

**Augmented Reality and Visuospatial Bootstrapping  
for Second-Language Vocabulary Recall**

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This paper examines second-language vocabulary memorisation using two technology-driven flashcard-based vocabulary learning tools. The use of augmented reality (AR) under visuospatial bootstrapping (VSB), a novel approach developed from work on the cognitive psychology of working memory, was contrasted with an application, Quizlet. Both were implemented using mobile devices. Quizlet has been extensively used in foreign-language teaching and learning practice. The experimental AR-VSB technique offered superior vocabulary learning compared with the Quizlet method in delayed post-tests, although statistical data indicate a somewhat higher forgetting rate after a week in the AR-VSB method. Even so, the experimental technique still offers superior retention compared with the method used in the control group and could be used as an effective initial input method for acquiring vocabulary items in second-language learning. These results imply communication between cognitive systems involved in storing short-term memory for verbal and visual information alongside connections to and from knowledge held in long-term memory when the target information is shown in a familiar array, which are deployed during the AR task and which support enhanced vocabulary learning. The main novel finding in this research has been that the integration of immersive AR experiences into familiar physical space has been seen to improve vocabulary recall test performance among a sample of twenty-first-century university students attempting to learn a second language. The evidence gathered from the experiment can have future practical applications and might contribute to immersive educational technology and innovative material development in second-language instruction.

Keywords: augmented reality; visuospatial bootstrapping; second-language learning; vocabulary learning

## **Purpose of this research**

Quizlet is a popular gamified application with 50 million monthly users (Glotzbach, 2018) which teaches vocabulary in lexical sets. Quizlet flashcards represent an example of typical

practice in modern second-language vocabulary learning. The present study attempts to see if a novel approach based on combining an augmented reality (AR) app with spatialization in the form of Visuospatial Bootstrapping (VSB) will offer the possibility of more effective learning of new vocabulary in a second language than the popular current Quizlet approach.

The experimental, AR-VSB enhanced method allows the possibility to use both visual and spatial memory as a support to verbal learning. This is in contrast the conventional method, which does not add spatial information to the process. While translational verbal aids on flashcards are used in the two input methods, the AR-VSB method also takes advantage of the possibility of linking to-be-learned vocabulary items to spatial locations. Spatial location can form a useful framework for integrating knowledge, a process that has become known as ‘spatialization’ (see, e.g. Guida, Leroux, Lavielle-Guida & Noël, 2016).

### **Review of current knowledge.**

Spatial intelligence has been associated with a heightened sense of situational awareness and of relationships in one’s own surroundings (Krokos, Plaisant & Varshney, 2019). The method of loci, a mnemonic strategy described by the ancient Greeks and Romans which links geographical location to items that need remembering (Yates, 1966; 1999) is currently used to improve memory in young people and elderly adults (Nyberg et al., 2003; Derwinger et al., 2003; Gross et al., 2012; Knauff, 2013 & Krokos; 2019). According to Qureshi et al. (2014) this technique relies on spatial relationships between “loci” (e.g., locations on a familiar route or rooms in a familiar building) to arrange and recollect memorial content. It was first attributed to Cicero in 55 BCE and it was used by medieval scholars to remember long speeches within the auditorium (Yates, 1999). The technique goes by a variety of names including the ‘Roman Room’, the ‘Memory Palace’

or the 'Journey Method'. As stated by Moè & De Beni (2005), application of the method of loci involves first selecting a series of distinct loci along a familiar pathway; then, creating an image for each item to be remembered or, if applied to passages, for each cue word corresponding to a concept; and finally placing images of the items in the selected loci and retrieving them mentally when retracing the loci pathway in the recall phase. According to Huttner and Robra-Bissantz (2017), on such a tour any simple object like a chair, cupboard or table can serve as an adequate locus.

In psychology and neuroscience, memory capacity is assessed by retention of digits, nonwords, unknown words, etc. It is more difficult to remember numbers than words (Bellezza et al., 1992), but strategic mnemonic procedures (such as encoding numbers as letters, words, locations or other visual-imagery organization) can facilitate memorization (Higbee, 2001; Pressley, Levin, & Delaney, 1982; Worthen & Hunt, 2011). According to Maguire et al. (2003), brain regions responsible for visuospatial memory and navigation such as the retrosplenial and hippocampal areas were demonstrated to be engaged during mnemonic encoding in non-spatial tasks, giving an indication of the neural basis for some spatialized effects.

Mnemonics, a set of memory-improvement techniques, enables the encoding of items "in a manner that makes these segments more familiar, abbreviated, or somehow less demanding to recall" (Atkinson, 1975). As discussed by Huttner and Robra-Bissantz (2017), people with superior memory may tend to apply a learning strategy that is based on spatial elements. Investigation of participants' brain activity with neuropsychological measurement instruments and brain imaging indicated that subjects had a higher engagement in brain regions associated with and crucial for human spatial memory. In accordance with the study performed by Maguire et al. (2003) and discussed by Huttner

and Robra-Bissantz (2017), the effectiveness and longevity of the method of loci suggests a natural human tendency to use spatial context to memorize and recall information.

“Visuospatial bootstrapping” (VSB) is a term used to describe the support of verbal memory by visuospatial memory— It was first demonstrated by initiated by Darling and Havelka in 2010 but has been frequently replicated (see Darling, Allen & Havelka, 2017 for a review). In the initial study (Darling & Havelka, 2010), three display conditions were employed: a condition in which digits were presented sequentially in the center of the screen, a linear condition in which digits were presented in a horizontal array across the screen and highlighted sequentially, and a keypad condition which used an array similar to that in the linear condition but based on the “T9” 3 x 4 mobile-phone keypad (Darling, Allen & Havelka, 2017) familiar from ATM machines and push-button telephones. Short term memory for sequences in the keypad condition was demonstrated to be better than those of the other two conditions. Visuospatial bootstrapping is an example of spatialized knowledge and information being used to support participants carrying out an essentially verbal task. Vocabulary learning (in a second language or otherwise) is itself a verbal memory task, and so it was considered that the bootstrapping phenomenon may form a useful basis from which to develop materials that may enhance vocabulary learning.

Vocabulary-acquisition techniques in EFL teaching could potentially be based on verbal (language-related) and visual (visual imagination (‘imagery’) based) aids: according to Solso (1995) and Baddeley (1999), useful strategic mnemonic devices can be of two types: visual imagery and verbal. These approaches echo dual coding theory (Paivio, 1971), which suggests retention is more efficient when both verbal and nonverbal codes are processed by the brain. Verbal units, named logogens by Paivio (1978), represent letters, syllables, conventional words, set phrases, idioms or sentences, among other options, and

they rely on visual and auditory encoding (Morton, 1979) as well as haptic (by touch) and motor (by movement) connections (Paivio, 1986; Sadoski & Paivio, 2001). The nonverbal units were called *imagens* or *pictogens* (Paivio, 1978) and could be used to assist memorization by providing associative connections with the *logogens*. Paivio's theory suggests that there may be benefits accruing from combining the two. A widely recommended means of enhancing foreign-language vocabulary through deliberate study has been using flashcards incorporating visual images (Elgort, 2010; Nakata, 2011; Nation, 2014; Nikoopour, Jahanbakhsh & Azin, 2014; Ashcroft et al, 2018), a technique that clearly is built on these theoretical foundations.

Flashcard techniques place a word in the target language (L2) on the front part of a card and the original-language (L1) translation on the back (Nation, 2001; Cross & James, 2001; Nation & Webb, 2011). Modern digital flashcards can be additionally supplemented with translations, images, sounds or animations (Chun and Plass, 1996; Chun and Payne, 2004). They are easily compatible with smart devices and provide more options to choose from for digital age teachers and learners. Quizlet (<https://quizlet.com/>) is one example of a commercial product translating flashcards into a digital presentation space.

Evidence of a memory benefit from presenting text and images together has already been extensively described in the academic literature (Wharton, 1980, 1985; Bernard, 1990; Glenberg & Langston, 1992; Reed & Beveridge, 1986, 1990) while in the area of Computer Assisted Language Learning (CALL), there was a shift during the 1990s from hypermedia (hypertext improved by sound and pictures), to multimedia approaches (text, pictures and sound appearing on the computer screen and being available to the use of various devices; Cameron, 1999).

Augmented Reality bridges the gap between the real and virtual worlds (Klopfer & Squire, 2008; Bronack, 2011; Siriborvornratanakul, 2018) by adding digital content on top of the already existing environment and by incorporating text, images, videos or 3D objects into a real-world scenario in real time (Azuma, 1997; Zhou, Duh, & Billinghurst, 2008; Giglioli Chicchi et al, 2015; Tzima, Styliaras & Bassounas, 2019). Unlike virtual reality, AR uses the real world as the backdrop for its computer images, thus avoiding cybersickness as well as eliminating the miscalibration of visuo-motor coordination often produced by other virtual environments (Valimont, 2007). As augmented reality is less immersive than virtual reality, it can be placed between a real environment and augmented virtuality (Milgram and Kishino, 1994), thus providing optimum possibilities for AR integration with familiar spatial environments. Augmented Reality can integrate 3D models from digital archives and libraries into any real-world scene with the help of mobile devices. AR techniques offer potential benefits beyond traditional flashcards and their derivatives in vocabulary learning because they offer the possibility of the easy incorporation of useful spatialized knowledge to the learning situation.

The educational potential of AR has been already noted (Bai, Blackwell, & Coulouris, 2013; Bacca et al. 2014; Santos et al., 2014; Santos et al., 2016; Walker et al, 2017), and the recent appearance of new mobile-phone augmented-reality applications for Android and iOS has changed the initial cost-related factors in the teaching/learning process, bringing new possibilities for educators and curriculum designers. Today it is increasingly common to find both teachers and students handling smart devices equipped with multiple embedded sensory inputs such as multi-megapixel cameras, microphones, speakers, high definition displays, 3D displays, and pico-projection technologies (Grier et al., 2016).

Currently, the explosive rise of free or affordable mobile-phone AR applications for Android and iOS has made it possible for individual researchers to easily investigate whether AR based approaches can help with vocabulary learning – and additionally they allow for the workflow adopted by the learner to integrate spatialized information as well to potentially benefit the tenacity of vocabulary acquisition.

The current study poses this as its principal research question, asking whether a spatialized implementation of AR based on ideas from the visuospatial bootstrapping literature (AR-VSB) might lead to a higher retention and lower forgetting rate in delayed tests of vocabulary learning among second language learners in comparison with the conventional method based on flashcards and implemented in Quizlet.

## **Method**

Sixty-two students ( $N = 62$ ) from the teacher-training department at the University of Valencia (28 males, 34 females; mean 19.08 ( $SD=1.58$ )) took part in this research. They took part as part of a series of research tasks related to language learning of which this was one. All the participants consented in writing to participate in the study, and the study was approved ethically by the University of Valencia and Queen Margaret University<sup>1</sup>. Prior to the main experimental sessions, participants had undertaken the Cambridge English Placement Test (Cambridge Assessment English, 2019) to verify their grammatical ability level on the Common European Framework for Languages (CEFR) six-point scale (Council of Europe, 2019). They were also administered a diagnostic vocabulary test developed by the researcher that was based on the Nelson-Denny vocabulary subtest (Brown, Fishco & Hanna, 1993) with a multiple-choice structure. The test contained 100 questions with 7

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<sup>1</sup> The work was originally conducted as part of a Master's project at Queen Margaret University, and hence had to have research oversight from that institution as well



response options each, based on the content of the book *English Idioms in Use* (McCarthy and O'Dell, 2017). The 10 items that were least well known by the participants were selected to be the learning set in the vocabulary learning task (Figure 1: Items selected as the least-known vocabulary).

After these pre-tests, the total of 62 students were randomly divided into two groups of 31 participants corresponding to the input method. The control group received vocabulary training on the Quizlet app for mobile phones and tablets with Android or iOS operating system through the links created by the researcher. Optionally, the Quizlet website-based materials were also made accessible through laptops and desktop computers. The control (quizlet) group was asked to dedicate 15 minutes to learning the ten set expressions introduced through digital cards featuring translations into Spanish and multimedia images. Students were advised to relate images to target words during the recall process (Figure 2: Quizlet card (reverse side) and Figure 3: Quizlet card (obverse side)).

The experimental (AR-VSB) participants were instructed to distribute paper-based cards with generated matrix barcodes prepared by the researcher around their houses either horizontally (on the floor) or vertically (on the walls) near familiar objects. They then had to dedicate fifteen minutes to learning ten idioms by scanning the quick-response codes through the “Augment” app (<https://www.augment.com/>) with their mobile phones or tablets. The card scan activated augmented-reality items related to the to-be-learned vocabulary, visible on participants’ device screens, and integrated with the background of the students’ homes. After the learning time, the students were asked to take an imaginary route through their houses recalling the familiar items one by one, associating them with the AR objects and thus with the target vocabulary (Figures 4: AR-VSB card with a QR

code to be scanned and Figure 5: A 3D model after the card's scanning integrated with the familiar environment).

The rationale was to compare among subjects the efficiency and forgetting rate introduced by the two study methods by testing the learning of the vocabulary. Retention was checked by means of two tests: a fifteen-minute-delay test, accessed by the students through the links placed on the university's Moodle platform fifteen minutes after the Augment/Quizlet learning exercise, and a week delay test for each group, administered similarly. The design of both tests was based on definitions in English with a requirement to insert the necessary idiom and to translate them from Spanish into English or vice versa. The list of vocabulary items was the same, but the questions and definitions of the first and second tests were different so as to check the students' real understanding of the expressions. Participants were asked to refrain from any further learning or revision between the two tests. Test materials were identical across the two learning condition groups (Quizlet vs. AR-VSB).

The fifteen-minute-delay and week-delay tests required the learners to answer ten open questions about the learned idioms by completing free-text fields in the questionnaires (Figure 6: An AR-VSB post-test at one-week delay). These were evaluated by the researcher and assessed by an independent evaluator on a scale from 0 to 3 for each idiom, which given the range of the test resulted in a total score from 0 to 30 points. Every response received the following values: 3 – excellent knowledge of the idiom; 2 – acceptable knowledge with mistakes in article use, incorrect orthography, etc., but the expression can be understood; 1 – only (the) key word(s) is/are memorized and the idiom cannot be recognized; 0 – wrong idiom or no answer provided. The researcher was not the usual instructor for those groups, and was unaware of which condition in the experiment

the work they were assessing was from. The data collection questionnaires were created and distributed using the JISC online survey tool (<https://www.jisc.ac.uk/>) and data were processed by Microsoft Excel 365 (<https://www.microsoft.com/>) and IBM's SPSS V24 (<https://www.ibm.com/>) statistical packages.

A new code was automatically generated by the JISC online survey tool for every test on every participant. Linkage between these codes was not configured by the JISC survey tool, excluding the opportunity for linking between background measures and experimental performance, and also meaning that it was not possible to take advantage of repeated measures statistical techniques to increase statistical power in comparisons between the 15 minute and 7 day tests. Nonetheless the use of between-subjects comparisons is conservative, and does not increase the risk of statistical error. The anonymised raw data from the learning task presented in this study are available for open download from <https://osf.io/4snzf/> ( DOI: 10.17605/OSF.IO/4SNZF)

## ***Results***

Mean score on the Cambridge English placement test was 18.70 (SD =3.54), indicating an English level of B1-B2 in accordance with Common European Framework of Reference for Languages, CEFR.

Initially, the researcher considered a 2 x 2 factorial ANOVA approach for data interpretation, but as several of the variables did not meet parametric assumptions, that method was discarded. Instead, analysis focused on multiple two-group tests across four critical comparisons: Quizlet vs. AR-VSB at the fifteen-minute delay, Quizlet vs. AR-VSB at one-week delay, 15 minute delay vs. 1 week delay for the Quizlet group, and 15 minute vs 1 week delay for the AR-VSB group. Because of the implementation of multiple hypothesis tests, a Bonferroni correction was applied to adjust  $\alpha$  for every comparison –

meaning that a critical level  $p < .0125$  was used to ensure that the familywise error rate remained below  $p < .05$ .

#### *Vocabulary Retention for Quizlet and AR-VSB at fifteen-minute delay*

Mean score (out of 30) after the fifteen-minute delay (15MD) for the AR-VSB-enhanced experimental it was 20.38 (SD = 6.29) and for the Quizlet-enhanced control group was 12.07 (SD = 6.26). The groups are visually represented in the boxplot (Figure 7: Comparisons between the methods and the delay). The highest scores were densely concentrated in the group that used the AR-VSB learning technique. Thus, 75% of students in the treatment group obtained a value higher than 17 points out of 30, while the same value was only reached by 16.9% of the Quizlet-input participants. There were two atypically high values in the control group and one atypical low value in the experimental group, while the rest of the data distribution is close to being symmetrical for both samples, with a denser distribution in the higher scores for the treatment group. Nonetheless, the Shapiro-Wilk test for normality and the Levene test for homogeneity of variance suggested that the data were suitable for parametric analysis (Shapiro-Wilk test:  $W = 0.99$ ,  $p = .71$ , Levene's test  $F(1,60) = 0.09$ ,  $p = .77$ ). Therefore a t-test for independent samples was conducted to determine if there was a significant difference between the means in the two conditions, which was confirmed ( $t(60) = 5.22$ ,  $p < .01$ , Cohen's  $d = 1.33$ ), indicating that vocabulary retention after fifteen minutes was significantly higher with the AR-VSB method than with the Quizlet technique.

#### *Vocabulary Retention for Quizlet and AR-VSB at one-week delay*

The global-score distribution after a week's delay maintained the tendency seen after 15 minutes, with higher scores being seen in the AR-VSB condition. Mean score in AR-VSB at 1 week was 15.07 (SD=3.88), whilst in the Quizlet condition it was 8.94 (SD = 6.10).

Analyses of normality and homogeneity of variance was applied to check the parametric conditions. Assumptions of normality but not homogeneity of variance were violated (Shapiro-Wilk test:  $W = 0.95$ ,  $p = .01$ , Levene's test  $F(1,60) = 3.10$ ,  $p = .08$ ). Hence in this comparison, a Mann-Whitney U non-parametric test was used to compare the scores between the samples. This indicated a significant difference between the two conditions ( $U=162.00$ ,  $p < .01$ ; Cohen's  $d = 1.20$ ).

#### *Retention for the Quizlet group compared between timepoints*

The boxplot for Quizlet fifteen-minute delay and Quizlet week delay shows the score declining over a weekly period (Figure 7: Comparisons between the methods and the delay). The median score (/30) was 11 after 15 minutes but only 8 after 1 week's delay. Mean learning score at 15 minutes was 12.07 (SD = 6.26) whereas after a week it was 8.94 (SD = 6.10). Assumptions of normality but not homogeneity of variance were violated (Shapiro-Wilk test:  $W = 0.94$ ,  $p = .004$ , Levene's test  $F(1,60) = 0.020$ ,  $p = .89$ ). Hence, a Mann-Whitney U test was used to see if the score varied between the samples. The results ( $U = 323.50$ ,  $p = .03$ ,  $d = 0.51$ ) showed significant differences between the two time points in the Quizlet condition.

#### *Global-score distribution for AR-VSB compared between timepoints*

The boxplot for AR-VSB fifteen-minute delay and AR-VSB week delay demonstrates that the score decline is faster compared with Quizlet over the week period (Figure 7: Comparisons between the methods and the delay). As the boxplot shows, the median decline value between the two AR-VSB samples is 7 points, while the median decline for the two Quizlet samples is 3 points. Mean score (/30) for the AR-VSB participants at 15 minutes was 20.38 (SD = 6.29) whilst at one week it was 15.07 (SD=3.88). There was no evidence against normality in the data, but homogeneity of

variance between the samples was rejected (Shapiro-Wilk test:  $W = 0.97$ ,  $p = .10$ , Levene's test  $F(1,60) = 5.78$ ,  $p = .02$ ). Hence a Mann-Whitney U test was used which showed the AR-VSB performance after a week was significantly lower than at 15 minutes ( $U = 210.00$ ,  $p < .001$ ,  $d = 1.02$ ).

## **Discussion**

The experimental AR-VSB method was significantly more efficient for second-language vocabulary learning than digital flashcards supported by image and translation after both 15 minutes and 1 week. The data also reveal that despite a higher forgetting rate, the AR-VSB technique still offers superior retention after an interval of a week compared with the Quizlet method used in the control group. This is an important observation as it suggests that AR-VSB is a technique that can enhance second language vocabulary learning, though as this is the first demonstration of that pattern we recommend further research to replicate and enhance understanding of this finding.

Under Paivio's dual-coding model, the use of augmented-reality 3D models in a familiar physical space likely enables better connections between logogens and imagens and eventually facilitates memorization due to the additional provision of useful spatialized information that can be integrated in the learning process. The apparently increased rate of forgetting in the experimental group might indicate that this technique could be used as the initial input method for vocabulary items, to be supported later with contextual vocabulary use, textual or auditory cues gained during subsequent encounters with the word (Schmitt, 2008 and Nation, 2015). We note that Paivio's model is not the only model allowing for the integration of verbal and spatial memory in learning – modern models of working memory (e.g. Baddeley, 2000; Baddeley, Hitch & Allen, in press; Cowan, 2010) also allow for this. It is also worth noting that the work of Calia et al (2019) indicates that bootstrapping

related spatialized benefits in memory may be relatively automatic, and unrelated to basic processes of memory (see also Race et al, 2015) – meaning that the benefits of spatialized AR-VSB presentation may accrue to all learners rather than just those who are already of a high level of ability. Further research should test this hypothesis.

This study has adopted an experimental methodology – hence it is likely that differences in performance are strongly linked to the differences between the AR-VSB and Quizlet conditions. It is worth paying some attention to these, because this research represents a pragmatic comparison between the current educational practice and a new technique. There are numerous differences between the AR-VSB technique and the flashcard Quizlet technique. For example, it may simply be more interesting to use the AR app than the Quizlet app. We do not know for sure which aspect of the comparison between conditions in the current study underlies the benefit to performance. It is likely, based on extensive evidence of the mnemonic benefits of spatialization (see introduction) that this effect is due to spatialization, but on the basis of the current results we cannot be certain. Future research should address this – and might begin by systematically addressing the differences between Quizlet and AR-VSB approaches. Another important approach to extend these findings would be to ask learners to introspect about their experience – to ask them about which aspects of the experience of the AR-VSB technique or the Quizlet approaches they felt best supported their learning. In a user-focused environment these are crucial questions, as a learner’s experience of the effectiveness of a method will likely determine their willingness to continuously engage with it. Such research efforts would be timely and useful.

To sum up, verbal and spatialized elements of AR-VSB technique potentially offer new “edutainment” opportunities in second language vocabulary training by transferring

learning activity from the classroom into other informal environments where the spatialization can help contextualise learning. This current research is a possible stepping stone to a larger-scale study with a final goal of developing such practical outcomes as tailored AR-supported smart-device second language learning applications. We look forward to such research being conducted.

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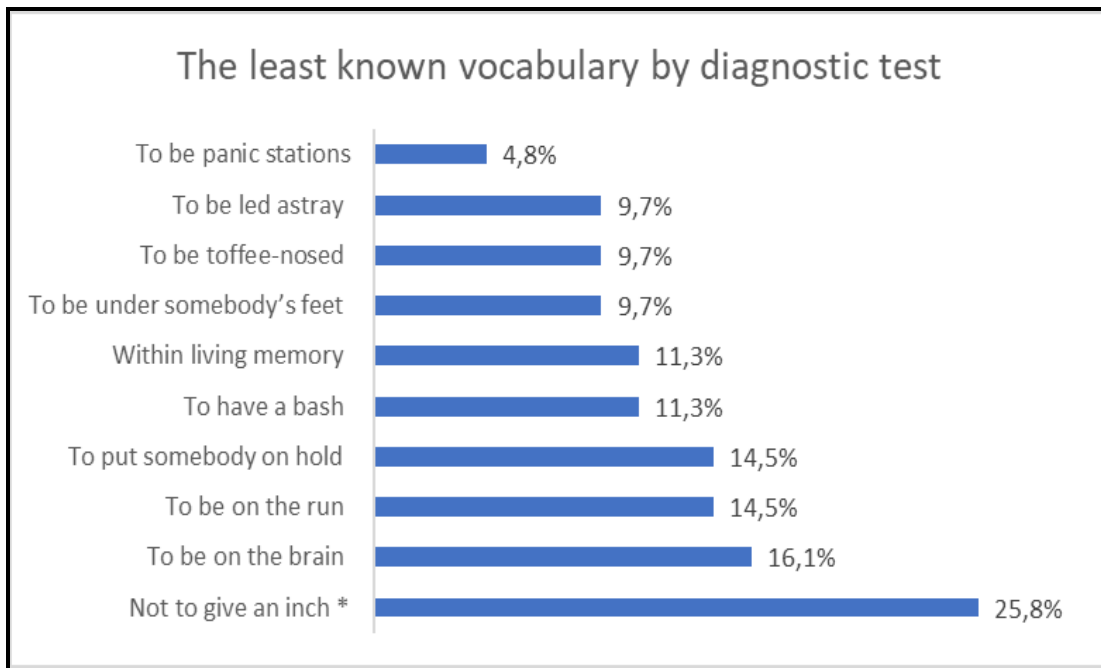
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### List of figures



**Figure 1: Items selected as the least-known vocabulary**

\* In case of this item the diagnostic-test design contained the possibility of choosing the right option by applying the grammar rule of "an before vowel sounds" (e.g. match the beginning of the idiom to its ending: won't give an –nutshell/coin/inch/circle/knots/test/account).



desde los tiempos más remotos

**Figure 2: Quizlet card (reverse side)**



within living memory

**Figure 3: Quizlet card (obverse side)**



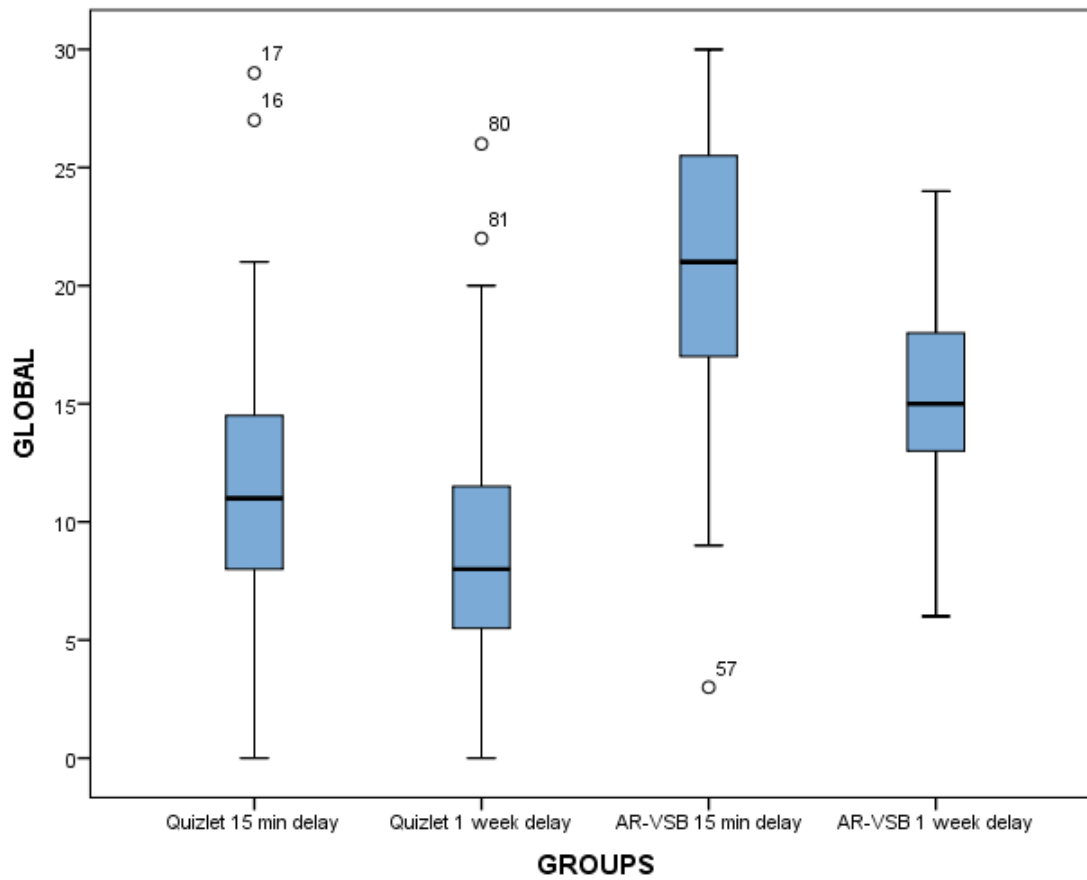
**Figure 4.** AR-VSB card with a QR code to be scanned



**Figure 5.** An example of a 3D model created after the scanning of a QR code from one of the cards, shown integrated with a familiar environment as part of an AR display

Response ID	Start date	Completion date
463239-463230-45769279	2 Apr 2019, 22:16 (BST)	2 Apr 2019, 22:17 (BST)
1	Please translate into English desde hace muchos años	live memory
2	Please translate into English no ceder ni un milímetro	not inch
3	What is the idiom of trying to do something?	
4	Please translate into English dejarse llevar	ash tray
5	Please translate into Spanish toffee-nosed	presumido
6	What is the idiom of molestar?	under feet
7	What is the idiom of making somebody wait?	on hold
8	Please translate into Spanish to be on the brain	obsesionarse
9	Please translate into English ser fugitivo	run
10	What is the idiom of to be stressed?	panic

**Figure 6: An AR-VSB post-test at one-week delay**



**Figure 7: Boxplot illustrating distributions of data broken down by learning method and delay**