Testing the effectiveness of crossword games on immediate and delayed memory for scientific vocabulary and concepts

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Abstract

Word games such as crossword puzzles are widely used in education to help familiarize students with technical vocabulary. Despite an extensive literature discussing their use, few published research articles have established their effectiveness on memory retention and retrieval, especially in comparison to control study methods. We report two experiments in which university introductory psychology students studied materials relevant to their coursework using an on-line interactive word game. Results showed that word games improved later tests of the material, both on immediate test and after a delay, and retention was most enhanced in comparison to control when the clues were solved repeatedly and given with difficult orthographic hints. Importantly, easy clues were not retained over time even with multiple repetitions. Results suggest that word games can be effective in this domain, but it depends on how they are implemented, and several factors predicted by existing cognitive theory can guide implementation choices.

Keywords: word games; learning; retrieval practice

An extensive body of research has been published that describes how word games such as crossword puzzles can be used to help train students in vocabulary and conceptual knowledge. Reports describing their use have primarily occurred in two areas: (1) foreign language learning, especially for English as a second language (Thanasuan, 2015; Thanasuan & Mueller, 2016); (2) discipline-specific training in technical vocabulary, primarily in scientific disciplines (see Yuriev, Capuano, & Short, 2016). In both areas, most existing published accounts in academic and educational literature have focused on how the training was implemented, with relatively few validating their effectiveness.

The cognitive rationale for their use is linked to the processes believed to be involved in solving individual clues (see Mueller & Thanasuan, 2013; Thanasuan & Mueller, 2015, 2016). In a typical example, a student might be shown a definition or sentence using a word, such as "The originator of the subtractive method.", and given some hints about the letters and/or length of the answer, such as "_ O _ _ E _ _ ", with the correct response DONDERS. If this were a pen-and-paper exercise the filled-in letters may only be visible when the crossing clues are solved. In computerized versions, the number of letters can be generated randomly. Depending on how it is implemented, students might be encouraged to look up answers in their textbook, which gives them opportunities to learn related information. The potential benefits of this in comparison to a flashcard method (which is essentially the same, except the entire answer is shown), or a learning-by-testing method (which is the same but with the response completely blank) may come in several ways. First, it is framed as a game, and so may be intrinsically more enjoyable or engaging (Veinott et al., 2013, 2014). Second, it provides an orthographic route to solving the clue. This may help either focus the student on exact spelling, or help produce strong and more resilient representations because of orthographic processing. Finally, it can be adaptive, and so have the possibility to benefit students of different levels–if the response cannot be made from the clue alone, the student gets another chance once additional crossing letters are shown.

Thus, we'd expect the greatest benefits for knowledge domains in which orthography is an important aspect of the knowledge. This is clear for second-language learning (see Thanasuan, 2015): students need to learn associations between words in two languages that have similar or identical meanings but different orthography. A crossword puzzle requires reasoning about both aspects simultaneously, and so it may support learning and awareness of the specific associations that link L2 orthography to L1 conceptual knowledge, enabling better second-language abilities. However, the benefit of word games in other academic disciplines is less clear. Depending on the content and the level of the student, there may be no need to form strong associations between a concept and a novel surface form. There is a real possibility that word games provide no general benefit to learning, but students and teachers like them anyway.

Yet the benefits might be substantial in domains with a large technical vocabulary, such as scientific and medical disciplines. These domains can present challenges for students, because some may never reach the higher-level scientific thinking goals of the STEM classroom if they don't understand the vocabulary and low-level conceptual issues that form the basis for higher-order reasoning. This may especially hamper students who perform more poorly overall, and so using word games may provide a structured way for introducing complex material that they otherwise find difficult.

Table 1: Review of research validating the effectiveness of crossword-style word games outside of language learning.

Lead author/year	Field	Control	Validation	Testing delay	Results
1. Crossman, 1983	Psychology	No	Pre- vs. Post-test	Weeks	Post-test better than pre-test
2. Berry, 2008	Athletics	Yes	Course test	Delayed	No improvement
3. Davis, 2009	Sociology	Yes	In-class exams	Days	No improvement
4. Gaikwad, 2012	Pharmacology	Yes	Post-test	Immediate	Significant improvement
5. Coticone, 2013	Biochemistry	Yes	Final exam scores	Delayed	No improvement
6. Yuriev, 2016	Chemistry	No	Class exams	Weeks	Students completing more games performed better.

Review of Validation Studies of Word Games in scientific and medical disciplines

In technical disciplines such as science and medicine, word games (typically in the form of custom crossword puzzles) have been frequently proposed as an enjoyable way to learn vocabulary (e.g. Raines, 2007, 2010). Numerous published accounts, usually in educational practice journals and discipline-specific publications have described their use and implementation in the classroom. For example, in social sciences, they have been used in economics (Lin & Dunphy, 2013; Martinez Serna & Parra Azor, 2011); local history (Virgin & Goodrow, 1997); sociology (Childers, 1996; Davis, Shepherd, & Zwiefelhofer, 2009); and psychology (Crossman & Crossman, 1983). In physical sciences, they have been used in ecology and earth science(Armenteros Rius, 1989; Barbarick, 2010; McKenny, 1970). For biological sciences, these include: Berry and Miller (2008a, 2008b), and Franklin, Peat, and Lewis (2003). For pharmacology and chemistry, reports include Gaikwad and Tankhiwale (2012); Coticone (2013); Joag (2014); Lee and Tse (1994); Most (1993); Snead (1975); Yuriev et al. (2016) For physiology and medicine, research has often focused on medical students or working nurses (Bailey, Hsu, & DiCarlo, 1999; Ber, 2003; Gagnon, 1995; Htwe, Sabaridah, Rajyaguru, & Mazidah, 2012; Krekeler & O'Neill, 1983; Manzar & Al-Khusaiby, 2004; Saxena, Nesbitt, Pahwa, & Mills, 2009; Shah, Lynch, & Macias-Moriarity, 2010; Talavinia-Pasek, 1995; Townsend, 1990). Interestingly, these reports have primarily demonstrated *ONLY* the widespread use of word games across disciplines. Most of the published reports simply documented their use and construction, or provided a published puzzle teachers might use in their classes.

In fact, only about 1/3 of the reports we have identified have studied behavioral consequences of the training in any way–the majority of which used subjective assessments of effectiveness. These primarily involve survey methods that asked learners or teachers whether they enjoyed the activity or thought that it was effective. Although these types of assessments typically show that learners and educators felt the games are useful, they do not show they are effective, especially in comparison to a properly controlled alternative study method. After reviewing more than 100 research papers reporting on the use of crossword games as study aids, and excluding the research conducted on second-language learning, we found that only six evaluated the effectiveness of the method on a secondary performance test.

These six publications are shown in Table 1, and constitute *all* known research looking at the performance impact of crossword puzzles in non-language courses. Of these, two studies involved no control group: one showed improvement versus a pre-test (Crossman & Crossman, 1983) and another showed that students who elected to complete more puzzles did better on post-tests (Yuriev et al., 2016). These do not constitute strong evidence of the effectiveness of the method because of limitations in the design. Three others (Berry & Miller, 2008b; Coticone, 2013; Davis et al., 2009) examined the impact of crossword study on a later course test, and found no systematic improvement in comparison to a control group. In these studies, there was no evidence that word games harmed learning, which may be useful to know, but also no evidence they were effective. In fact, Gaikwad and Tankhiwale (2012) is the only study we have found that used a proper control condition and found improvements in a knowledge test as a result of study via a crossword puzzle. Thus, it is fair to say that the effectiveness of word-game training in science and medical fields has not been widely studied or consistently established. Consequently, we carried out four studies designed to test the effectiveness of word games for scientific vocabulary in a controlled study.

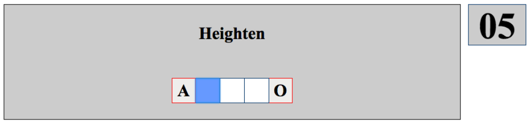
Experiment 1A and 1B: Immediate Testing

Experiment 1 involved two studies carried out during three sessions of an introductory psychology course, using different materials. The study was approved by the MTU IRB.

Participants

Participants were recruited from an introductory psychology course at Michigan Technological University, in exchange for partial course credit. Studies were offered during three different semesters, and participants were able to complete either or both studies. A total of 65 participants completed Experiment 1A, and 40 completed Study 1B.

Figure 1: Screenshot of crossword training software. The clue (Heighten) is shown at the top; the partially-filled response at the bottom (correct response: ADDTO), and time remaining on the right.



Materials and Design

Experiment 1A and 1B each involved a 2x3 mixed factorial designs. Training materials were counterbalanced across the conditions for a total of six counterbalancing groups, to which participants were randomly assigned. Experiment 1A manipulated feedback (fireworks present/absent) between and practice (control, 1x, 2x) within participant. Experiment 1B manipulated clue difficulty (easy or difficult) between and practice (control, 1x, 3x) within participant.

We developed 90 clues/questions, taken from review materials for the introductory psychology class covering the entire semester of concepts. In Experiment 1A, 45 clues were selected and divided into three sets of 15 items, which were counterbalanced across the practice conditions. In addition, half of the participants were given simple correct/incorrect feedback when each trial was completed, and a second group was shown a fireworks animation on correct completion, which was larger when the response was given faster. Animated feedback was manipulated to see if a more game-like training would be more effective. All trials began with a random number of starting letters in the clue, so that some were more difficult and others were easier. In Experiment 1B, the other 45 clues were selected and counterbalanced across practice condition. All participants were given the fireworks feedback, but difficulty was manipulated as a between-participants factor with either easy (all but 3 letters were given) and difficult (only 3 letters were given).

Procedure

Each study was comprised of a single 30-minute session, which took place on-line at a location of the students choosing. Participants were directed to a web page that provided a sequence of training links for them to complete, with the last link leading to a knowledge test.

The training rounds were implemented using on-line word game software described by Thanasuan and Mueller (2016). During the training rounds, each clue/response pair was provided on the computer screen, and the answer typically had several letters filled in (see Figure 1). Participants had 30 seconds to complete each clue, after which they were either told they were correct, or shown the correct answer.

The final link on the page directed them to a testing page, which was implemented via a Google Drive form. The test was comprised of the 45 questions with a free response. The order of the clues was randomized. Participants completed as many of the test questions as they chose to, with all test questions on the same page. Once they completed the test, they submitted it for credit. To measure performance, one full point was given for each response that was identical to the learned material. For several questions, partial credit of .5 points was given for minor mistakes.

Results

Results for Experiments 1A and 1B are shown in Figure 2. For Experiment 1A and 1B, we first examined correct recall scores with a Type-II factorial ANOVA using the R package `ez` (Lawrence, 2016). For Experiment 1A, there was no significant effect of animated feedback ($F(1,59) = .34$, $p = .56$, $ges = .004$), a significant effect of repetition ($F(2,118) = 105$, $p < .001$, $ges = .37$), and no significant interaction ($F(2,118) = .12$, $p = .88$, $ges = .0007$). In Experiment 1B, although there was no main effect of difficulty ($F(1,36) = 2.9$,$p = .098$, $ges = .048$), there were significant effects of repetition ($F(2,72) = 38$, $p < .001$, $ges = .28$) and the difficulty x repetition interaction ($F(2,72) = 3.8$, $p = .026$, $ges = .037$). The significant interaction indicates thatwhen the questions were trained, difficult training was more effective than easy training.

It is also useful to test whether repetition had an effect in each difficulty condition in Experiment 1B when control materials were excluded. Post-hoc paired t-tests showed that for the easy learning condition, improvement was marginally significant as repetitions increased from 1 to 3 times ($t(18) = 1.9$, $p = .069$, $\eta^2 = .43$). In contrast, for the difficult learning condition, recall increased significantly for the same comparison ($t(17) = 3.2$, $p = .005$, $\eta^2 = .77$).

Discussion

Experiment 1 showed that for immediate testing, both repetition and problem difficulty are important predictors of recall. In contrast, an animation designed to provide feedback had no impact on later recall.

The animation may have been ineffective for several reasons; it may be that the game-based aspects of word games already provide an engaging activity, and so additional aspects do not improve performance further. On the other hand, it may be that because the fireworks animation had no direct effect on gameplay, it was ignored and neither enhanced nor interfered with performance.

The effect of difficulty may appear counter-intuitive, but is in line with the notion of "desirable difficulty" (Bjork & Bjork, 2011). Here, the easy problems may not have required deep semantic search and processing, and so they may not have left robust memory traces as a side-effect of processing. Thus, these experiments show that word-game training can be effective at improving immediate retrieval of vocabulary and conceptual knowledge in a scientific discipline. Such results have been only shown once previously.

Although effective learning in immediate testing is a minimally-sufficient bar, it may have important uses in the

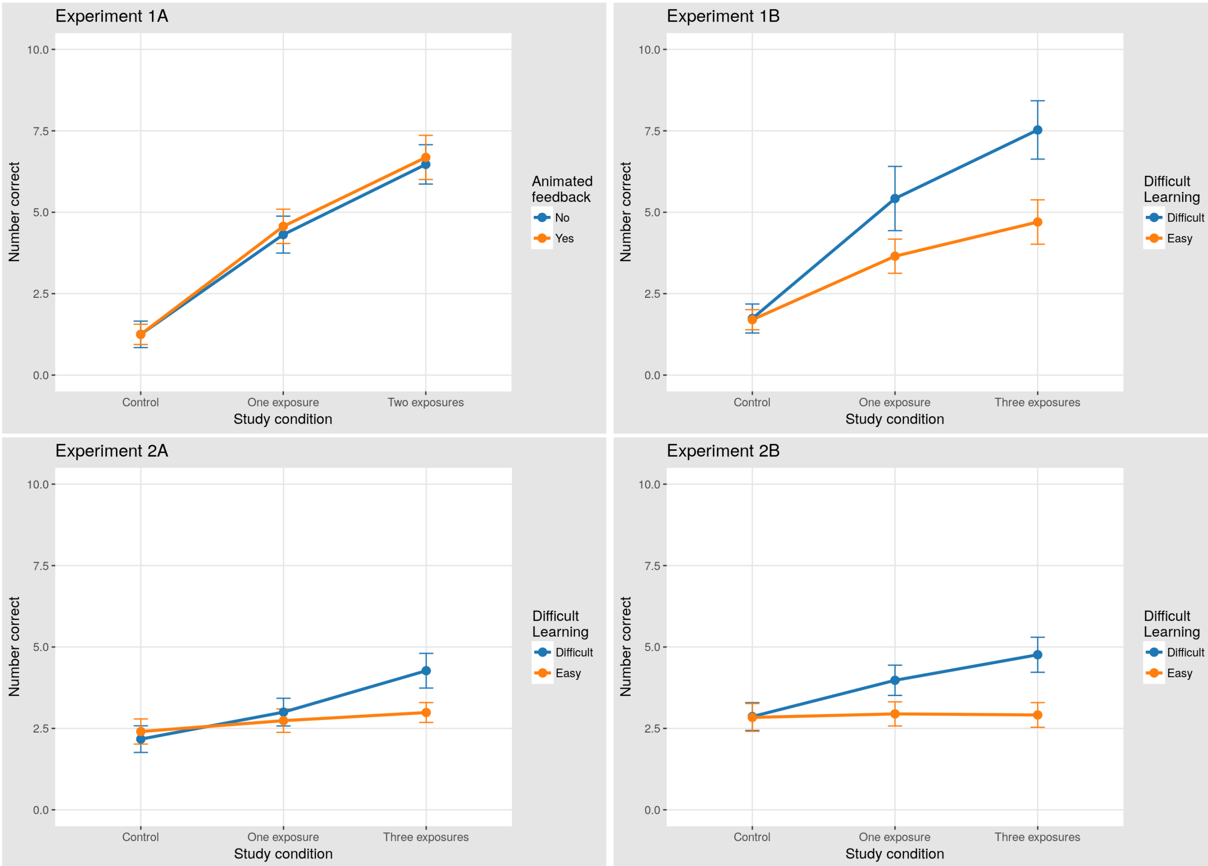


Figure 2: Results from Experiment 1 (top panel) and 2 (bottom panel). Experiment 1 involved immediate tests of retention, and varied feedback and orthographic difficulty. Experiment 2 involved the same materials but with delayed testing.

classroom. For example, a brief word game at the beginning of a class session may be used to ensure students have a short-term familiarity with material, allowing them to follow a deeper lecture or applied lesson that puts those concepts into use and helps solidify knowledge. However, it would be more important to show that the knowledge learned during word games is retained after a delay as well. The difficulty manipulation we examined in Experiment 1B may be especially relevant. Past researchers have extensively examined how deeper processing (Craik & Lockhart, 1972) promoted by more difficult activities (Bjork & Bjork, 2011) not only enhances recall, but produces more resilient and long-term knowledge. Thus, we may expect that after a delay, the benefit from the difficult learning will remain, while the benefit from the easy learning condition will be minimal. Experiment 2A and B were designed to investigate this.

Experiment 2A and 2B: Delayed Testing

Experiments 2A and 2B used the same materials as in Experiments 1A and 1B, the same methods as Experiment 1B, but required testing to be done at least one day after the learning session. We anticipated that retention would be diminished, but expected that the difficult learning condition would produce better performance than the easy learning condition.

Participants

All participants were recruited from a single introductory psychology class at Michigan Technological University, in exchange for partial course credit. Participation was voluntary. A total of 77 participants completed Experiment 2A, and 83 participants completed Experiment 2B.

Design

Both experiments used an identical 2x3 design, with repetition (control, 1x, and 3x) a within-participant variable and difficulty (easy versus difficult letter clues) a between-participant variable. The only distinction between the two studies was the materials used, which were identical, respectively, to Experiments 1A and 1B.

Procedure

The basic procedure was identical to Experiemnts 1A and 1B, except that once participants completed the training phase of the study, they were instructed that the testing phase could not begin until at least one day later. The testing phase was made available daily to participants who had completed the study on previous days, but when they completed it (and whether they completed it at all), was up to the participant.

Results

Results are shown in the bottom panel of Figure 2. We examined correct recall scores with a Type-II factorial ANOVA using the R package ez (Lawrence, 2016). For Experiment 2A, there was no significant main effect of difficulty ($F(1,75) = .82$, $p = .37$, $ges = .008$), a significant effect of repetition ($F(2,150) = 14.4$, $p < .001$, $ges = .04$), and a significant interaction ($F(2,150) = 5.9$, $p = .0035$, $ges = .017$). The same pattern was seen in Experiment 2B, for difficulty: ($F(1,85) = 3.3$,$p = .07$, $ges = .028$), repetition ($F(2,170) = 5.97$, $p = .003$, $ges = .017$) and the difficulty x repetition interaction: ($F(2,170) = 5.78$, $p = .003$, $ges = .017$).

As in Experiment 1, it is also useful to test whether repetition had an effect in each difficulty condition when control materials were not considered. Post-hoc paired t-tests showed that in Experiment 2A for the easy learning condition, there was no significant improvement as repetition increased from 1 to 3 times ($t(41) = .59$, $p = .56$, $\eta = .09$). In contrast, for the difficult learning condition, recall increased significantly as repetitions increased from 1 to 3 times ($t(34) = 3.2$, $p = .003$, $\eta = .53$). For Experiment 2B in the easy learning condition, there was again no significant effect ($t(45) = .1$,$p = .9$,$\eta^2 = .015$), but in this case only a marginally significant improvement for the difficult condition as repetitions increased from 1 to 3 ($t(43) = 1.88$,$p = .066$,$\eta^2 = .28$).

Experiment 2 Discussion

The results showed that word game training can be effective after a delay. Although the delay was fairly short (often as short as one day), effectiveness after delay has not been previously been demonstrated. In comparison to Experiment 1, results show relatively poorer performance, and no detectable learning effect for the easy learning condition. These suggest that word games on their own may not always be effective training, and the conditions under which they are used should be selected for maximum benefit.

General Discussion

The research reported here is only the second published controlled experiment showing that word games improve learning on scientific vocabulary, and the first to show that this improvement is retained the following day or later. This provides some important validation for a widespread practice in science and medical classrooms. In fact, this is just the second controlled research study to show a benefit to learning scientific or technical vocabulary on an immediate test, and the first to show that the benefit is retained after a delay. In addition, the results demonstrate that although word game training can be effective, it is highly dependent on implementation details that are linked to psychological theory on learning and memory. Several of the testing conditions we examined produced no significant benefit. This is especially true for easy letter clues that are studied just once.

Nevertheless, most existing teaching advice has used a single exposure of a crossword game to train vocabulary. We found that a single training incident typically produced only small gains in comparison to control, and gains were only significant and resilient over time when multiple exposures were given. This likely stems partly from repetition, but also because the initial exposures often led to failure to retrieve, and subsequent exposure lead to opportunities for retrieval practice. But repeated exposure alone is not sufficient. When completions were relatively easy, neither single nor repeated exposure produced substantial improvement in performance, especially after a delay.

It is perhaps ironic that the learning conditions we found to be least effective appear to be very similar to the preferred methods students have for studying: reading term-definition pairs one time, which gives them the impression that they know the concept, but does not present the retrieval challenge that is likely to produce long-term resilient memory traces. These factors, together with other methods we have yet to investigate such as using multiple distinct clues, examining spacing of practice, and using adaptive difficulty, may yield even stronger benefits.

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