don't close the game now or it won't save".

The inclusion of the resting room provides participants with an opportunity to pause the game and attend to personal needs, such as drinking water or using the bathroom. Pausing the game during the training or testing blocks is not feasible as it could disrupt participant performance. Upon completing the entire procedure, Miner emerges from the tomb into a safe and open space, signaling the end of the game. It is important to note that the end of the procedure is independent of the participant's performance in the tests, ensuring that the game never ends with Miner being trapped in the tomb.

During the training phases, the number of consecutive correct doors and the number of diamonds are displayed for the participant (see Figure 1d – upper corners). The first is associated with progressing to the next phase: one point is added for each correct selection, while an incorrect selection resets the value to 0. Once a specified number of consecutive correct responses (e.g., 12 correct consecutive trials) is achieved, Miner enters the resting room and proceeds to the next phase of the experiment. The selection of correct or incorrect doors also affects the number of diamonds, with each correct selection adding diamonds and each incorrect selection subtracting diamonds. However, the game continues even if the number of diamonds is down to zero (the number of diamonds is never lower than zero). During the testing phases, no diamonds are won or lost, and the participant does not have access to the number of correct doors or the number of diamonds.

Other information that are recorded but not made available to the participant, are: block identifier, number of trials, correct or incorrect selections, the sample and comparison stimuli used in each trial, and the selected door. Additionally, the program has the capability to record time intervals, including the time between trial start and Sample Door opening, the time between Sample Door opening and entering the Comparison Room, the time interval between entering the Comparison Room and selecting a comparison, and the total trial duration. These intervals correspond to the durations typically measured or controlled in MTS tasks, such as the visualization time for samples and comparisons, the delay time between sample withdrawal and presentation of comparisons, response latency for selection response, and the overall duration of the trial (these are the information initially planned to be recorded, but other information can also be recorded depending on the aim of the particular experiment).

Therefore, as other MTS software, Miner Troubles characteristics can be manipulated depending on the user's goals[2]. Different instructions can be presented, it is possible to manipulate the number and order of training and testing blocks, the stimuli used, the mastery criteria for the training blocks, number of trials, and other details, with simple modifications.

And with some knowledge to use the UPBGE software and Python programming it is possible to change the character's movement from keyboard keys to joystick (and even virtual reality headsets), to present a simultaneous rather than delayed MTS, or to present an auditory sample stimulus. Different manipulations can be done but are dependent on different levels of knowledge[3] of the user about the software and about programming. And although this might seem discouraging initially, it only shows the need for collaboration when conducting this type of research.

Gamification elements

A taxonomy of gamification elements in educational environments was utilized to describe the characteristics considered when planning Miner Troubles (Toda, Klock, et al., 2019; Toda, Oliveira, et al., 2019). These authors categorize various gamification components into five main dimensions: performance, ecological,

[2] Different components were already changed and tested using Miner Troubles software. As an example, the instructions were eventually changed because the first instruction (the one described here) suggested that the participant could occasionally fail, in purpose, to maximize the number of diamonds they could earn (what actually happened for one participant in the first pilot study).

[3] With the use and further development of the software, some variables became easier to manipulate. And although a detailed discussion of the programming code and how to change different parameters of the software is beyond the scope of this paper, questions regarding parameters and software availability can be addressed to the corresponding author.

social, personal, and fictional. These dimensions group elements with distinct characteristics that may generate specific effects on the learning outcomes.

The *performance* elements in Miner Troubles are directly linked to the consequences of participants' behaviors within the procedure. These elements include points, progression, and stats. Points in the game correspond to the diamonds won or lost based on participants' performance and are considered a crucial gamification element (Toda, Oliveira, et al., 2019). Progression refers to the number of correct consecutive trials and, also, the progress through different rooms and phases of the game (such as completing a training block, entering the resting room, moving to a testing block, etc.). Stats provide participants with feedback on their performance by displaying the points earned and the number of correct consecutive trials.

Another significant game element in this procedure falls within the *ecological* category, known as imposed choice (Toda, Klock, et al., 2019). Imposed choice occurs when participants must select a path in the game that leads to different consequences. The structure of the procedure compels an imposed choice in each trial since participants must choose only one of the comparison stimuli and cannot select more than one.

The *personal* elements, related to engagement through the procedure, consist of objectives, sensations, and puzzle. Objectives provide a description of what should guide participants' behavior and are considered one of the most important game elements (Toda, Oliveira, et al., 2019); sensations depict the game's ambiance, including visual and auditory stimuli; and puzzle is the challenges provided by the MTS task itself (figuring out why some relations lead to diamond and others not). In Miner Troubles these elements involve the combination of the instruction in the beginning of the procedure ("getting out of the tomb") with the corresponding sensations presented during the game (the dark environment, the focused light of the lantern) and the challenge to discover which stimulus goes with which.

The *fictional* element in Miner Troubles is the storytelling, which encompasses the integration of game features into a coherent and cohesive narrative that holds meaning for the participant. Storytelling has been found to contribute to better behavioral learning outcomes (Sailer & Homner, 2020). Some authors argue that better results are more likely to occur when learning is connected to the game's outcomes, such as the learning of conditional relations guiding the participant to help the character escape the maze (Clark et al., 2016). *Social* dimension, which involves interactions with other learners within the procedure, such as competition and cooperation contingencies, was the only category not included in this particular procedure.

As discussed by other authors, certain elements described in the literature on gamification can also be interpreted using variables manipulated by behavior analysts (Morford et al., 2014). For instance, the focus on different consequences for behavior to stimulate learning outcomes, the establishment of rules that specify contingencies (referred to as objectives), and the effects of cooperation on behavior have all been explored in behavior analysis studies (de Carvalho et al., 2018, 2020; de Toledo et al., 2022; Harte et al., 2020; Zapparoli et al., 2021). However, the gamification literature may introduce new variables not commonly addressed by behavior analysts, such as the impact of storytelling and sensations on learning outcomes.

Toda, Klock, et al (2019) used the dimensions described in their paper to describe gamified learning environments. And the same can be done with the dimensions interpreted using terminology of behavior analysis. Performance elements can be described as different conditioned reinforcers: points, progression and stats all change as consequences of the participant's response, and are described by the authors as "feedback elements". And although they are all consequences, this division help us pay attention to different types of feedback that might be presented.

Fictional and personal elements can be interpreted as motivational operations, increasing the reinforcement value of the performance elements (Michael, 2000; Miguel, 2013). But they can also be described as characteristics that give coherence to the procedure: the objective, storytelling and sensations must "make sense" as well as to be interesting and motivating (if Miner was an astronaut, the story wouldn't make sense), and consequentially, be reinforcing for the participants (Bordieri et al., 2016).

Although not present in Miner Troubles, the social element is broadly studied in behavior analysis as the effect of different competition/cooperation contingencies in the behavior of individuals or groups (Azrin & Lindsley, 1956; Couto et al., 2023). And ecological elements are described as characteristics of the procedure that might influence participants' behavior. That could be interpreted simply as the contingencies in which responding can occur (chance, imposed choice, rarity, time pressure), but their specific effects on behavior might not be well understood yet. Therefore, ecological elements could be interpreted as "setting conditions", situational factors that affect behavior, but are not specifically described in a traditional three term contingency (Hayes & Fryling, 2023).

DISCUSSION

Miner Troubles was described based on its characteristics and gamification elements, but it can also be examined through the variables studied in the field of stimulus equivalence (Arntzen, 2012). For instance, the software utilizes a DMTS procedure, the criterion for completing a training block is based on the number of consecutive correct responses, the procedure involves three comparison stimuli, the program is divided into training and testing blocks, it allows for manipulations in the stimuli used, and in the training structure (linear, one-to-many, many-to-one). Therefore, the software encompasses attributes from both the stimulus equivalence and gamification field.

And although Miner Troubles is an innovative way to present an MTS procedure, this is not the first attempt to propose a new software for teaching and testing stimulus relations. The formation of equivalence classes has been accomplished using various procedures, including the go-no-go procedure (Debert et al., 2007), respondent type procedure (Leader et al., 1996; Ribeiro et al., 2020), IRAP procedure (Leech & Barnes-Holmes, 2020), MTS with paper sheets (de Rose et al., 1996), and computer applications and games (de Souza et al., 2017; Nascimento et al., 2012). These studies demonstrate that the process of learning relations between stimuli, particularly through a conditional discrimination procedure, is a powerful technology that can develop complex behavior.

Creating the Miner Troubles software was an attempt to incorporate that vast behavioral technology and knowledge to gamification research. There are several studies that show how manipulation of different parameters can change equivalence class formation, such as training structure (Oliveira et al., 2021), delay to present comparison stimuli (Arntzen, 2006; Arntzen et al., 2018), and number of class members (Regaço et al., 2023; Zhi et al., 2023). But the development of the software also aimed to increase the number of variables that can be studied by behavior analysts, by incorporating what is known in gamification research.

For example, studies on rule following that utilize conditional discrimination procedures (de Almeida et al., 2020; Harte et al., 2017, 2018; Schmidt et al., 2021), could benefit from the use of a gamified MTS approach, expanding the range of variables studied. A more complex software could allow for the manipulation of various characteristics, such as narrative elements, the inclusion of different characters and target audiences (with different characteristics, such as gender), the presence of multiple players, different consequences for behavior, among others. And, considering the advances that gamification research has made in enhancing learning environments (Sailer & Homner, 2020), studies on EBI can develop and test different gamified procedures to establish socially relevant behavior with better motivational operations elements.

From the other perspective, behavior analysis can contribute with gamification research by providing procedures that can be used to test different gamification elements (such as the MTS); providing different ways to test and manipulate variables experimentally (as single subject designs); and developing a more comprehensive description of gamification elements better aligned with behavioral principles. The MTS procedure serves as an excellent example, as it is based in well-known behavioral principles (Sidman, 1994), and has been employed to assess the efficacy of several different variables in learning outcomes (e.g., Arntzen, 2012; Mizael et al., 2021).

As examples, a central question that remains underexplored in gamification is how different game elements can impact performance and engagement (Dichev & Dicheva, 2017; Majuri et al., 2018; Ofosu-Ampong, 2020). In a literature review, it was found that over 60% of papers applied and tested at least three game elements, but without controlling for the effect of each individual element (Dichev & Dicheva, 2017). Furthermore, most studies tend to focus on the combination of the same three elements (points, badges, and leaderboards) without examining other potential game elements such as progress, choice, and narrative (Majuri et al., 2018). The challenge of testing the effects of different game elements arises when there is a lack of traditional procedures to assess the impact of various gamification elements. Therefore, the creation of gamified behavior analytic procedures, such as Miner Troubles, not only allows for the experimental investigation of new variables by behavior analysis but can also help develop a better understanding of the behavioral outcomes of parametric manipulations in game design research.

The procedure presented in this paper has been tested in a master's dissertation (Regaço, 2021) and in some lab exercises within the undergraduate psychology program at Universidade Federal de São Carlos (Brazil). However, no comparisons were conducted between the conventional MTS procedure and the Miner Troubles software. This question should be addressed in future experiments to determine whether the inclusion of game design elements has an effect not only on learning but also on the evaluation of the procedure. But many other questions arise from the creation of a gamified software that can only be answered by experimental research. Miner Troubles is only one example of a collaboration between behavior analysis and game design research that, we hope, can foster more interdisciplinary and broader research agendas within behavior analysis (Killeen, 2018).

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