Mineral Supertrumps: A New Card Game to Assist Learning of Mineralogy

Carl Spandler[1,a]

ABSTRACT

Mineralogy is an essential component of Earth Science education, yet many students struggle to obtain adequate comprehension and knowledge of mineralogy during tertiary (postsecondary) degree programs. The use of educational games can be an effective strategy for science teaching as games provide an active learning environment that enhances student engagement and motivation. This paper introduces a new card game called "Mineral Supertrumps" that can be used to counter the challenge of learning mineralogy at either secondary or tertiary level. The card game includes information on the properties of 54 minerals, which include the most important rock-forming minerals as well as minerals of industrial and economic significance. The game is easy to learn and play, and it is designed to motivate learning of mineral properties through active and competitive game-play in a group setting. Group play also helps to build identity and culture around student cohorts, which may also promote learning outcomes. Most students in the second year of a tertiary geology program surveyed after playing the game found it enjoyable to play and considered it to be effective for enhancing learning about mineral properties and their application to society and other Earth Science disciplines. Nevertheless, our survey results also indicate that student engagement with the game (and hence, learning benefits) may be limited if the game is not integrated with other course content, and/or it is not linked to incentive-based exercises (e.g., assessment). © *2016 National Association of Geoscience Teachers*. [DOI: 10.5408/15-095.1]

Key words: card game, mineralogy, active learning, group learning

INTRODUCTION

Mineralogy is considered one of the cornerstone subjects of geoscience curriculum because it provides the basic information from which we can understand the composition and behavior of Earth and planetary materials. Knowledge of mineralogy is essential to a range of geoscience fields, such as ore geology, petrology, geochemistry, mineral processing, geophysics, and environmental science, and it is also important to other research fields such as materials engineering, medicine, agriculture, and planetary sciences (Bibring et al., 2006; Sahai, 2007; Dyar et al., 2008). Nevertheless, in recent decades, there has been a trend towards reducing the amount of mineralogy teaching in undergraduate Earth Science courses across much of the globe, as course contact hours have decreased and additional subject content (e.g., hydrology, environmental sciences) has been introduced (e.g., Dyer et al., 2004; Gunter, 2004; Cook, 2011). Basic knowledge and understanding of the properties of rock-forming minerals remain the most powerful tools for gaining deep understanding of Earth systems (Dyar et al., 2008), yet students of the Earth Sciences often have difficulty learning mineralogy because it requires extensive knowledge of the properties, classification, and uses of minerals (e.g., Wulff, 2004; Manduca, 2007). Traditionally, mineralogy is taught via lecture-based content delivery that progresses from crystallography theory through aspects of various minerals groups, and practical exercises designed to teach specific mineral properties (e.g., Dutrow, 2004; Dyar et al., 2004). This approach uses rote learning of mineral properties, and it is often perceived as too onerous (Dohaney et al., 2012) or boring by students (Boyle, 2007). This format also does not easily allow integration of the ways in which mineralogy can be applied to real-world problems, such as mineral processing, economic geology, and environmental management.

Recent pedagogical research indicates that diverse student cohorts—as many undergraduate Earth Science classes are today—learn most effectively when they are exposed to a range of different teaching approaches (Manduca, 2007) and when they are engaged as active learners (Perkins, 2007; Wirth, 2007). Therefore, in recent years, many alterative teaching strategies have been proposed to improve student engagement and learning of mineralogy, including using poetry, mnemonics, and cartoons (Rule, 2003; Rule et al., 2004; Rule and Ague, 2005), project work (Moecher, 2004; Wirth, 2007), group exercises (Goodell, 2001; Dohaney et al., 2012), and social media (Kennelly, 2009).

Games and simulations have been demonstrated to be highly effective educational tools in many science fields (Franklin et al., 2003; Kumar and Lightner, 2007; Martí-Centelles and Rubio-Magnieto, 2014). Educational games can focus student attention, can enhance positive peer relationships, and can lead to a deeper understanding of material and more advanced problem-solving skills (Nemerow, 1996; Srogi and Baloche, 1997; Kumar and Lightner, 2007; Wilson et al., 2009). Despite this, there are surprising few cases where games are used as pedagogical tools in the Earth Sciences (see Reuss and Gardulski, 2001).

Through this paper, I introduce a new card game called "Mineral Supertrumps" that presents the properties and importance of 54 rock-forming minerals. The game involves three to five players, is relatively easy to learn

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[1]Economic Geology Research Unit (EGRU), James Cook University, Townsville, QLD 4811, Australia

[a]Author to whom correspondence should be addressed. Tel.: 617 47816911; Electronic mail: Carl.spandler@jcu.edu.au

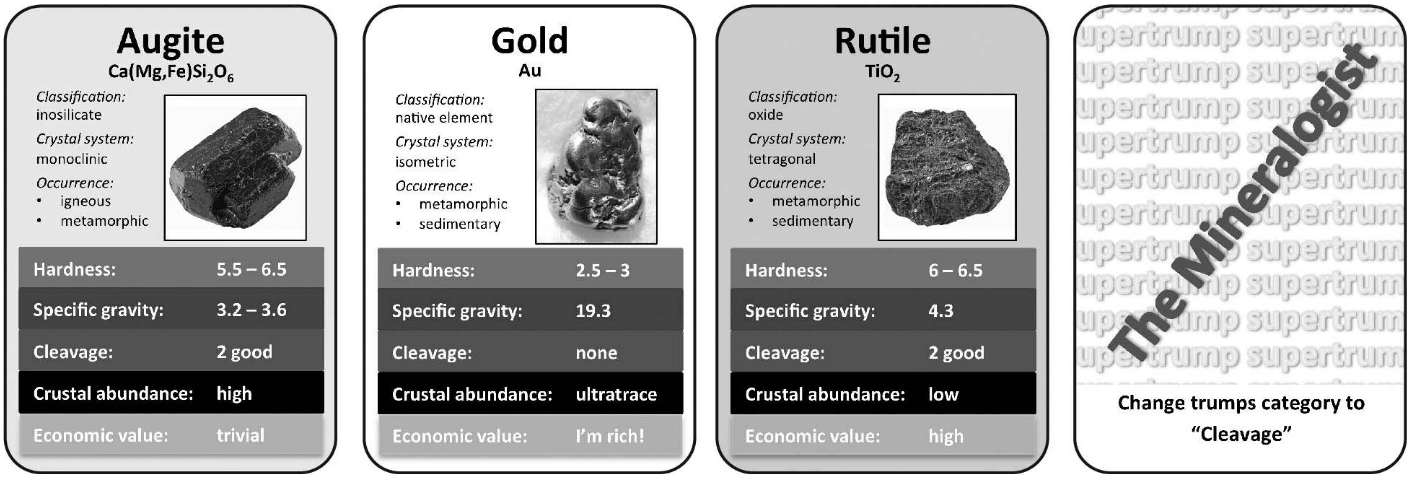

FIGURE 1: Examples of Mineral Supertrumps cards. Each of the mineral cards (augite, gold, and rutile, in this case) features an image of the mineral, the mineral name, generic chemical formula, classification, crystal system, and occurrence environment (mantle, igneous, sedimentary, metamorphic). The five trump categories (Hardness, Specific Gravity, Cleavage, Crustal Abundance, Economic Value) are shown in the colored rectangles in the bottom half of each card. The card backgrounds are color-coded according to the mineral group. For example, silicates (e.g., augite) are shaded green, native elements (gold) are white, and oxides (rutile) are shaded blue. The fourth card labelled "The Mineralogist" is an example of a supertrump card that allows the player to change the trump category. In this case, "The Mineralogist" card would be used to change the trump category to "Cleavage."

and play, and requires little more than the card pack to play. The game can be used as a resource for teaching mineralogy to students at various education levels (high school, undergraduate, postgraduate) and is designed to promote active learning of the properties and classification of minerals, as well as aspect of their importance to Earth Science disciplines and modern society. Inclusion of Mineral Supertrumps into Earth Science curriculum at secondary or tertiary level has the potential to enhance development of student culture and interaction, and it may redress the difficulties students face in acquiring knowledge of mineral properties and uses.

ABOUT MINERAL SUPERTRUMPS

Mineral Supertrumps is a group card game that has similarities to other card games such has Crazy Eights, Uno™, and Top Trumps™. The pack consists of 54 mineral cards and six additional cards called supertrump cards (Fig. 1). The cards are durable, colorful, and easy to read, which make them visually appealing to students (see also Franklin et al., 2003). The suite of minerals featured was chosen to cover the most important rock-forming minerals (e.g., Deer et al., 1992), as well as some rare minerals of economic significance and public interest, such as gold and diamond. The full list of minerals (available in the online journal and at http:dx.doi.org/10.5408/15-095s1) covers a diverse range of geological environments, including the upper mantle, oceanic and continental crust, metalliferous ore bodies, and regolith environments.

Each mineral card includes information about the mineral, such as the generic chemical formula, the classification, crystal system, and the geological environment where the mineral is commonly found or formed (igneous, metamorphic, sedimentary, or the mantle), as well as information in the five playing categories of Hardness, Specific Gravity, Cleavage, Crustal Abundance, and Economic Value. Hereafter, these playing categories will be referred to as trumps. The first three trump categories relate to distinct physical properties that are used for mineral identification, while the last two categories rate the importance of the mineral in terms of abundance in the Earth's crust (continental and oceanic) and value to modern societies. The mineral cards are also color coded by mineral type and feature an image of a well-formed crystal of the mineral.

The values used for the trump categories have been designed with not only geological relevance in mind, but also to ensure effective and easy playing of the game. The Hardness and Specific Gravity categories use numerical values of Mohs hardness scale and g/cm^3, respectively, whereas the more complex system of values used for Cleavage is based on how well and how many cleavage planes are usually expressed in natural forms of the mineral. The Crustal Abundance and Economic Value categories are ranked by importance into six values (available in the online journal and at http:dx.doi.org/10.5408/15-095s1). The system of values was formulated based on reference to many mineralogy sources (e.g., Deer et al., 1992; Nesse, 2004; Johnsen, 2007; http://www.mindat.org; http://www.webmineral.com), as well as the author's own expertise in mineralogy, economic geology, and petrology.

The six supertrumps cards (Fig. 1) are named for general geological professional fields (The Geologist, The Geophysicist, The Miner, The Mineralogist, The Gemologist, and The Petrologist), and each relates to a particular trump category (except The Geologist, which relates to all categories). These cards are used to change the trump category during card play, which keeps game-play dynamic and allows the players to play strategically (see following).

INSTRUCTIONS FOR GAME-PLAY

Mineral Supertrumps is played by three to five players and only requires the card pack and a space for play (e.g., a card table). For players, the objective of the game is to lose all of their cards. Like most card games, there are elements of luck and strategy to winning, and knowing the mineral properties of the cards is a clear advantage, although specific prior knowledge of mineralogy is not required for play. A full list of playing instructions (available in the online journal and at http:dx.doi.org/10.5408/15-095s1) is included with the card pack (available in the online journal and at http:dx.doi.org/10.5408/15-095s2). The instructions for play are as follows:

1. A dealer (randomly chosen) shuffles the cards and deals each player eight cards. Each player can look at their cards, but they should not show them to other players. The remaining card pack is placed face down on the table.
2. The player to the left of the dealer goes first by placing a mineral card on the table. The player must state the mineral name, one of the five trump categories (i.e., either Hardness, Specific Gravity, Cleavage, Crustal Abundance, or Economic Value), and the top value of that category. For example, a player placing the Glaucophane card may state "Glaucophane, Specific Gravity, 3.2." This verbal articulation is designed to enhance memory retention of the mineral and its properties for all of the players.
3. The next player to the left takes the next turn. This player must play a mineral card that has a higher value in the trump category than the card played by the previous player. In the case of the example of the Glaucophane card, the player must place a card that has a value for specific gravity above 3.2. The game continues with the next player to the left, and so on.
4. If a player does not have any mineral cards that are of higher value for the specific trump category being played, then the player must pass and pick up one card from the card pack on the table. The player then cannot play again until all but one player has passed, or until another player throws a supertrump card to change the trump category, as described next. A player is allowed to pass even if they still hold cards that could be played.
5. If the player has a supertrump card (The Miner, The Geologist, The Geophysicist, The Petrologist, The Mineralogist, The Gemologist), then they may play this card at any of their turns. By placing a supertrump card, the player changes the trump category according to the instructions on the supertrump card (e.g., see Fig. 1). The player then plays a mineral card of their choice to resume play. At this stage, any other player who had passed on the previous round is now able to play again. If a player happens to hold both The Geophysicist card and the Magnetite card in their hand, then that player can place both cards together to win the round.
6. The game continues with players taking turns to play cards until all but one player has passed. The last player then gets to lead out the next round and chooses the trump category to be played.
7. The winner of the game is the first player to lose all of their cards. The game continues until all but one player has lost their cards. A typical game will last 10 to 15 min and will use all, or nearly all, of the cards in the pack.

Like many card games, there are strategies that can increase the chance of winning. Knowledge of the values of the trump categories (i.e., mineral properties) of the mineral cards enables the player to judge the strengths and weaknesses of the cards in their hand in relation to the entire suite of cards. This in turn allows the player to evaluate their chance of winning a round using their cards, particularly if they can remember the cards that have already been thrown. The cards with high values in various trump categories and supertrump cards should be used to try and win a round, so that the player can lead out the next round, and hence choose the trump category of play. When leading out a new round, a player should begin with a card that tends to have low values for many categories; these cards are difficult to get rid of otherwise. Awareness of the game-play of other players (e.g., which cards they throw, when they pass on a round, how many cards they have in their hand) is also useful for formulating playing strategies (e.g., which trump category to choose) and increasing the chances of winning.

BENEFITS TO STUDENT LEARNING OF MINERALOGY

The game was developed at James Cook University, Australia, over a period of 18 mo and involved consultation and review by geology staff and students. The game was specifically designed with two main objectives: (1) to provide an interactive, cooperative, and fun way to teach the important properties of economically significant and common rock-forming minerals, which traditionally required a substantial amount of individual rote learning and was often perceived by students to be particularly challenging (e.g., Dohaney et al., 2012), and (2) to develop the link between minerals and their importance to modern societies (i.e., economic value) and as the building blocks of Earth. This aspect of the game helps tie core mineralogy curriculum to broader aspects of Earth Science, including the natural resource sector, where many geology graduates develop their career path. The trump categories were specifically chosen so that the game attributes match to the desired learning outcomes—a design feature that is recognized to be crucial to the effectiveness of education games for learning (Wilson et al., 2009).

The game is designed to improve player's knowledge of mineralogy primarily through memorization of mineral properties and uses. In this regard, Mineral Supertrumps is similar to chemistry games such as ChemMend (Martí-Centelles and Rubio-Magnieto, 2014) and Elements (Sevcik et al., 2008), which facilitate memorization of the periodic table. Although falling into disfavor in much of the contemporary pedagogical literature (e.g., Novak, 2010), memorization is arguably an effective, if not essential, initial step to reaching a deep understanding of subject material (Klemm, 2007). Using Mineral Supertrumps for memorization of mineral properties and their uses is likely to be much more effective than traditional methods of rote memorization because: (1) The game is designed to focus the student's attention to the mineral information, which improves retention of the information (Franklin et al., 2003; Klemm, 2007). Based on results of other pedagogical research (Nemerow, 1996; Cagiltay et al., 2015), it can be expected that the competitive nature of the game will also build student motivation and further promote learning outcomes. (2) Most players have fun playing the game (see questionnaire results presented later herein), and positive emotions have been demonstrated to enhance learning (e.g., Bisson and Luckner, 1996; Srogi and Baloche, 1997), including improved memory development (Hu et al., 2007). (3) The game not only motivates memorization of specific values of mineral properties, but also their relative value compared to other minerals and other properties. For example, a proficient player may not only learn that galena has a specific gravity of ~7.6 g/cm^3 and three perfect cleavages, but also that these values are high compared to the majority of other minerals (most have a specific gravity of between 2.5 and 4.5 g/cm^3, and less than three perfect cleavages). This level of knowledge construction is more amenable to reaching a deeper understanding of mineralogy and, ultimately, to real-world applications; an example of the case in point may be how to effectively separate Pb-rich ore from unmineralized country rock. (4) The group nature of game-play also aims to foster social interaction and develop student culture and identity, which have been demonstrated to be particularly effective for successful learning of Earth Sciences (Srogi and Baloche, 1997; Perkins, 2005, 2007; Wirth, 2007; Dohaney et al., 2012).

A convenient aspect of the game is that it is easy to learn and does not require any significant time or resources from the instructor or students to set up, although it is recommended that the instructor provide clear instructions for game-play, and a discussion or debriefing session after game-play to promote student experience and engagement (see Franklin et al., 2003; Kumar and Lightner, 2007). The game is amenable to use in a variety of settings and locations, from the classroom to the field, and it is suitable for a range of players, from those with no background knowledge of mineralogy through to expert mineralogists. Given the quantity of information provided on the playing cards, even players with advanced knowledge of mineralogy can benefit from using the game.

STUDENT EVALUATIONS

There are over 5,000 known mineral species, each with their own list of properties and potential uses (e.g., http://rruff.info/ima/), so it is not surprising that mineralogy is considered to be particularly difficult to learn (Wulff, 2004; Manduca, 2007). Mineral Supertrumps includes 54 of the most important of minerals (i.e., about 1% of the total), but it still provides a wealth of mineralogical information that is not expected to be learned entirely from playing the game in one, or even several, sessions. Rather, it is expected that optimal learning outcomes would come when the game is used recurrently over extended time periods and in conjunction with other methods of mineralogy instruction, such as hand sample descriptions (see following). For this reason, many of the testing procedures commonly used to evaluate educational methods, such as pre- and posttests, are not well suited to assessing learning outcomes of playing Mineral Supertrumps. Instead, insights into student perceptions and experiences with the game were obtained through the use of questionnaires that focused on the use and learning benefits of the game. A similar approach has been used for evaluation of other educational games (e.g., Reuss and Gardulski, 2001; Franklin et al., 2003; Kumar and Lightner, 2007; Spiegel et al., 2008).

Geology degree programs at James Cook University have a strong focus toward economic geology, so mineralogy is an essential component of the curriculum. Aspects of mineralogy are introduced at the first-year level, and they are further developed through dedicated mineralogy subject content in year two, and by embedding mineralogy into most second-, third-, and fourth-year subjects (e.g., field classes, petrology, economic geology, geochemistry, sedimentology). Second-year students taking the core subject of introductory mineralogy and igneous petrology were each given a Mineral Supertrumps card pack to keep, and then they were asked to complete two separate questionnaires; Questionnaire 1 was taken directly after playing the card game for 1 h during a regularly scheduled practical class, and Questionnaire 2 was taken by the same student cohort approximately 5 mo later. The students were not formally asked or required to use the game in the intervening time period. Participation in both surveys was voluntary, and student anonymity was maintained, in accord with Australian standards of human research ethics.

The first questionnaire consisted of eight questions or statements, as listed in Table I, to which the participating students were asked to respond by way of ranking from "strongly disagree" through to "strongly agree." To a large degree, this survey measures students' perception of the effectiveness of the game for learning. Sixty out of 64 students that attended the class completed and returned the questionnaire. Questionnaire 2 was completed by 43 students and was designed in a similar fashion to the first, except it only consisted of five questions/statements. The percentage of responses in each category for each question/statement is given in Table I.

Results from Questionnaire 1 taken immediately after playing the game were very positive. Over 80% of students surveyed found the game easy to learn (93% agree or strongly agree) and enjoyable to play (82%; Table I). Students perceived that the game would assist learning of mineral properties (89%), but they were less positive (60%) about the benefits to other fields of Earth Science (e.g., geophysics, geochemistry, economic geology), possibly because they had not had substantial exposure to these disciplines at this early stage of the degree program. A strong majority (>85%) of students indicated that they would use the game outside of scheduled class times, and they indicated that it would be well suited to first- and second-year undergraduate students. Also, 88% of students agreed that the group activity of game-play leads to enhanced learning outcomes.

Results of the Questionnaire 2 were overall less positive than the first questionnaire. The first two questions about the game being enjoyable to play and assisting learning of mineralogy (Table I) were very similar to questions in Questionnaire 1, with similar results obtained between the two questionnaires. In contrast, the students were much less positive about their received learning benefits from the game, with only around 40% of students agreeing that the game helped them study for their mineralogy class and led to improvements in their knowledge of mineralogy. These responses at first seem to be at odds with the general

TABLE 1: Survey results of student questionnaires, as percentage of respondents.

Question/Statement	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree	Agree + Strongly Agree
Questionnaire 1 (n = 60)						
1. This game is easy to understand and play	0	0	7	55	38	93
2. I enjoyed playing this game	0	0	18	57	25	82
3. This game will help me learn about mineral properties	0	5	7	67	22	89
4. This game will help me learn about applications of mineralogy to other geoscience fields, such as geophysics, geochemistry, and economic geology	0	12	28	57	3	60
5. I would use this game outside of scheduled lecture and practical class times to help me learn about mineralogy/geology	0	2	13	55	30	85
6. This game would be useful for teaching geology at first-year level	0	2	8	53	37	90
7. This game would be useful for teaching geology at second-year level	0	2	7	63	28	91
8. Playing the game in a group enhances the learning outcomes of the game	0	3	8	68	20	88
Questionnaire 1, Overall Average	**0**	**3**	**12**	**59**	**25**	**85**
Questionnaire 2 (n = 43)						
1. I enjoyed playing this game	0	5	18	44	33	77
2. This game helps me learn about mineral properties and uses	0	2	19	53	26	79
3. This game helped me study for my mineralogy/petrology class	5	16	40	30	9	39
4. My knowledge of mineralogy has improved due to playing this game	5	5	53	30	7	37
	Never	Rarely	Sometimes	Often	Very Often	
5. I have played this game outside of scheduled class times to help me learn about mineralogy	12	35	44	0	9	

perception that the game does help learning of mineralogy (89% and 79% agree or strongly agree in Questionnaires 1 and 2, respectively; Table I), but they are perhaps reconciled by examining how often the students used the game outside of scheduled class time, which was only the initial 1 h immediately before taking Questionnaire 1, and 5 mo before taking Questionnaire 2. Nearly half of the students had never or had rarely used the game, and these students

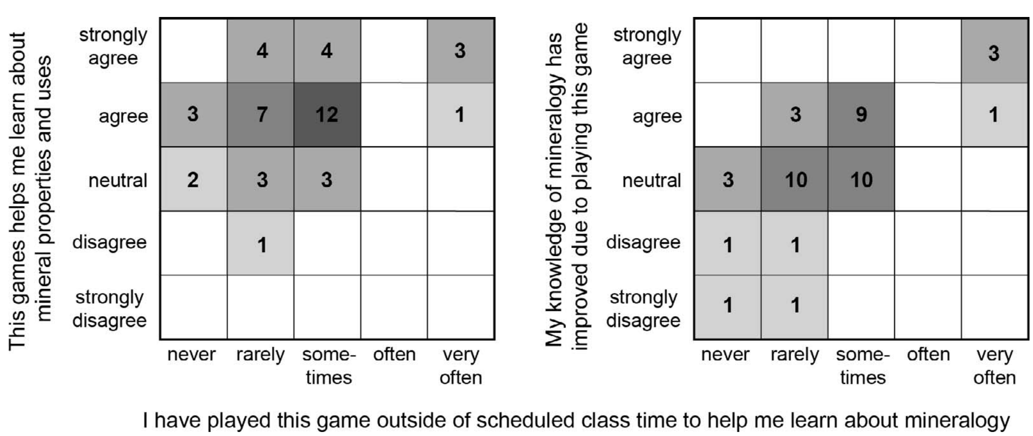

FIGURE 2: Correlation matrix plots comparing responses to statements from Questionnaire 2. The rows of the left and right matrices record the student responses to Statement 2 and Statement 4 (see Table 1), respectively. The columns of both matrices record the student responses to Statement 5. The numbers in each of the matrix elements refer to the number of returned questionnaires that answered with these specific response combinations.

tended to be less positive about their received benefits from the game (Fig. 2). In contrast, those students who had used the game occasionally to very often did consider that their knowledge and academic performance had improved. The relatively low usage rate of the game was an unexpected result for the author, as 85% of the same student cohort had initially agreed or strongly agreed that they would use the game outside of class times (Question 5 of Questionnaire 1). Clearly, for many students, their initial intentions to use the game did not translate into actual usage, and several students commented that they would have used the game but did not have time or forgot that they had it, or they could not find a group to play with. This result is consistent with the study of Franklin et al. (2003), who found that educational game usage was significantly higher for curriculum-embedded (i.e., compulsory) games compared to noncompulsory games.

The student questionnaires were not designed to evaluate all aspects of student learning of mineralogy. Nevertheless, the results do lend support to the potential of using Mineralogy Supertrumps as a tool for teaching mineralogy. Most students enjoyed playing the game and perceived that the game-play promotes active learning of the properties and uses of minerals. However, despite their initial intentions, a relatively small number of the students actually used the game to substantially enhance their learning. The data indicate that game usage may have contributed to learning outcomes (Fig. 2), so better outcomes could be achieved if the game were integrated with other teaching material or exercises on mineralogy (i.e., prescribed use of the game in the curriculum), or if there were incentives to use the game beyond just the satisfaction of winning. Although the game involves no direct assessment to motivate student use, knowledge of mineralogy is an inherent advantage to winning the game (see instructions for game-play, above). Therefore, using the game with a reward-based objective for a class, such as an elimination tournament with a prize for the ultimate winner (e.g., Mineral Supertrumps Grand Slam), is likely also to enhance game usage outside of class times. Students can also be encouraged to use the game cards in different formats, for example, as flash cards for memorization, or as a ''Celebrity Heads'' [https://en.wikipedia.org/wiki/Celebrity_(game)] type game format that requires two or more people to play.

Experience with other educational games (e.g., Franklin et al., 2003) indicates that it is unlikely that all students will benefit from the game, even with extended use, so it is recommended that the game be used in conjunction with other practical approaches to teaching mineralogy, such as optical microscopy exercises and examinations of mineral specimen and crystal models.

The survey results reported here were taken from only one class of university students and, hence, are only considered as a preliminary appraisal of the game. Further testing of the game with student groups over longer time periods (e.g., the full duration of a Earth Science degree), with a greater diversity of students (high school, undergraduate to postgraduate students, students from a variety of cultural backgrounds), and in different educational settings (classroom or field) is recommended to provide a more comprehensive assessment of the use of the game for learning mineralogy. Despite the challenges of conducting pre- and posttests in this case (as discussed already), it is an aspiration to collect both qualitative (student perceptions and experiences) and quantitative data on the learning benefits of the game.

CONCLUSIONS

The use of Mineral Supertrumps as an aid to teaching mineralogy holds many benefits over traditional instructional methods. Being a card game that is relatively easy and enjoyable to play, it is suitable for student levels ranging from high school through to postgraduate, and it can be played in diverse environment from the classroom to the field. The interactive and competitive nature of game-play not only assists in active learning of mineral properties and their uses, but also can foster social interaction and development of student culture. Nevertheless, the game may not appeal to all students, and therefore it is recommended that game usage should be integrated with other instructional methods or approaches to optimize learning outcomes in mineralogy.

High-quality, professionally printed card packs are available at cost price by contacting the author at: carl.spandler@jcu.edu.au. Alternatively, the cards can be printed from the electronic file available in the online journal and at http:dx.doi.org/10.5408/15-095s2.

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