8-1-2016

The Effect of Stereoscopic Three-Dimensional Images on Recall of Second Language Vocabulary

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by

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A Dissertation
Submitted in Partial Fulfillment of the Requirements for the
Doctor of Philosophy Degree

Department of Curriculum and Instruction
in the Graduate School
Southern Illinois University Carbondale
August, 2016

DISSERTATION APPROVAL

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A Dissertation Submitted in Partial
Fulfillment of the Requirements
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Doctor of Philosophy
in the field of Instructional Technology & Design

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Graduate School
Southern Illinois University Carbondale
April 8, 2016

AN ABSTRACT OF THE DISSERTATION OF

Regina Kaplan-Rakowski, for the Doctor of Philosophy Degree in Education,

presented on April, 8th 2016 at Southern Illinois University Carbondale.

Title: The Effect of Stereoscopic Three-Dimensional Images on Recall of

Second Language Vocabulary

Major Professor: Dr. Christian Sebastian Loh

The purpose of this experimental study was to investigate the effect of stereoscopic three-dimensional (S3D) images on productive and receptive recall of foreign language vocabulary. S3D images are highly-realistic and differ from non-stereoscopic three-dimensional (NS3D) images in that they provide the impression of the added third dimension of depth.

This within-subject study exposed the participants (N = 82) in a controlled setting to a series of carefully designed and randomly distributed NS3D and S3D images. The subjects were then given immediate productive and receptive tests of foreign language vocabulary items that were represented by NS3D and S3D images. Quantitative data consisted of the scores from the vocabulary tests. Qualitative data, gathered through background questionnaires and follow-up surveys, included a mixture of open-ended and Likert questions.

The statistical analyses of the data using a series of paired *t*-tests showed NS3D and S3D images to be equally effective for vocabulary recall. In addition, significantly more subjects found S3D images to be engaging and/or more useful, while subjects also indicated that they perceived the main benefits of learning with S3D images to come from enhanced focus, realism, engagement, and association. At the same time, some learners reported being distracted and experiencing discomfort while viewing S3D images. Post hoc tests revealed that lower

performance on S3D images was driven only by those subgroups that exhibited discomfort and / or lack of experience with S3D technology.

DEDICATION

I dedicate this dissertation to my Parents: Lidia and Jurand Kapłan. They showed me how to work hard regardless of conditions and how never to give up. I will be forever thankful for their sacrifice to me.

Dedykuję tę pracę doktorską moim Rodzicom: Lidii i Jurandowi Kapłan. Pokazali mi Oni jak należy ciężko pracować bez względu na warunki i jak się nigdy nie poddawać. Dozgonnie będę Im wdzięczna za Ich poświecenie dla mnie.

ACKNOWLEDGEMENTS

During my journey to this doctorate, I have been very fortunate to have encountered numerous supportive people. Without their help and encouragement, this dissertation would be close to impossible. While it would be difficult to list everyone who contributed to my success, I would like to at least mention a few.

First and foremost, my sincere appreciation goes to the Chair of my Doctoral Committee, Dr. Christian Sebastian Loh. This dissertation has been constantly enriched with his constructive feedback. Dr. Loh greatly influenced my education and seeded my great interest in anything that concerns learning through technology, especially through immersive gaming and virtual environments. I find his creativity and out-of-the-box framework of teaching very inspiring. Dr. Loh was also the first professor who encouraged me to publish, which was possibly the most crucial step in the development of my professional career.

My further gratitude is directed towards Dr. Krassimira Charkova, whose expertise on linguistics, methodology and statistics was extremely valuable. Dr. Charkova is a model professor who unconditionally finds time for her students and is always eager to share her knowledge. Her generous heart, kind words and warm smile have helped me to a large extent through this challenging journey.

I am thankful to Dr. Peter Fadde, Dr. Lourdes Albuixech, and Dr. Lingguo Bu for serving on the committee and their suggestions for improvements on this dissertation.

I further wanted to extend my appreciation to former members of my Doctoral Committee: Dr. Sharon Shrock and Dr. Thomas Thibeault. They both devoted a lot of time and effort to help me at the early stages of this project.

The acknowledgements would not be complete without thanking the members of the faculty at the Department of Foreign Languages and International Trade at Southern Illinois

University Carbondale, who helped me recruit volunteers for this project. Consequently, I would like to thank the volunteers for their time to participate in this study.

Last, but not least, I gratefully acknowledge the help of my husband, Dr. David Rakowski. David has been inspiring me as a researcher and acted as an informal advisor throughout my entire Ph.D. program. Without his help, advice and time spent on proofreading and re-proofreading this manuscript, I possibly would never have reached this stage.

Finally, huge thanks go to Susan Berg, who kindly proofread this work on multiple occasions and who offered her valuable advice concerning editing.

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CHAPTER I

Approaches to second language (L2) vocabulary learning have progressed through various stages over time. An emphasis on vocabulary learning has vied with a focus on grammatical rules. For example, during the Roman period, when Latin speakers studied Greek, the mastery of vocabulary was prominent because of the importance of rhetoric. In the Medieval period, when Latin was learned, the dominant methodology promoted grammatical analyses of Latin texts. In more recent centuries, foreign language education has been dominated by different, often competing, instructional methods. Despite common agreement that mastering the lexis is indispensable to language learning, few methods emphasized vocabulary learning (Schmitt, 2000, 2008; Zimmerman, 1997).

Because vocabulary learning has not been the primary focus of recent language learning methods, L2 learners have often resorted to cramming lists of bilingual words when learning vocabulary. However, there is strong evidence that such an approach only proves effective for short-term retention (Nation, 2001). In order to retain L2 vocabulary longer, one must provide learners with more meaningful and effective learning conditions.

There have been various attempts by educators to create more meaningful and effective learning conditions through the use of visual aids. These attempts include the incorporation of both images and physical objects (Bush, 2007; Ollila & Olson, 1972). The simplest images, composed of line-art drawings, lack any portrayal of depth and can reasonably be referred to as being two-dimensional (2D). However, most images are constructed to provide the perception of depth while being displayed on an otherwise 2D surface, such as paper or a computer screen. The most sophisticated examples of images that use complex techniques to provide viewers with a sensation of depth are stereoscopic images, which are discussed in detail in the sections below.

For the purposes of this dissertation, images that use stereoscopic technology to provide the sensation of three-dimensional (3D) visualization are referred to as stereoscopic 3D (S3D) images, while those that use the continuum of non-stereoscopic techniques to provide the appearance of 3D are called non-stereoscopic 3D (NS3D) images. Figure 1 portrays examples illustrating the two types of images. Note that anaglyph 3D glasses (like those shown in Figure 2) must be worn in order to obtain the stereoscopic perception of the S3D image.

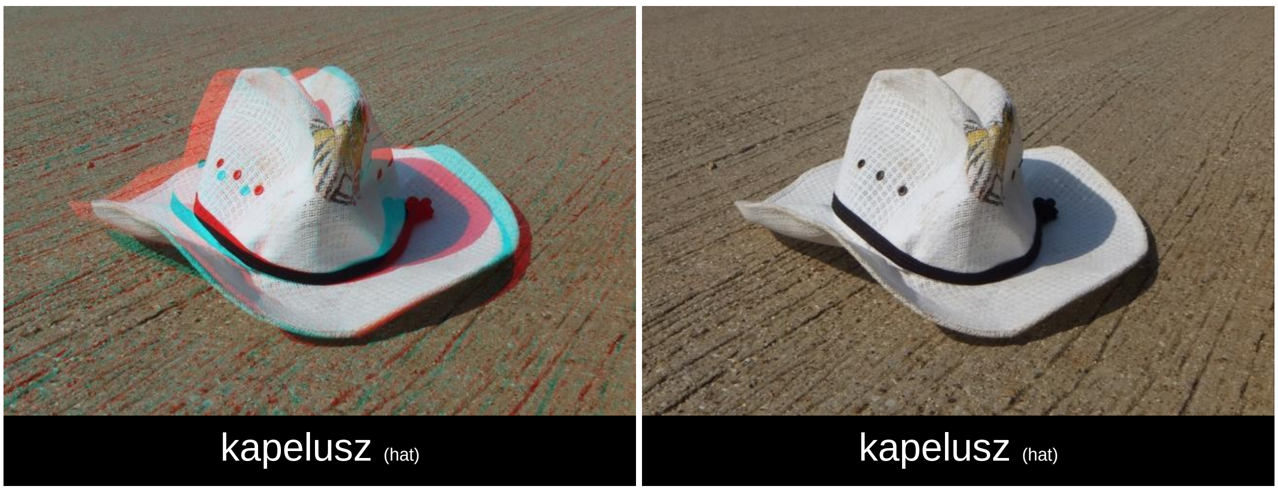

Figure 1. An example of a stereoscopic (S3D, left) image and its non-stereoscopic 3D (NS3D, right) counterpart with their corresponding labels.

The most accurate portrayal of depth is provided by actual 3D objects. Such 3D objects are commonly referred to as *realia*. The use of realia has some benefits for learning but also leads to difficulties. For example, suitable objects may not be easily accessible, distributable, appropriate, or safe. The use of realia is therefore more effective in fostering meaningful learning when instruction is unconstrained, such as in one-on-one instruction, the natural learning of a child, or when budgets and time are generous. However, the efficiency of rote learning (supplemented with simple NS3D visual aids) is difficult to surpass when subjected to the practical constraints of realistic class settings.

Figure 2. Three examples of anaglyph glasses: a) simple, paper blue-and-red anaglyph glasses; b) green-and-red anaglyph glasses; c) blue-and-red anaglyph glasses. (Retrieved from https://www.google.com/search?q=anaglyph+3d+glasses)

With the growing availability and affordability of digital technology in the classroom, the limitations preventing widespread use of realia may have been partially alleviated. Traditional forms of realia (i.e. physical, real-life, 3D objects) can now be represented virtually via computers. In particular, the visual perception of 3D realia can now be simulated relatively quickly and efficiently on students' computers via the use of S3D images in a manner that was not possible with older display technology. The possibility of using new forms of realia (such as S3D images) in a digital environment motivates the need for research into the effectiveness of these new tools for education.

The implementation of realia for education is generally recognized to be effective for learning (Rule & Barrera, 1999; Rule, Barrera, & Steward, 2004; Webb, Rule, Cavanaugh, & Munson, 2014) but identification of the attributes driving this effectiveness is still incomplete. The identification of these attributes is essential so that modern educational technology can be designed in a way that succeeds in improving educational outcomes. The enhanced visual perception of depth that is achieved with realia, relative to simple images portrayed on flat surfaces, is one potential attribute that may be responsible for the effectiveness of realia in learning. However, studies of the effects of realia have been inconclusive due to various sensory stimuli involved in using realia. Many empirical studies contained confounding variables that made precise interpretations difficult. This led the existing literature on visual perception in education to be largely opinion-based. Prior studies on the effects of learning with NS3D and S3D images are mainly limited to testing spatial-learning outcomes.

Almost none of the existing studies on visual perception for education have considered foreign language education. The closest research topic in foreign language education concerns the use of glossing (in L2 learning, g*lossing* means explaining vocabulary with various multimedia assets, including images). No prior study has empirically tested the impact of increased dimensionality of images used for foreign vocabulary learning. This study made use of innovative computer display technology to overcome the presence of confounding variables by limiting the variation in object representations to just one factor, namely, the perceived dimensionality (NS3D vs. S3D), by using the same images on the same computer display. This approach allowed for a precise evaluation of the impact of perceived dimensionality on vocabulary learning. This study is valuable to the community because the results will provide educators with guidance on how to facilitate explicit vocabulary learning by including either NS3D and S3D images in foreign language activities.

Background

This chapter proceeds with sections that describe the background information that motivates this dissertation: the evolving use of images and realia for education, the psychological process of visual learning, the technological design of realism in visual representations, and the use of stereoscopic images in education. Following the background section, the next sections discuss the rationale and significance of the study, the contribution to be made, the delimitations and limitations, and the key terms involved.

The evolving use of images and realia in education. Teaching with realia in the form of physical objects was already present in ancient times, centuries before formal education was established (Saettler, 1968). Those examples of realia (often physical tools) were used to teach survival skills. The use of realia was combined with verbal methods of teaching, such as oral instruction, and was later supplemented by the use of instructional aids in the form of simple drawings or pictographs. As Saettler (1968) described, "tribal priests systematized bodies of knowledge and early cultures invented pictographs or sign writing to record, preserve, transmit, and reproduce information" (p. 11). Over centuries, the implementation of both images and realia evolved, depending on the needs and materials available.

The adoption of printing encouraged verbal instruction through texts, in which images were a more convenient way to represent physical objects, compared to the use of realia. However, these images were not necessarily more effective than the older practice of physically handling the actual objects. The use of printed images was further reinforced with the later invention of photography.

Instructional methods advocated by Comenius (17^{th} century), Francke (17^{th} -18^{th} century), Basedow (18^{th} century) and Montessori (20^{th} century) were some of the few to (re)advocate the implementation of realia in teaching. Pestalozzi (19^{th} century) initiated educational experiments promoting the use of realia. These educators believed that learners should have a chance to see and manipulate the realia they are learning about "instead of merely hearing about them or seeing them on maps or in drawings" (Saettler, 1968, p. 32).

Visual learning. Although realia may incorporate multiple forms of sensory input, the use of visual aids is particularly important because visual learners are prevalent in our society (Dunn & Dunn, 1972). The theoretical background that guides modern understanding of visual perception in learning is Mayer's cognitive theory of multimedia learning (Mayer, 1997). Broadly speaking, this theory claims that our cognitive system processes information through verbal and imagery channels that cooperate. Therefore, well-designed instruction takes advantage of the capacity of those channels. Teachers are able to deliver information more effectively when they transmit knowledge via multiple sensory channels. Based on Mayer's theory, educators have extensively examined the impact of various teaching aids on learning, including visual aids. This research is most visible in studies on multimedia learning (Mayer, 1997, 2009; Mayer & Anderson, 1991; Mayer & Moreno, 2003; Moreno & Durán, 2004).

In foreign language instruction, different forms of visuals have been used to help learners with comprehension, memorization, and cultural understanding (Lee**,** 1979; López Campillo, 1995). Some of the most common ways that visuals have been incorporated in foreign language instruction have been through glossing with different multimedia assets (Al-Seghayer, 2001; Chun, & Plass, 1996; Tversky, Morrison, & Betrancourt, 2002; Zhu & Grabowski, 2006), mnemonics (Pressley & Levin, 1978; Van Hell & Mahn, 1997), and realia (Milone, 1938; Renshaw, 1927; Sibold, 2011; Smith, 1997).

Visual representations and their realism. Graphical representations can vary significantly in complexity and their degree of realism. Alessi and Trollip (2001) list several kinds of graphical representations, progressing from the most basic to the more complex: "simple line drawings, schematics, artistic drawings, diagrams, photographs, three-dimensional images, and animated images" (p.71). The realism of some of these graphical representations is enhanced by the improved portrayal of depth, with S3D images being a particularly intriguing example of how this can be done. However, an augmented degree of realism is often associated with the increase in production cost (Alessi & Trollip, 2001). Therefore, instructional technologists, who are concerned about the efficiency of learning, have been interested in finding learning approaches that are as cost-effective as possible.

The effects of using representations with varying degrees of realism have been tested for over fifty years. Dwyer's series of publications (Dwyer, 1967, 1968a, 1968b, 1969, 1970; Dwyer & Berry, 1982; Dwyer & Joseph, 1984), in addition to other researchers' endeavors (for example, Schwartz, 1995; Scheiter, Gerjets, Huk, Imhof, & Kammerer, 2009) resulted in solid pedagogical principles indicating the optimal circumstances for the use of particular levels of realism in visual representations. While the testing of the effectiveness of animated images (Lowe, 1999; Mayer & Anderson, 1991), line drawings (Dwyer, 1970), or photographs (Mayer & Sims, 1994) received a lot of attention, empirical research on the use of NS3D and S3D images in education is limited to studies involving spatial learning (McIntire, Havig, & Geiselman, 2014).

The difficulty of accurately representing 3D objects on 2D displays (either on paper or a computer display) has led to a conflict between the potential superiority of realia and the increased feasibility of NS3D images. Static NS3D images, although with greater and greater realism, still lack some of the crucial components of spatial perspective that would allow viewers' brains to more fully perceive depth.

With the advance of technology, a number of techniques have been used in order to obtain a 3D illusion on a 2D surface. Monocular (one-eyed) visual cues have been used to create “pseudo” 3D, or “2.5D” images (in this dissertation referred to as non-stereoscopic 3D or NS3D). Some techniques for creating NS3D images include the application of shade, texture, contour, motion (Peters, 2000), interposition, relative height, relative size, linear perspective, tone, and gradient (Skorge, 2006). From a cognitive perspective, a more realistic version of NS3D images are ones that fully exploit the binocular visual perception system within the brain, which is what S3D images achieve. Figure 3 represents an example of three varying levels of realism.

2D NS3D S3D

Figure 3. These three images represent increasing levels of realism: the image on the left depicts a 2D egg. No cues of depth are used. The image in the middle depicts an NS3D egg. Shade and illumination are used to cue depth. The image on the right depicts an egg in S3D – an S3D image requires a pair of anaglyph glasses to be viewed properly.

Stereoscopic 3D Images. Stereoscopic 3D (S3D) images are images that have a technologically-enhanced sense of depth, through which they appear to be 3D. Based on the concept of binocular disparity, the perception of depth is achieved by taking two nearly identical pictures from two slightly different angles (eyes-width apart). This action mimics the way our eyes view the world and, consequently, the illusion of depth is obtained (Price, Lee, & Malatesta, 2014). Figure 4 provides a graphical explanation of binocular disparity. Some methods that are used to obtain 3D visualizations using stereoscopic visual cueing are those using anaglyph, polarization, and interference filter technology. The low-cost (less than $10) and relatively unobtrusive gear for anaglyph S3D technology make it an attractive option for educators. This is the option that was explored in this study.

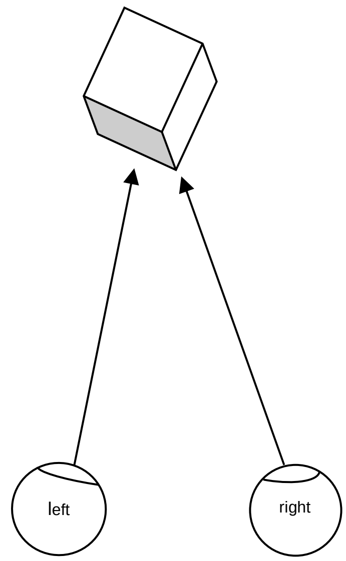

Figure 4. Binocular disparity occurs when two almost identical pictures are taken from two slightly different angles (eyes-width apart; Price, Lee, & Malatesta, 2014). In this particular drawing, the left eye sees the shaded area of the object, while the right eye sees the corner of the object. The brain processes this object as three-dimensional; i.e. a cube.

The potential of stereoscopy was first explored by Euclid (circa 300 BCE) and Galen (circa 200 CE); followed by that of binocular visualizations by Leonardo Da Vinci in the 15th century (Sands, 1956). It was not until the 19th century that the use of S3D images became feasible for education. The invention of the first patented device for viewing stereoscopic images by Sir Charles Wheatstone in 1838 significantly expanded the popularity and the accessibility of stereoscopic viewing (McIntire, Havig, & Geiselman, 2012). Figure 5 provides an example of an early stereoscope from the 19th century. Educators of various disciplines then started to implement activities using specially-designed sets of S3D images for teaching biology, geography, architecture, industry, and sculpture, among others (Sands, 1956).

Figure 5. An example of stereoscope with a stereoscopic card. This type of stereoscope was created by Oliver Holmes in 1861 and has been in common use since then for over a century. Retrieved from (https://commons.wikimedia.org/wiki/File:Holmes_stereoscope.jpg).

A major advantage of using S3D images was that learners could see realistic images of places which were normally difficult to access geographically (e.g. mines, factories, remote locations). Another noteworthy benefit of using S3D images was the help provided to students in understanding concepts where depth mattered (e.g. architectural principles). Despite these useful characteristics, the advancement of popular S3D viewing technology stalled in the mid-20th century, leading to the decreased popularity of the stereoscope and a lapse of interest in exploring its potential (Sands, 1956). It was not until the early 21st century that interest in S3D viewing experienced a renaissance. Its renewed popularity is especially visible in entertainment, medicine, and military applications (McIntire, Havig, & Geiselman, 2012).

New technological advancements and the lower cost of S3D viewing devices allowed for increased accessibility and encouraged the development of several educational projects involving

S3D formats. With the re-emerging popularity of S3D viewing, researchers were newly motivated to test ideas about the effectiveness of using S3D technology for learning. Their research yielded various outcomes regarding the effectiveness of S3D technology for education, ranging from positive (Drascic, 1991; Holford & Kempa, 1970), through mixed (Barfield & Rosenberg, 1995; Hansen, Barnett, Makinster, & Keating, 2004), to non-significant (Cid & Lopez, 2010; Cliburn & Krantz, 2008; Keebler, 2011).

Rationale and Significance

In the past, learners were often limited to NS3D, non-immersive, minimally-interactive materials for learning. Modern digital technology now allows us to employ settings which provide learners with fully immersive and realistic visual stimuli. A large and growing portion of students' time is spent in environments where rich visual stimuli are present (Lenhart et al., 2008), such as while playing digital games, watching movies, or exploring virtual environments. As McGraw (2004) pointed out: "With the increasing prevalence of three-dimensional instructional media and immersive environments, it is imperative that the effects of three-dimensional stimuli on learners be considered" (p. 154). It is therefore a useful empirical question whether or not S3D viewing allows for more effective learning (Price, Lee, & Malatesta, 2014) of foreign language vocabulary.

We know from the published literature that realia can be preferable (Baird, 2003; Gibbons, 2008) and effective for learning (Rule & Barrera, 1999; Rule, Barrera, & Steward, 2004; Webb, Rule, Cavanaugh, & Munson, 2014). Some of this effectiveness appears to arise from the enhanced visual perception that learners achieve when viewing 3D objects. Tavanti and Lind (2001) state: "realistic 3D representations of the real world allow a more direct connection between information environments and their electronic representations (...). In contrast, 2D

[NS3D] representations are thought to be more unnatural and require training to be used" (p.139). Theories of multimedia learning (Mayer, 2009), as well as the claims that we naturally favor three-dimensionality (Tavanti & Lind, 2001) lend support to the idea that increased dimensionality should activate learners' germane cognitive load, which is advantageous for learning (Sweller, 1994; Sweller, van Merrienboer & Paas, 1998). On the other hand, access to S3D images may not necessarily ensure that the learners will be cognitively engaged (Garrison & Cleveland-Innes, 2005). Research postulates several possible pitfalls of increased dimensionality that may provoke extraneous cognitive load, which is disadvantageous for learning (Pass, Renkl, & Sweller, 2003; Sweller, 1994).

In sum, the existing literature, practice, and the theories behind the issue of visual perception motivate the non-directional research question of this study: "*Is there a statistically significant difference between NS3D and S3D images in their effect on immediate productive and immediate receptive recall of second language vocabulary?"*

Contribution

The field of instructional technology aims to provide learners with instruction that is **e**ffective, **e**fficient, and **e**ngaging (Merrill, 2002). The concept of Merrill's *E3* postulates that when an instructional unit successfully considers these three components, then the instruction can be considered as "good". This dissertation applied Merrill's advice and interpreted its findings in the context of the *E3*. Namely, the performance tests in this study provided quantitative evidence on a difference in effectiveness between NS3D or S3D images for learning. The follow-up questions helped to reveal whether participants found NS3D or S3D images more **e**ngaging. The data and tests were supplemented by subjective notes and observations on the **e**fficiency of implementing NS3D vs. S3D images from the researcher's experience.

Producing and viewing traditional NS3D images (photographs) has become ubiquitous, easy, and affordable (Richter, 2014). On the other hand, compared to NS3D images, creating S3D images is considerably more challenging. More time, more equipment (e.g. stereoscopic camera, stereoscopic glasses) and more demanding photographic skills are required to create S3D images. Therefore, it is possible that NS3D images are more efficient than S3D images. If the performance tests of this study show that NS3D images are as effective as (or, more effective than) S3D images, then these findings will question the logic for the incorporation of S3D images in instruction. Then, S3D images will be not as efficient because they require greater cost to create but yield no greater learning benefits. The same applies to the notion of engagement: if NS3D images are reported to be as engaging as (or more engaging than) S3D images, then the efficiency of implementation of S3D images will be low.

This dissertation contributes to the union of two areas: instructional technology and second language acquisition. This union is commonly designated as Computer-Assisted Language Learning (CALL). The results of this study provide instructional designers, instructional technologists, and foreign language instructors with better information on how to facilitate explicit vocabulary learning by either including NS3D images (cheaper and easier, but less realistic) or S3D (more expensive and more difficult to create, but more realistic). Furthermore, the study contributes to the development of autodidactic materials --- for example NS3D and S3D flashcards and digital dictionaries --- for distance education. In the broadest sense, findings from this study provide evidence for cognitive psychologists on how a precise type of perceived dimensionality in a controlled setting affects the measured recall of information.

Delimitations of the Study. This study focused on how NS3D vs. S3D images affect vocabulary learning. In order to focus precisely on this narrow topic, it was necessary to set several boundaries, or delimitations, that may limit the generalizability of the study. The first delimitation was that the study only focused on computer-based learning. Therefore, any results generated may be unique to this setting and do not necessarily extend to the physical world. The second delimitation was that the study only investigated the learning of concrete nouns. This could imply that the effects of the treatment are not generalizable to other types of nouns, nor to the other parts of speech, or other learning material. The choice of concrete nouns was intentional in view of the fact that the experiment in this study involved absolute beginners, and according to Van Hell and Mahn (1997), concrete words are easier to learn than abstract words. In addition, evidence has already been provided on the effectiveness of NS3D images for learning words with distinct spatial components, such as spatial prepositions (Sato & Suzuki, 2010). The third delimitation was that the NS3D and S3D images in this study were static rather than dynamic or animated. This delimitation may make the results of this investigation not generalizable to contexts involving the use of movies, video games, or more sophisticated virtual reality platforms, such as *Oculus Rift*. The fourth delimitation was that S3D images using anaglyph S3D technology may have a different learning effect than S3D images using other technologies.

Definitions of Key Terms

This section provides definitions of the following key terms: *anaglyph 3D glasses*, *anaglyph S3D technology, cognitive load, explicit vocabulary learning, gloss, L1, L2, label, non-stereoscopic three-dimensional (NS3D) image, productive recall of second language vocabulary, realia, receptive recall of second language vocabulary, stereoscopic three-dimensional (S3D)* *image, stereoscopy, two-dimensional (2D) image*. In addition, synonyms are listed for several terms which may have been used in place of the key words in the references cited. Although these synonyms could be used interchangeably for the key terms for the purposes of this study, it should be noted that these additional terms may have more precise and distinctive meanings in other contexts.

Anaglyph 3D glasses – glasses for viewing anaglyph S3D images. The glasses have red and blue lenses with which each eye filters one of these two chromatically-opposite colors. (Cyan, green, or magenta can be used as an alternative to blue). The visual cortex of the brain processes this viewing in such a way that the image appears as in 3D. Figure 2 shows examples of anaglyph 3D glasses.

Anaglyph S3D technology – technology using S3D anaglyph images. The S3D anaglyph images "consist of two perspectives imposed onto an image in shades of red and blue, which are then channeled to the appropriate eye with glasses containing red and blue lenses." (Anthamatten & Ziegler, 2007, p. 231). The current study used this type of technology for the experimental group of words.

Cognitive load – From a cognitive psychology standpoint, *cognitive load* is the amount of mental effort imposed on working memory. When too much information is being processed at a certain time, cognitive *over*load takes place.

Explicit vocabulary learning – the deliberate learning of words and their meanings (often through translations or definitions). In this approach it is not uncommon for the words to be introduced in a decontextualized form (e.g., a list of words) or in a partially decontextualized way (e.g., in sentences). This approach is considered to be complementary to the incidental vocabulary learning/teaching approach (Nation, 2001).

The term *explicit vocabulary learning* simultaneously applies to *explicit vocabulary teaching*.

Gloss – A *gloss* refers to text with some type of linked explanation, which may consist of a synonym, translation, definition, image, audio or video recording, or other multimedia files. In the context of language learning, Nation (2001) defines *a gloss* as "a brief definition or synonym, either in L1 or L2, which is provided with the text" (p. 174). In the literature, the term *gloss* is often used interchangeably with the term *annotation*. However, in order to remain consistent, only the term *gloss* will be used throughout this paper.

Figure 6 provides a screenshot of an example of a gloss. In the text on the left, learners want to check what the word *Busverkehr* means. The word is hyperlinked so when learners click on it, there appears an image representing the word, *bus traffic*.

Glossing, such as when an image is provided as explanation for text (see Figure 6), can be contrasted with *labeling*, where a text explanation is provided for an image (see Figure 1).

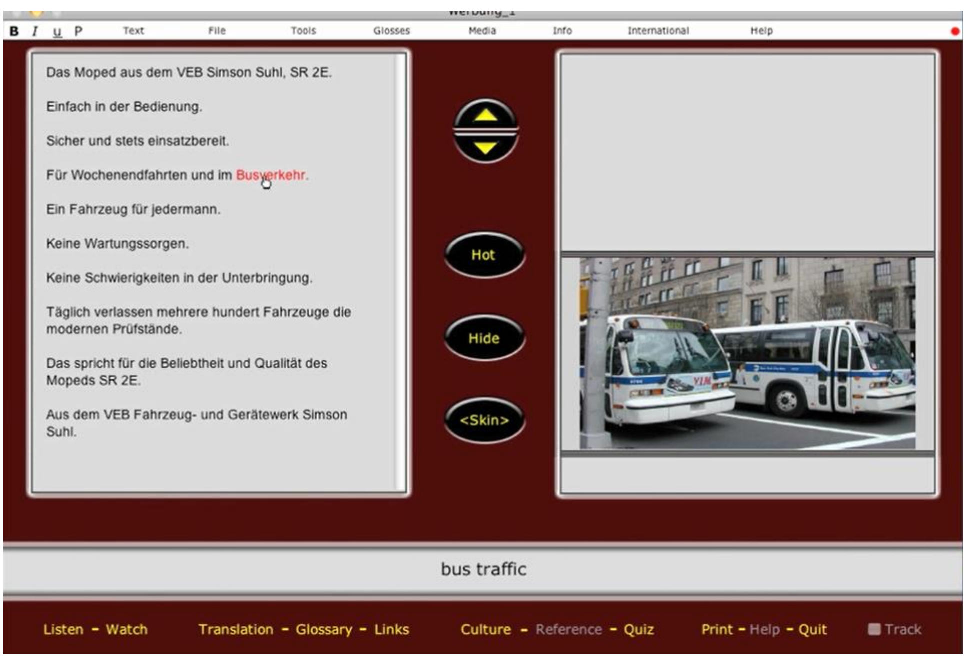

Figure 6. An example of a gloss (retrieved from http://redhotwords.com; FLAn by Thibeault, 2011).

L1 – the first language that is learned; the native language (Gass & Selinker, 2008).

L2 – the language learned after the native language (Gass & Selinker, 2008). The term *L2* is synonymous with the terms *second language* and *target language*.

Label – an L2 name and/or an L1 translation that is displayed near an object representation. A *label*, which is the provision of a text explanation for an image (see Figure 1), can be contrasted with a *gloss*, which is where an image may be provided as an explanation for text (see Figure 6 for an example).

Non-stereoscopic three-dimensional (NS3D) image – an image displayed on a 2D surface, which has height, width, and the appearance of depth. An NS3D image can be obtained by using various monocular visual cues, such as shade, tone, or texture. No special equipment needs to be used to view NS3D images. NS3D images can sometimes be referred to as *2.5D* or *pseudo 3D* images. In this study NS3D images formed the material for the NS3D treatment. They were distinguished from S3D images, which formed the material for the S3D treatment. In studies that do not involve S3D images, NS3D images are simply referred to as 2D images. However, this dissertation uses the term *NS3D* throughout the study to distinguish NS3D images from simpler 2D images (with no component portraying depth) and S3D images (using stereoscopic techniques to portray depth). To see an example of an NS3D image, see Figure 1 or Figure 7.

Productive recall of second language vocabulary – the ability to recognize the meaning of L2 words, as measured by providing the appropriate L1 translations in a L2-L1 translation test (Schmitt, 2000). See Appendix A for the productive recall test.

Realia – physical, real-life 3D objects used as teaching aids; "actual objects and items which are brought into a classroom as examples or as aids to be talked or written about and used in teaching" (Richards & Schmidt, 2013, p. 445). In this dissertation, this term is viewed similarly and is defined as *visual teaching aids that can be brought to class so that learners can make direct connections between the objects and their meanings.* Examples of realia are any objects (e.g. chairs, apples, or computers) that students have contact with and are used as teaching aids.

Receptive recall of second language vocabulary – the ability to recognize the meaning of L2 words, as measured by choosing the appropriate L1 translations in a multiple choice test (Schmitt, 2000). See Appendix B for the receptive recall test.

Stereoscopic three-dimensional (S3D) image – an image displayed on a 2D surface, which has height, width, and the appearance of depth. The 3D perception is obtained by using binocular visual cues. This study used anaglyph S3D technology. Therefore, S3D images had to be viewed through 3D anaglyph glasses. In this dissertation, S3D images composed the material for the experimental group. Each S3D image in the experiment of this dissertation was labeled with its name in L2 and a translation in L1. See Figure 1 or Figure 8 for an example of an S3D image.

Stereoscopy – the science pertaining to stereoscopic 3D images. Based on the concept of binocular disparity (the difference between what the left eye and the right eye can see), stereoscopic images appear to have depth. Depth, e.g. the third dimension, is the distinguishing element that 2D images lack. Because S3D images are displayed on a flat surface (e.g. on a screen, a piece of paper, or a slide), there is often a need for special viewing devices to see the images in 3D. In the experiment of this study, participants viewed S3D images using *anaglyph S3D glasses*.

Two-dimensional (2D) image – an image displayed on a 2D surface, which has height and width but lacks the appearance of depth. An example of a 2D image can be a simple line drawing.

Summary

This introductory chapter addressed the necessary background information that motivated this dissertation. The sections elaborated on the following topics: the evolving use of images and realia for education, visual learning, and visual representations and their realism - with particular focus on NS3D and S3D images. The following sections explained the contribution of the study and identified its delimitations. Finally, the definitions of key terms were presented. The next chapter will provide the description of the technology behind S3D display systems, followed by a review of relevant literature.

CHAPTER II

LITERATURE REVIEW

The purpose of this study was to investigate the effect of stereoscopic three-dimensional (S3D) images versus non-stereoscopic three-dimensional (NS3D) images on immediate receptive and productive recall of second language vocabulary. In order to examine these effects, the experiment in this study employed images generated using S3D technology. Therefore, Chapter II starts with a brief section describing the technology behind S3D display systems. The second part of Chapter II provides a review of related literature, which is divided into several sections. These sections elaborate on the following themes: the effectiveness of realia in education, the effectiveness of virtual equivalents of realia (with sub-sections covering NS3D and S3D representations for learning), the effectiveness of glossing, and the potential impact of cognitive overload. Finally, the chapter offers a summary of the entire literature review and the research question.

3D Viewing Technology

Monocular visual cues. The human brain is able to obtain a sense of depth through monocular (one-eyed) and binocular (two-eyed) visual cues (Pastoor & Wöpking, 1997; McIntire & Havig, 2014). Monocular visual cues are employed to provide an impression of depth on flat surfaces, such as in paintings or photographs. The most basic depth cue is interposition, which is when one object overlaps another. Other methods include the use of relative height, relative size, and linear perspective. In addition to these methods, the makers of pictorial representations have been using line-and-tone techniques, shading, and texture gradients (Skorge, 2006) to create an illusion of depth.

Monocular visual cues help learners perceive images as being more realistic compared to simple drawings because the cues add a partial impression of the third dimension. An image that employs only monocular cueing, however, is limited in its depiction of depth and therefore it is sometimes referred to as *pseudo 3D*, or *2.5D*. In this dissertation, monocular images are classified as a type of NS3D images. No special equipment is necessarily required to view NS3D images. Figure 7 provides an example of an NS3D image.

Figure 7. This image uses monocular visual cues (in this case, shade) to provide the appearance of depth. This type of image is known as a *pseudo 3D*, or *2.5D* image. In this dissertation, it is referred to as a *non-stereoscopic three-dimensional (NS3D)* image.

Binocular visual cues. Binocular visual cues, on the other hand, provide an enhanced impression of depth relative to monocular visual cues. Images using binocular visual cues are more appropriately described as being 3D. More precisely, these can be referred to as being *stereoscopic* 3D (S3D). “Binocular depth perception is based on local displacements between the projections of a scene onto the left and right retina (disparity)” (p. 100, Pastoor & Wöpking, 1997). This style of viewing is processed by the visual cortex of the brain. In consequence, the brain perceives the image being viewed as in 3D. Regardless of the type of S3D technology being used, the illusion of depth is obtained by showing a slightly different image to each eye. Figure 8 presents an example of an S3D image.

Figure 8. This is an example of a stereoscopic three-dimensional (S3D) image. Anaglyph 3D glasses must be worn to view this image in S3D.

Displaying and viewing S3D content can be executed in numerous ways, using different technologies. The most common types of systems displaying 3D content are stereoscopes, transparency viewers, head mounted displays, anaglyphs, polarization systems, eclipse methods, interference filter technology, and autostereoscopy. Each of these systems provide similar effects but with varying degrees of quality and viewing comfort. There are certain advantages and disadvantages associated with each of these methods. Table 1 shows several major (nonexhaustive) stereo display systems and briefly pinpoints their advantages and disadvantages. Examples of some stereoscopic display systems are also provided.

Table 1

Major Stereoscopic Display Systems (based on information in Kooi & Toet, 2004; Pastoor & Wöpking, 1997; Sands, 1956)

Type	Viewing System	Advantages	Disadvantages
Side-by-side images	Stereoscope, transparency viewers, or Head-Mounted Displays	Easy image generation	One user at a time, possible viewing discomfort, necessity for special optical equipment
Anaglyph*	Red and cyan glasses	Cost, no need for any special display/screen	Possible color rivalry and unpleasant aftereffects
Polarization	Polarized glasses	Affordability, no need for power, nor for special transmitter to synchronize glasses with the display; no flickering, lightweight	Cost, need for special display/screen; headaches, possible poor resolution
Eclipse method	LCD shutter glasses	Unlike anaglyph, glasses are color neutral so full color, full resolution viewing is possible	Cost, "flickering", glasses incompatible across various brands; possible distortion
Interference filter technology	Active shutter glasses	No need for special screen	Fancier glasses
Autostereoscopy	Special screen	No glasses necessary, special screen necessary	Cost, incorrect viewing angle may distort the 3D illusion

Note *The anaglyph technology is the one used in this study.

Anaglyphs. "Anaglyphs consist of two perspectives imposed onto an image in shades of red and blue, which are then channeled to the appropriate eye with glasses containing red and blue lenses" (Anthamatten & Ziegler, 2007, p. 231). This is the technology that was used in this study. The choice of this technology is justified by the affordable cost and by the flexibility of data collection. Future research can extend the findings of this study by using more advanced (but also more expensive) devices. Some alternative systems are described by Pastoor and Wöpking (1997).

The Effectiveness of Realia in Education

Initial studies on the use of realia in education found them to be advantageous for learning. However, due to the diverse and complex nature of these studies, the presence of numerous confounding variables led to mixed results. In this study, a strictly-designed setting allowed for a cleaner test of the effectiveness of virtual equivalents of realia. These were S3D images, used for learning vocabulary.

Published studies on the use of realia in education suggest that realia can have a beneficial effect on learning (Rule & Barrera, 2003; Rule & Fuletti, 2004; Rule et al., 2004; Webb, Cavanaugh, & Munson, 2014). Qualitative research reveals that both teachers and learners have a positive attitude toward using realia (Baird, 2003; Gibbons, 2008; Smith, 1997). Students exposed to realia were described as "excited", "interested", and "curious" because they "liked seeing the objects and playing with them before they had to use them in a lesson. This enabled the students to incorporate background knowledge and become familiar with the objects that they would then be using throughout the lesson" (Gibbons, p. 52). This finding is in line with Smith (1997), who claims realia are "motivating" and "meaningful".

Realia can be highly complex and can involve rich sensory stimuli. Depending on the item, realia can engage a learner on multi-sensory levels (e.g., a learner can touch, manipulate, build, see, hear, taste, and/or smell). However, it is difficult to discern which particular feature of realia has a positive or a negative effect. This difficulty has led to challenges in testing and interpreting the effects of realia on learning in the studies mentioned above (Rule & Barrera, 2003; Rule et al., 2004; Rule & Fuletti, 2004). For example, the experiments in the series of studies by Rule and colleagues (Rule & Barrera, 2003; Rule et al., 2004; Rule & Fuletti, 2004) suffer from the existence of multiple confounding variables. The experimental group in the study by Rule and Barrera (2003) used not only realia but also additional items, such as word cards and definition cards. The use of the supplemental learning aids and the involvement of participants in additional activities made it difficult to draw specific conclusions about the visual perception of realia. Therefore, it is impossible to be confident about what really drove the positive effect that was detected for realia: was it the increased dimensionality, was it the tangibility of objects, was it the use of additional learning aids, or was it something else?

One way to address the challenges in testing the effectiveness of realia is to introduce a more strictly-designed environment, which is now more feasible with modern computer-based settings. Some studies on realia compared the use of realia in traditional classrooms and their virtual equivalents of realia (i.e. S3D objects) shown on a computer monitor. These research studies generally did not detect statistically significant differences between the effect of realia and their virtual equivalents. However, Kealy and Subramaniam (2006) concluded that learning with virtual equivalents of realia is more time-consuming than learning with realia because virtual equivalents of realia may provoke a more demanding load on our cognitive processes, or, alternatively, that it may be more engaging.

The virtual setting of this study allowed for the isolation of the impact of S3D images on visual perception since additional factors (such as tactile sensory input or additional learning aids) were no longer present. As a result, the tests in this study were cleaner than in prior studies in testing for the effect of realia.

The Effectiveness of Virtual Equivalents of Realia in Education

Virtual equivalents of realia can take various forms, depending on how complex the designers desire them to be. The most basic form of those equivalents would be a simple line drawing on a computer screen. However, such a drawing would not appropriately display the multifaceted and textured surfaces of realia. More complex, three-dimensional images are more suitable for conveying the complex features of realia in a virtual setting. This dissertation explicitly distinguishes stereoscopic three-dimensional (S3D) images from other alternative types of techniques to display depth, referred to as non-stereoscopic three-dimensional (NS3D) images.

The effectiveness of NS3D representations for learning. Empirical research on the effectiveness of 2D and NS3D visualizations for education is scarce (Keller, Gerjets, Scheiter, & Garsoffky, 2006; Tavanti & Lind, 2001) and when it is present, it offers inconclusive findings. Certain studies show that 2D is superior to NS3D (Keller et al., 2006). Other investigations reveal weak or mixed results (Huk, Steinke, & Floto, 2010; Sato & Suzuki, 2010; St. John et al., 2001). One study indicated that NS3D is superior to 2D (Tavanti & Lind, 2001).

The conflicting results on the effectiveness of 2D and NS3D images appeared to be dependent on the conditions under which the experiments were conducted. Under restricted learning conditions, the NS3D format was marginally better, while under more realistic conditions, the 2D format proved superior (Huk, Steinke, & Floto, 2010). In addition, NS3D representations appeared to be beneficial only for learners with high spatial abilities, and detrimental for learners with low spatial abilities (Huk, 2006; Huk, Steinke, & Floto, 2010).

The studies cited above investigated the effect of NS3D vs. 2D visualizations. However, the methods used to achieve a NS3D perspective differed from the method in this study. To obtain an NS3D perspective this study employed techniques, such as shading, linear perspective, tone, or interposition.

The studies above compared the effectiveness of NS3D and 2D images, whereas this study compared NS3D and S3D images. S3D images provide richer stimuli than NS3D images, producing a more realistic effect. The method that was used in this study advances research by accessing additional levels of perception in learners.

The differences in effectiveness between NS3D and 2D images have been studied in aviation (Haskell & Wickens,1993); telerobotics (Park & Woldstad, 2000); computer science (Smallman, John, Oonk, & Cowen, 2001); Springmeyer, Blattner, & Max, 1992); biology (Huk, Steinke, & Floto, 2010); and psychology (Hasbrouck, 2013; St. John, Cowen, Smallman, & Oonk, 2001).

Only one study thus far investigated the effects of NS3D images on foreign language instruction (Sato and Suzuki, 2010). Sato and Suzuki (2010) embedded two different types of treatments in a multimedia dictionary: a 2D static gloss and a NS3D animation gloss. The learning content consisted of spatial prepositions, such as “above”, “on”, and “over”. Therefore, the content had an inherent aspect of dimensionality involving visual perception. The experiment consisted of 24 students, divided into treatment and control groups.

Unfortunately, Sato and Suzuki's small sample size made for statistically insignificant results. The complexity of learning through a tool such as a multimedia dictionary also illustrates the challenges that researchers face in designing studies of visual perception and language learning. As more than one factor was being investigated (2D vs. NS3D, animated vs. static), the sample would have had to be larger to detect any significant differences. It is also possible that the lack of statistically significant findings in Sato and Suzuki's study was due to the added cognitive load associated with animation (see Lowe, 1999).

The effectiveness of S3D representations for learning. As in the studies on the effectiveness of NS3D representations, the implementation of S3D visualizations and studies of their effectiveness are more common in disciplines where cognitive endeavors are oriented around spatial learning (Price, Lee, & Malatesta, 2014). Some examples of domains where research has been conducted on depth-related tasks using S3D technology are surgery (Lewis, Zaritsky, Heinrichs, & Nezhat, 2006), imaging (Cherniy, Kanter, Serova, & Ratobyl'skii, 2007), display design (Miller & Beaton, 1991), teleoperation (Drascic, 1991), aviation (Parrish, Williams, & Nold, 1994), and military science (CuQlock-Knopp, Sipes, Torgerson, Bender, & Merritt, 1995). Studies using S3D images for non-spatial learning tasks are much less common.

McIntire, Havig and Geiselman (2014), from the US Air Force Research Laboratory, performed a comprehensive review of studies that compared the effectiveness of NS3D vs. S3D displays on various types of learning. Their review took 162 articles under account and analyzed the outcomes of 184 experiments. An overall comprehensive measure showed that in 60% of the experiments, S3D viewing was more advantageous for performance as compared to NS3D viewing. Mixed results were found in 15% of the experiments, while the remaining 25% of experiments showed no advantage of S3D. A general conclusion was that when tasks are not depth-related, there is no significant benefit of using S3D. The study by McIntire, Havig and Geiselman confirmed a gap in the literature in that there has been no research pertaining to the effectiveness of foreign language vocabulary learning with S3D images, which was the focus of this study.

The Effectiveness of Glossing

This study examined the effectiveness of (NS3D vs. S3D) images that were *labeled* with their L2 name and L1 translation. In the language learning literature, the most closely related concept to *labeling* is *glossing*. The distinction is that labeling occurs when a text explanation is provided for an image, while glossing describes when a multimedia asset (an image, video, etc.) is used to supplement text (such as a vocabulary item).

Research on glossing expanded rapidly in the 1990s, due to the rise of multimedia learning used in computer-assisted instruction. Since then, research on glossing has provided evidence on the effectiveness of various types of multimedia assets that are useful for glossing (Acha, 2009; Chun & Plass, 1996; Kim & Gilman, 2008; Yeh & Wang, 2003; Yoshii & Flaitz, 2002). Examples of those assets are video, animations, sound, images, and text, as well as their various combinations. Because this study used images labeled with text, the variables in glossing research that are most relevant are text, images, and the combination of text-and-images.

Most of the published studies on glossing showed a decisive benefit of using the combination of text-and-image (Chun & Plass, 1996; Kim & Gilman, 2008; Yeh & Wang, 2003; Yoshii & Flaitz, 2002) rather than text-only or image-only. However, research on different levels of realism of images used for glossing or labeling in foreign language learning is scarce. The primary contribution of this study is therefore to provide empirical evidence on the impact of glossing with images of different levels of realism regarding dimensional perspective.

The Potential Impact of Cognitive Overload

Pass, Renkl, and Sweller (2003) claim that the sound instructional design of a learning unit ought to be comprised of tasks that challenge the learners' cognitive load to the point where the most effective learning occurs, but without overloading the cognitive capacity of working memory. However, cognitive overload is a theme that often appears in the literature on the effectiveness of learning. Therefore, it is possible that S3D images may overwhelm the mental capacity of the participants and these participants may consequently have lower scores for S3D images as compared with NS3D images. The following section examines the issue of cognitive overload in studies of realia, NS3D images, S3D images, and glossing.

Widespread attention not to overburden students' mental capacity has been documented for many decades. Leung and Franson (2001) advised teachers to keep in mind that even though using realia can help students comprehend content ideas, using realia does not guarantee that learners will effectively accomplish academic tasks. Renshaw (1927) urged that “we should be careful not to crowd the room [with too many realia]” (p. 356).

Kealy and Subramaniam (2006) documented no difference in effectiveness between using realia and their virtual equivalents, although they found that virtual equivalents demanded significantly more time to work with. The researchers indicated that the increased time required to complete a task was caused by the richer visual stimuli of virtual equivalents of realia.

Compared with NS3D images, S3D images are more realistic and have a visually richer depth added to them. Therefore, it can intuitively be stipulated that this richer, additional factor may increase the risk of cognitive overload. In a timed experiment, such as the one that was employed in this study, there was a risk that the learners may have been cognitively overloaded and thereby may not have had enough time to memorize all the vocabulary in a timely fashion. In consequence, their scores may have been lower. In fact, while comparing the effectiveness of NS3D vs. 3D representations, several investigators found 3D to be less effective compared to NS3D in some situations. They concluded that the inferiority of 3D representations was caused by extraneous cognitive load (Huk, 2006; Keller et al, 2006). This finding was supported by both performance data (Huk, 2006) and by learners' subjective reports (Keller et al., 2006).

In the experimental study by Huk (2006), a hypermedia tutorial with NS3D representations proved more effective relative to 2D representations only for learners with high spatial ability, while for subjects with low spatial ability the NS3D format resulted in cognitive overload. In the study by Keller et al. (2006) learners reported that they perceived increased difficulty with tasks involving three-dimensionality. The researchers concluded that "this could be due to the fact that learners had to invest more effort and experienced more difficulties during learning in the latter [3D] conditions" (p. 279). In other words, the students perceived extraneous cognitive load.

Compared to text, richer stimuli demand more cognitive load from learners (see Sweller, 1994, cognitive load theory). The assumptions behind this theory were confirmed by Chun and Plass (1996) who found out that while glossing with the combination of text-and-image was effective, glossing with the combination of text-and-video was not effective. Presumably, the video gloss demanded so much attention that it overwhelmed the effect of glossing.

It is evident that in each area of focus of this section (realia, NS3D images, S3D images, and glossing) there re-occurs the issue of cognitive overload. Therefore, this issue was kept in mind when forming the research question of this dissertation.

Summary of Existing Research

Research on the effectiveness of realia shows that realia are a constructive aid for learning. Nevertheless, because studies on realia often involved numerous confounding variables, it is difficult to discern which features of realia contribute to their effectiveness. The strictly-designed setting of the experiment in this current study allowed for an investigation that was free of confounding variables; focused on understanding the major differences in NS3D vs. S3D visual perception.

Past studies comparing the effectiveness of NS3D and 2D images showed inconsistent results. Some studies found 2D to be superior to NS3D (Keller et al., 2006; Park & Woldstad, 2000), while in other settings NS3D was found to be superior (Adeosun, 2008; Rule & Barrera, 2003), and others provided mixed results (Huk, Steinke, & Floto, 2010). The literature on S3D images is more consistent in showing that S3D images are beneficial for learning (McIntire, Havig, & Geiselman, 2014). One common trend is, however, that most explorations on the effectiveness of NS3D and S3D images focus on spatial learning with subject matter that is typically depth-oriented, with only limited applicability for foreign language learning. This dissertation filled this gap.

Finally, the investigations into the effectiveness of foreign language vocabulary glossing show that students learn best when provided with a text-and-image format. Therefore, this format served as the starting point in designing the experiment of this dissertation. Studies on glosses typically focus on linguistic aspects of learning. This dissertation also keeps linguistic aspects in mind but, in addition, it applies the perspectives and theories from the field of instructional technology. Studies on glossing have examined various aspects on learning with images (animation, video, etc.) but they do not consider how different aspects of images, such as increased dimensionality, impact vocabulary learning. This dissertation considers those missing aspects.

Research Question

The research question for the study is therefore: *"Is there a statistically significant difference between NS3D and S3D images in their effect on immediate productive and immediate receptive recall of second language vocabulary?"*

Hypotheses

The conflicting results of the existing literature and the differences between the literature and this proposed study made it difficult to make a clear prediction for the expected outcome of the hypothesis tests of this dissertation. This was the reason for the non-directional hypotheses of this study.

The null hypothesis was:

H_0: *There is no statistically significant difference between NS3D and S3D images in their effect on immediate productive and immediate receptive recall of second language vocabulary.*

The alternative hypothesis was:

H_1: *There is a statistically significant difference between NS3D and S3D images in their effect on immediate productive and immediate receptive recall of second language vocabulary.*

The next chapter describes the methodology used to answer this question.

CHAPTER III

METHODOLOGY

Based on the literature review in the previous chapter, this study aimed to fill the gap in literature on the effectiveness of S3D images in foreign language instruction. Specifically, this study examined the effect of S3D images, as opposed to NS3D images, on immediate receptive and productive recall of second language vocabulary.

This chapter details the methodology in the following sections:

- research design, research paradigm, and method;
- research question, hypotheses, variables, statistics;
- instrumentation and data sources;
- selection of participants and their characteristics;
- experiment content;
- experiment and testing setting;
- research procedure;
- post hoc analyses.

Research Design, Research Paradigm, and Method

This study employed quantitative methods to measure the effect of S3D images on L2 vocabulary recall. After the experiment and the performance tests, the participants answered eight follow-up questions, which were qualitative in nature. Figure 9 depicts the design of the study.

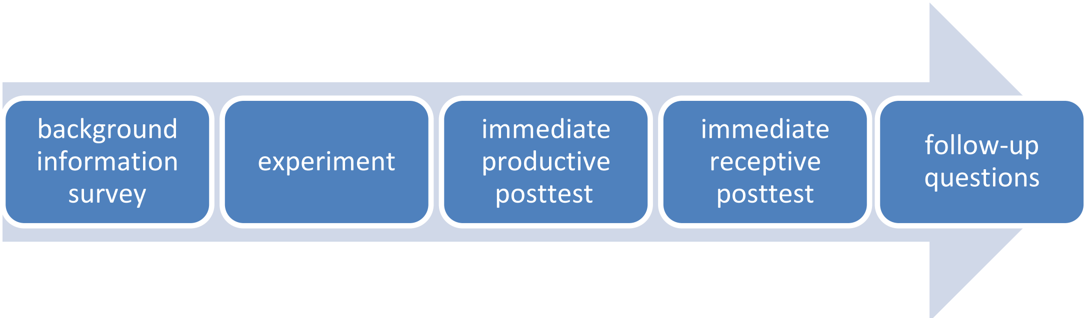

Figure 9. The Design of the Study.

The within-subjects design is similar to a counterbalanced repeated measures design. In studies such as these multiple treatments are applied to the same group of participants. With this design, the pretest could be omitted with the rationale that because the same participants were assigned to both treatments (NS3D and S3D), the test data comparison was unbiased by construction. All participants were tested on the same sets of words with equal numbers of NS3D and S3D image exposures.

According to Schmitt (2010), there is no need for a pretest in a study "if learners have had no exposure to an L2, because then it can be assumed that they have no knowledge of its vocabulary, as long as it is not a cognate language and there are no loanwords from the learners' L1" (Schmitt, 2010, p. 179). Because Polish is not a cognate language to English, it was assumed that the participants had no knowledge of the language – eliminating the need for a pretest in the design of this study. Further, the researcher assured that the participants had no knowledge of L2, nor a language that is a cognate to L2; furthermore, no loanwords and no cognates were included in the experiment.

This study examined the performance of the participants under the NS3D treatment compared to their performance under the S3D treatment. For this reason, methods to control for biases in the overall performance of both conditions, such as pretests, distractors (i.e. words intended to distract the participants from guessing what the experiment is testing), testing environment, etc., should not have influenced the hypotheses tests of this study. General impacts on the testing environment should have influenced both the NS3D and the S3D treatment values in the same way. However, the setting and the characteristics of the participants and content were carefully considered when judging how the findings could or could not be generalized to other contexts.

Research Question

Is there a statistically significant difference between NS3D and S3D images in their effect on immediate productive and immediate receptive recall of second language vocabulary?

Hypotheses

The null hypothesis was stated as:

H_0: *There is no statistically significant difference between NS3D and S3D images in their effect on immediate productive and immediate receptive recall of second language vocabulary.*

The alternative hypothesis was stated as:

H_1: *There is a statistically significant difference between NS3D and S3D images in their effect on immediate productive and immediate receptive recall of second language vocabulary.*

Variables

The independent variable in each test was the image type with two values: the NS3D and the S3D treatments. The dependent variables were the average recall scores on the two vocabulary tests: the immediate productive test and the immediate receptive test.

Statistics

Two-tailed, paired *t*-tests measured whether average recall test scores of the NS3D treatment were significantly different from average recall test scores of the S3D treatment. Each *t*-test used scores from 82 participants.

According to Cumming (2012), *p*-values are not sufficient for understanding statistical significance and should be considered together with effect size values. In the context of the present study, effect size was calculated following Cohen's (1988) formula for dependent *t*-tests: mean difference/standard deviation of the difference. The results were interpreted according to Cohen's reference values of .2, .5, and .8 for small, medium and large effects, respectively. Specifically, a significant test with a small effect size should be interpreted with caution because the results may be of little practical importance. On the other hand, a non-significant test with a moderate or above-moderate effect size signals that the lack of significance should also be interpreted with caution. The latter case is often observed in studies with small sample size which do not have enough power to reach a significant effect.

Instrumentation and Data Sources

The instruments of the study included a background information survey, an immediate productive recall test, an immediate receptive recall test, and follow-up questions. A description of each instrument is given below.

Background information survey. A pen-and-paper background information survey containing 10 questions was administered in class after collecting consent forms. These fill-in-the-blank and multiple-choice questions covered issues such as participants' gender, age, school rank, native language, and foreign language knowledge. This survey also helped to check for any prior knowledge of Polish. Further, the participants answered questions on their ownership of electronic devices, especially those capable of displaying S3D images (to ascertain prior exposure to S3D materials). Finally, the participants provided their email addresses so that they could be contacted for the data collection. A copy of the background information survey is provided in Appendix C.

Immediate productive recall test. The immediate productive recall test was in pen-and-paper and was administered immediately after the experiment. The test consisted of all the 30 second language (Polish) words encountered in the experimental activity for which the participants were asked to provide L1 (English) translations. The pool of 30 words included 15 words represented by NS3D images and 15 words represented by S3D images. Appendix A provides a copy of the immediate productive recall test.

The reason for the test to include all 30 items was influenced by Nation's (2001) advice. In order to increase the test reliability, this vocabulary expert recommends including as many items as possible, while keeping in mind that too many items are likely to cause fatigue. The sample size of this study was comparable to previously published studies, with the number of vocabulary items in previous, similar studies ranging from seven (Sato & Suzuki, 2010) to eighty (Lotto & De Groot, 1998).

Prior to the test, the participants were informed that they would have only five minutes to complete the test. This restriction meant that the participants had approximately 10 seconds per word on the test. In order to reduce the risk that participants would devote more time and/or attention to the items appearing earlier in the test than to the items appearing later in the test, the sequence of words was varied thanks to four different versions of the experiment. The time allowed for the experiment and the data collection was limited to 30 minutes.

Immediate productive recall test: Scoring rules. The participants received one point for each word translated correctly. Missing or incorrect translations received zero points. This open-ended test should have reduced the possibility of guessing. Possible total scores ranged from zero to 15.

The translations that were considered correct were those which had appeared in the activity or were close synonyms of the expected translation. For example, the correct translation of the word *kamień* is *rock*, just as it appeared in the activity. If instead of *rock*, a participant wrote *stone*, they also received the one point for this item.

There were two observations made for each participant: (1) the NS3D treatment observation, consisting of the participant's score on the words represented by NS3D images; and (2) the S3D treatment observation, consisting of the participant's score on the words represented by S3D images. Because paired NS3D and S3D observations were generated for each participant, the paired *t*-test was the appropriate statistic test to measure differences in the means (Howell, 2009). The mean score for the words in the NS3D treatment was then compared with the mean score for the words in the S3D treatment and the *t*-test was used to judge if the mean score for the words in NS3D treatment words was significantly different from the mean score for the words in S3D treatment.

Immediate receptive recall test. Following the immediate productive recall test, the participants took the immediate receptive recall test. The receptive recall test was a multiple-choice test. Therefore, if the sequence of those tests had been reversed, the receptive test would serve as a learning experience. This learning experience would not be desirable because it could influence the answers on the productive recall test. This process would increase the risk of a cross-test effect, causing an internal validity flaw.

The immediate receptive recall test was administered in person. This test was a multiple-choice test and consisted of 30 items which were the same words that the participants encountered in the experiment. The participants were asked to choose the appropriate translation of the target words from among the four choices provided. All the choices provided were taken from the same database of words as the words from the experiment. A copy of the immediate receptive recall test is provided in Appendix B.

Follow-up questions. After the immediate tests had been conducted, the participants were asked to answer eight follow-up questions. The reason for asking the follow-up questions after the tests were taken was that the researcher wanted to avoid making the participants aware of what the study was testing prior to performance testing.

The follow-up questions, which were of a qualitative nature, helped to triangulate certain findings that would be difficult to discern from the quantitative data alone. The follow-up questions had been designed to provide the researcher with some information on the perceived engagement of the participants during the experiment.

The follow-up questions investigated the participants' self-perceived engagement, performance, usefulness, discomfort, and preference within the overall activity, and especially concerning NS3D vs. S3D images. A copy of the follow-up questions is provided in Appendix D.

Selection of Participants and their Characteristics

Volunteer participants were recruited to participate in this study. First, the researcher contacted several instructors at a large university in the US Mid-West region and asked them if they would agree to make an announcement in their classes for volunteers to participate in the study. The instructors informed the students that the study would be on vocabulary learning but they did not reveal its main focus: the effect S3D images on learning vocabulary. In order to encourage participation in the study, there were incentives in the form of three $50 gift cards. The researcher was able to collect data from 82 participants.

There were several restrictions on who could be included in the sample. First, the participants could not know the Polish language. Second, they could not know any language that is a cognate to Polish. The reason for these two requirements was that the study was to test whether S3D images had an effect on learning *new, unfamiliar* words (Polish words, in this case). Therefore, potential participants who reported knowing Polish or a language that is a cognate to Polish (this was confirmed in the background information survey), were not included in the study. The languages that are cognate to Polish are: Russian, Ukrainian, Czech, Slovak, Bulgarian, Slovene, Macedonian, Belarusian, Lithuanian, Latvian, and Serbo-Croatian. The third requirement was that the participants needed to be native speakers of English. The last requirement was that the participants needed to be 18 years old or older.

Sample Characteristics. After the screening and the elimination of the volunteers who did not match the requirements for participating in the study, data was collected from a total of 82 participants. Table 2 shows the demographics of the 82 subjects in the study. There were more females (n = 57, 70% of the sample) than males (n = 25, 30%). "Junior" was the most numerous school rank represented (n = 25, 30%), followed by "freshman" (n = 23, 28%), "senior" (n = 19, 23 %), "sophomore" (n = 13, 16 %), and "graduate" (n = 2, 2%). The average age was 20.5 years, with subjects ranging from of 18 to 33 years old.

Table 2

Demographic Information about the Participants

		Gender		School rank					Age
	N	F	M	Freshman	Sophomore	Junior	Senior	Graduate	(mean)
Total	82	57	25	23	13	25	19	2	20.5
%		70%	30%	28%	16%	30%	23%	2%	

A total of 74 subjects (90%) had knowledge of a language other than English. The subjects had the most experience learning Spanish (*n* = 53, 65%), followed by German (*n* = 18, 22%), French (*n* = 18, 22%), Japanese (*n* = 4, 5%), Chinese (*n* = 4, 5%), Amharic (*n* = 1, 2%), and Latin (*n* = 1, 2%). The number of languages sums to greater than 82 because some subjects had knowledge of more than one non-English language.

Table 3 displays background summary information describing the experience of subjects with 3D technology and electronics use. On average, subjects reported using electronics for 6.34 hours a day. A large percentage (97%) of subjects reported having seen a movie in 3D but only 28% of them had experience of playing a 3D video game. Only 22% of the subjects reported owning a system that displays 3D content, with Nintendo 3DS being the most popular system to own (12%). Less popular systems included Visio 3D TV, LG 3D TV, and Samsung HD 3D TV.

Table 3

The Experience of the Participants with 3D Technology

3D movie experience	3D video game experience	3D system ownership
97%	28%	22%

Experiment Content

The study measured the effect of S3D images on learning the names of common objects in Polish. Before the actual experiment took place, the participants viewed six slides consisting of three S3D and three NS3D images. Viewing those slides served as a “warm-up” and was intended to explain what the subjects were supposed to do, as well as to decrease the novelty effect.

Next, during the experiment, the participants were exposed to 30 images with Polish labels and their English translations (see Figure 1). The labels in Polish were written in a larger font (44 pts), while the translations in English were written in a smaller font (20 pts). The list of words consisted of 30 concrete nouns of varying levels of difficulty. Of the 30 images, half (15) of the images were NS3D, while the other half (15) of the images were S3D.

Assignment of words to control and treatment conditions. In order to insure an equal exposure of the words in the NS3D and the S3D treatments to participants, four different versions of the experiment were created (Table 4). The four versions tested the same vocabulary items. However, the format (NS3D vs. S3D) of individual images and the sequence of their exposure varied from version to version. There were three major steps that took place in creating the four versions of the experiment. These steps are described below:

Step 1: Generating a list of appropriate concrete nouns, labeled in Polish and English. The word list was generated using the Internet application *Random Noun Generator* (http://www.desiquintans.com/noungenerator.php). From the randomly generated nouns, only concrete nouns were chosen. It was assured that the selected 30 English concrete nouns were neither loanwords, nor cognates of Polish. Appendix E features the complete list of the selected Polish words with their English translations.

Step 2: Creating NS3D and S3D images representing the words in the concrete noun list. The researcher took photographs of objects representing the 30 words in the above-mentioned list of concrete nouns. The photographs were taken with a stereoscopic camera *Fujifilm Pix 3D W3*. Next, the researcher created NS3D versions of S3D photographs.

Step 3: Creating four versions of the experiment for the participants. In order to remove any possible bias due to word ordering, the sequence in which words were presented was alternated from subject-to-subject. In order to accomplish this, the first 15 words were numbered 1-15 and were assigned as set *A*. The rest of the words were numbered 16-30 and were assigned as set *B*.

Step 3.A.: In version #1 of the experiment, *set A* (words 1- 15) was represented by NS3D images. *Set B* (words 16-30) was represented by S3D images. Participants receiving version #1 of the experiment viewed the images in *Set A* first, next they viewed the images in *Set B.*

Step 3.B.: Version #2 of the experiment was identical to version #1 with the difference that the dimensionality of images in sets was reversed. That is, s*et A* (words 1- 15) was represented by S3D images. *Set B* (words 16-30) was represented by NS3D images.

Step 3.C.: In version #3, *set A* (words 1-15) was represented by S3D images. *Set B* (words 16-30) was represented by NS3D images. Participants receiving version #3 of the experiment viewed words in *Set B* first. Next, they viewed the words in *set A.*

Step 3.D.: In version #4, *set A* was represented by NS3D images. *Set B* was represented by S3D images. The participants receiving version #4, viewed the words in *Set B* first. Next, they viewed the words in Set A.

Table 4

Summary of the Four Versions of the Experiment

Experiment version #	Set A (words 1-15)	Set B (words 16-30)	Sequence
1	NS3D	S3D	Set A, Set B
2	S3D	NS3D	Set A, Set B
3	S3D	NS3D	Set B, Set A
4	NS3D	S3D	Set B, Set A

Labels description. Each image was labeled below with its name in Polish. The corresponding English translation was displayed in parenthesis next to the Polish word (see

Figure 1 for an example of a label). Both the Polish labels and their English translations were seen in the same color (white) and the same type of font (Arial). The size of the font, however, varied: L2 words were in a larger font (44 pts), while words in L1 were in a smaller font (20 pts).

Experiment and Testing Setting

Experiment setting. The experiment took place in a conference room. The room had no windows, which was convenient because possible glare on the monitors could have caused problems with viewing the images. Four laptops (Dell Latitude E6420, i5-2430M, nVidia NVS) were used for the experiment. Each participant had a separate experiment station and was participating on an individual basis. The researcher was present in the room in case of technical problems. However, the researcher was not helping the participants with any answers to the test questions.

The experiment itself took place on a computer screen. The participants watched a slideshow with 40 automatically-alternating slides. First, there was an introductory slide welcoming the participants and instructing them, if necessary, to put on their anaglyph glasses. Second, the participants viewed three slides with S3D images and then three slides with NS3D images. These introductory slides served as a “warm-up” and they gave instructions of what the students were supposed to do. The “warm up” slides were also intended to decrease the novelty effect. Third, there was a transition slide notifying the participants of the beginning of the experiment. Fourth, the participants viewed the first set of 15 experiment slides. Fifth, there was a transition slide requesting the participants to take on, or take off the anaglyph glasses (depending on the version of the experiment). Sixth, there was the second set of 15 experiment slides. Finally, there appeared the slide informing the participants about the end of the experiment. There was no difference in appearance between NS3D treatment slides and the S3D treatment slides, with the exception of the image dimensionality.

Each participant was exposed to each slide for an equal amount of time (15 seconds). Based on feedback from the pilot study, 15 seconds of exposure was deemed adequate for the participants to view each image. After that time, the next slide automatically appeared for the identical amount of time. This sequence was repeated until the participant had been exposed to all the 40 slides. The reason for the timed exposure was that the researcher wanted to assure that there was equal exposure of both NS3D and S3D images.

Testing setting. The data collection was in pen-and-paper form. An electric timer was set for each participant so that they could manage their testing time if they desired to do so. Copies of the tests can be seen in Appendices A and B.

Research Procedure

The research procedure consisted of the following six steps: (1) consent form and background information survey, (2) "warm up", (3) experiment, (4) immediate productive recall test, (5) immediate receptive recall test, and (6) follow-up questions.

Upon arrival to the conference room for the experiment, the participants were briefly instructed about what they would have to do. In addition, the explanatory / introductory slides of the experiment presentation reminded the participants of what they are supposed to do during the experiment. The summary of the research methodology is provided in Table 5.

Table 5

Summary of the Research Methodology

Research question
Is there a statistically significant difference between NS3D and S3D images in their effect on immediate productive and immediate receptive recall of second language vocabulary?
Research design: Background information survey + experiment + immediate productive recall test + immediate receptive recall test + follow-up questions
Research paradigm: Quantitative
Method: Experimental
Data sources: background information survey, immediate productive recall test scores, immediate receptive recall test scores, follow-up questions
Participants: 82 university students
Content: Thirty labeled images (15 represented with NS3D images + 15 represented with S3D images)
Statistics: Two-tailed, paired *t*-tests

Timing. The participants were expected to participate in the study on two occasions. The first time took part during the students' regular class with their teacher and the researcher present in the classroom. At that time the participants' recruitment took place. Those who agreed to participate in the study needed to fill out a consent form. Further, the participants completed a brief background information survey (see Appendix C for a copy of the background information survey) and they filled out the scheduling sheet. Overall, the first participation session took about five minutes. The second time that the volunteers needed to participate was on the actual experiment day, which took place in the conference room. The first 2-3 minutes were spent assigning the participants to their computers and instructing them what to do. Further, the volunteers viewed the "warm up" introductory/explanatory slides. Next, there was time for the experiment, which took eight minutes. After the experiment finished, the participants completed a five-minute immediate productive recall test and a five-minute immediate receptive recall test. After the performance post-testing, there were eight follow-up questions for the participants to answer. Answering the follow-up questions took about five minutes. Overall, the second participation session took up to 30 minutes. The summary of the participation timing is provided in Appendix F.

Post hoc analyses

The analyses of the emerging data motivated several additional tests, which were exploratory rather than primary research questions. The post hoc tests explored the following topics: the impact of discomfort on the effectiveness of S3D images; the impact of experience with S3D technology; the self-perceived retention of vocabulary presented through NS3D and S3D images; and, the self-perceived usefulness of using S3D images for learning vocabulary.

In order to explore each of these issues, the same procedure was used. First, the full sample of subjects (*N* = 82) was divided into two appropriate subgroups. These subgroups included:

a) the subgroup that reported discomfort and the subgroup that reported no discomfort;

b) the subgroup that reported having an experience with S3D technology and the subgroup without such an experience;

c) the subgroup that reported that they self-perceived their performance to be superior on words represented through S3D images and the subgroup that reported that they self-perceived their performance to be superior on words represented through NS3D images;

d) the subgroup that reported that they self-perceived S3D images to be useful for vocabulary learning and the subgroup that reported no such usefulness of using S3D images.

Next, the subjects' performance between NS3D and S3D words was analyzed separately for each set of subgroups. This procedure involved the computation of paired *t*-tests measuring whether average recall test scores of the NS3D treatment were significantly better from average recall test scores of the S3D treatment within each subgroup.

Each hypothesis in the post-hoc analyses was one-directional. This approach was driven by the rationale that there was an expected outcome in each observation. For example, for the subgroup who reported having experience with S3D technology, it was expected they would do better on words represented through S3D images, rather than on those represented through NS3D images. For the subgroup who reported discomfort with S3D technology, it was expected that they would do worse on words represented with S3D images than on words represented through NS3D images. Those one-directional expectations motivated the employment of one-tailed tests in all the post-hoc analyses.

Last but not least, Likert scale data is traditionally treated as ordinal and may present concerns when analyzed with parametric statistics tests (see Turner, 1993; Reid, 1990). To be cautious, the use of Likert response data in this study is restricted to the supplementary ad hoc analysis, where the procedure follows Allen (2002) and Braun (2007), with illustrative analysis used only to provide additional insights that aid in the interpretation of the main hypothesis tests.

CHAPTER IV

RESULTS

In order to make learning more meaningful, visual aids have been used to enhance the connection between words and their visual representations. Some forms of teaching with visual aids have included the use of physical objects (realia), which are thought to be beneficial for learning (Rule & Barrera, 1999; Rule, Barrera, & Steward, 2004; Webb, Rule, Cavanaugh, & Munson, 2014). However, realia are often impractical in the classroom and therefore teachers rely on the digital substitutes of realia, such as images displayed on computer screens. The realism of digital images ranges from the simplest 2D images with no depiction of depth, through 2.5D images (in this dissertation referred to as NS3D images) with a *pseudo* depiction of depth, to complex stereoscopic 3D images (S3D), which appear to be highly realistic. The major goal of this experimental study was to investigate the effect of S3D images on immediate receptive and productive recall of second language vocabulary.

The null hypothesis of the study was:

H_0: *There is no statistically significant difference between NS3D and S3D images in their effect on immediate productive and immediate receptive recall of second language vocabulary.*

The alternative hypothesis was:

H_1: *There is a statistically significant difference between NS3D and S3D images in their effect on immediate productive and immediate receptive recall of second language vocabulary.*

As described in the methodology chapter, this within-subjects experimental study began with background information surveys, which were then followed by the experiment. Four different versions of the experiment covered various experimental scenarios and ensured variation in image exposure across participants. Immediate productive and receptive recall tests measured the learners' performance. Additionally, a follow-up questionnaire was used to obtain feedback from the participants.

For the full sample of subjects, the primary hypothesis tests showed no significant differences in test scores for words represented with NS3D and S3D images. However, S3D images were statistically significantly more engaging. Further, the majority of subjects reported S3D images to be more useful for vocabulary learning than NS3D images, even though this self-perception was not reflected by performance. The favorable attitude toward S3D images was supported by positive comments, which helped identify several self-perceived benefits of S3D images, including enhanced focus, enhanced realism, enhanced engagement, and enhanced association. Meanwhile, several participants also reported self-perceived drawbacks of S3D technology, such as distraction and discomfort. Post hoc tests suggested that discomfort and / or lack of experience with S3D technology may impede learners from learning through S3D images. In addition, only the subgroup of the learners who self-perceived superior performance with NS3D images did indeed perform better on NS3D words.

Hypothesis Tests

The null hypothesis was that there is no statistically significant difference between NS3D and S3D images in their effect on immediate productive and immediate receptive recall of second language vocabulary. To test this hypothesis, quantitative methods were used to measure students' performance. Statistical Package for the Social Science (SPSS), version 16.0, was used to perform a series of *t*-tests. Cohen’s *d* values of 0.2, 0.5, and 0.8 for small, medium and large size effects, respectively, were taken into account when reporting the results. The details of the immediate productive and receptive tests are presented in the following two sections.

Immediate productive test results. Table 6 displays the mean scores (number of correct items) from the productive recall test, as well as associated hypothesis test statistics. Mean scores are given for words displayed with NS3D and S3D images. The mean score for words displayed with NS3D images was 4.87 (out of 15). The mean score associated with S3D images was 4.61. This means that when the subjects learned through NS3D images, they scored .26 higher, on average, than when the subjects used S3D images — a difference that is of no statistical significance (p = 0.40). Table 6 also provides percentages of the scores, as well as minimum and maximum scores for each measure. In addition, the effect size calculated using Cohen's d was 0.19. Therefore, for the full sample of subjects, we cannot reject the null hypothesis of no significant difference between the effect of S3D and NS3D images, on foreign language recall in the productive recall test.

Table 6

Results of the Paired T-tests on Productive and Receptive Test Scores

	Means (%, min, max)		Means difference	*df*	*p* (two-tailed)	*t*	Cohen's *d*
	NS3D	S3D					
Productive	4.87 (32%, 1, 15)	4.61 (31%, 1, 10)	0.26	81	0.40	0.84	0.19
Receptive	9.72 (65%, 3, 15)	9.43 (63%, 3, 15)	0.29	81	0.23	1.20	0.27

Immediate receptive test results. As seen from Table 6, the mean score on receptive recall test with NS3D images was 9.72 (out of 15). The mean score for S3D images was 9.43. Therefore, subjects scored 0.29 points higher on average for NS3D words relative to S3D words. However, the t-test results indicate that this difference between NS3D words and S3D words was not statistically significant, ($t_{(82)} = 1.20$, $p = 0.23$). The effect size was 0.27. Therefore, the null hypothesis of no significant difference between S3D and NS3D images, on foreign language vocabulary learning in the receptive recall test, could not be rejected.

Test score levels. The analysis of the test scores revealed that the raw test scores were quite low compared to normal academic standards. With the maximum score being 15, mean scores for words represented with NS3D images were 4.87 (32% correct) on the productive tests and 9.72 (65%) on the receptive tests. Mean scores for words represented with S3D images were 4.61 (31%) on the productive test and 9.43 (63%) on the receptive test. Generally, such score levels would translate to a failing grade if this were a standard university classroom test. However, in the context of the current study, the low scores were expected, with the rationale explained below.

The subjects were exposed for the first time to thirty Polish words, a language they had never studied before. These words were neither loanwords nor cognates of English, which made them difficult to remember for non-native speakers of Polish. The exposure to each word lasted only 15 seconds, which is rather a short time for word learning processing. This means that the large amount of new information put a heavy demand on the working memory, making the novel vocabulary difficult to acquire in such a short time of exposure and without the chance for repetition. The levels of the scores in the current study are consistent with established cognitive theories on the limitations of human memory, which pinpoint how limited human memory is (Miller, 1956; Cowan, 2001; Feldon, 2010; Janssen, Kirschner, Erkens, Kirschner, & Paas, 2010). In addition, the testing itself had time limits of 10 seconds per word. Such a restriction further diminished the chances for higher scores.

Regarding the difference in scores for the receptive and the productive tests, as Read (2000) confirms, it is commonly accepted in the field of language acquisition that we are able to recognize and understand words (passive knowledge) much better than we can produce them (active knowledge). Therefore, it is not surprising that the learners scored much higher on receptive tests, as compared to the productive tests.

Posttest follow-up feedback from participants. After the performance tests had been conducted, all 82 participants completed an eight-item follow-up questionnaire (see Appendix D). The questionnaire was administered to elicit participants' perceived engagement of NS3D and S3D images, 3D-system ownership and use, self-reflection on their performance tests, opinions on the usefulness of S3D images for learning vocabulary, and the subjects' discomfort while using S3D technology. Participants also had the possibility to provide additional comments.

In order to clarify a possible confusion with nomenclature, it is important to repeat that this dissertation uses technical terms *non-stereoscopic 3D images (NS3D)* and *stereoscopic 3D (S3D) images.* Because the general public, including the participants of the study, are not expected to be familiar with these technical terms, the respective terms *2D images* and *3D images* were used in the questionnaire.

Engagement toward NS3D and S3D images. The subjects were asked in the follow-up questionnaire to indicate how engaging they found NS3D and S3D images, respectively. A Likert Scale ranging from 1 to 5 (with 1 being *low*, and 5 being *high*) was employed for the ranking. Table 7 displays the mean rating scores given to engagement for NS3D and S3D images, along with associated test statistics. Test statistics are provided for a *t*-test of differences in means between the mean rating scores for NS3D engagement and S3D engagement. The mean score for NS3D image engagement was 3.22, while the mean score associated with S3D image engagement was 3.66. The difference of 0.44 points represents how much more engaging subjects perceived S3D images relative to NS3D images. The *t*-test statistics ($t_{(82)} = 2.60$, $p = 0.01$) indicates that the difference between engagement levels for NS3D words and S3D words was statistically significant. That is, subjects indicated that they found S3D images more engaging than NS3D images. The calculations of effect size using Cohen's *d* revealed a value of 0.58. Figure 10 depicts the engagement levels for NS3D and S3D images across the 5-point Likert scale.

Table 7

Results of the Paired T-Test Comparing Engagement Levels toward NS3D and S3D Images

Engagement mean score		Means difference	*df*	*p* (two-tailed)	*t*	Cohen's *d*
NS3D	S3D					
3.22	3.66	0.44	82	0.01	2.60	0.58

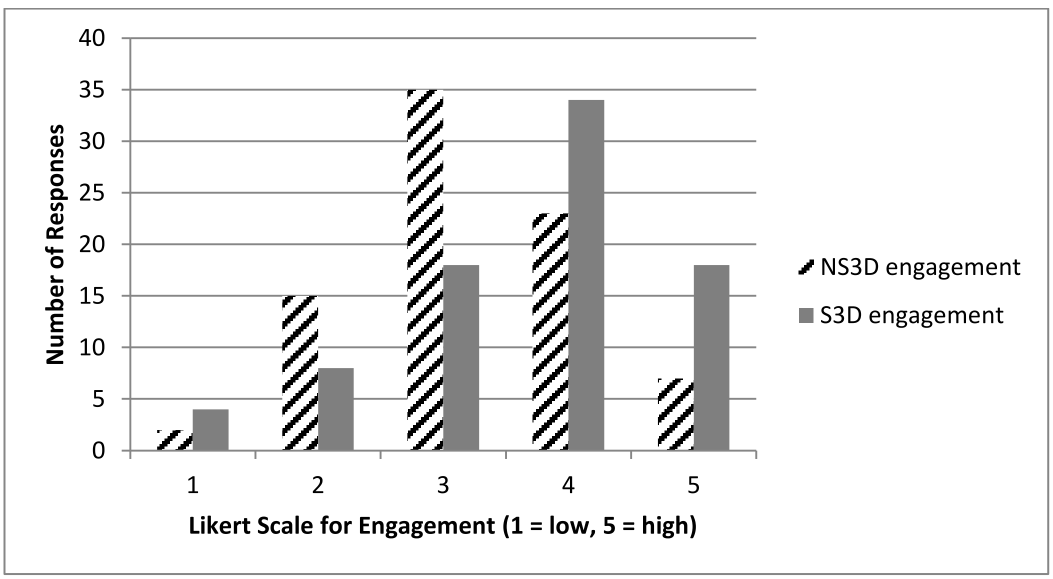

Figure 10. Reported levels of engagement toward NS3D and S3D images from the follow-up questionnaire. Engagement toward NS3D images (striped bars) peaks in the middle, while engagement toward the S3D images (solid bars) is skewed toward higher ratings.

Perceived usefulness of 3SD images for vocabulary learning. The subjects were asked the following Yes-No question on the follow-up questionnaire: "*Do you think it would be useful for you to learn vocabulary using 3D images*?" Then they were encouraged to elaborate on the reasons for their responses by answering "*Why / Why not?*"

All the 82 participants responded to the question, with the majority (n = 48, 58.54%) confirming that they perceive S3D images as useful for vocabulary learning. Comments explaining the reasoning behind their opinions were provided by 79 participants (96%).

Based on the reoccurring themes provided by the subjects, the comments were organized into three broad categories, which then were divided into several subcategories: 1) Comments supporting the usefulness of S3D images for vocabulary learning (enhanced focus, enhanced realism, enhanced engagement, enhanced association); 2) Comments negating the usefulness of S3D images for vocabulary learning (distraction, discomfort); and 3) Mixed comments. Figure 12 summarizes the distribution of the themes.

Comments supporting the usefulness of S3D images for vocabulary learning. A total of 13 comments (16% of the subjects) included the notion of "**enhanced focus**." Some participants stated that the S3D images "stand out" and that they directed the focus on the objects being shown. Subjects implied that the background in such images was of less importance and, consequently, there was less distraction.

Some examples of specific comments include:

- "*The image felt more real, so it was harder to get distracted.*" [subject # 71, female, 19]
- "[S3D objects] *helped me focus on the image and not the background.*" [subject# 49, female, 18]

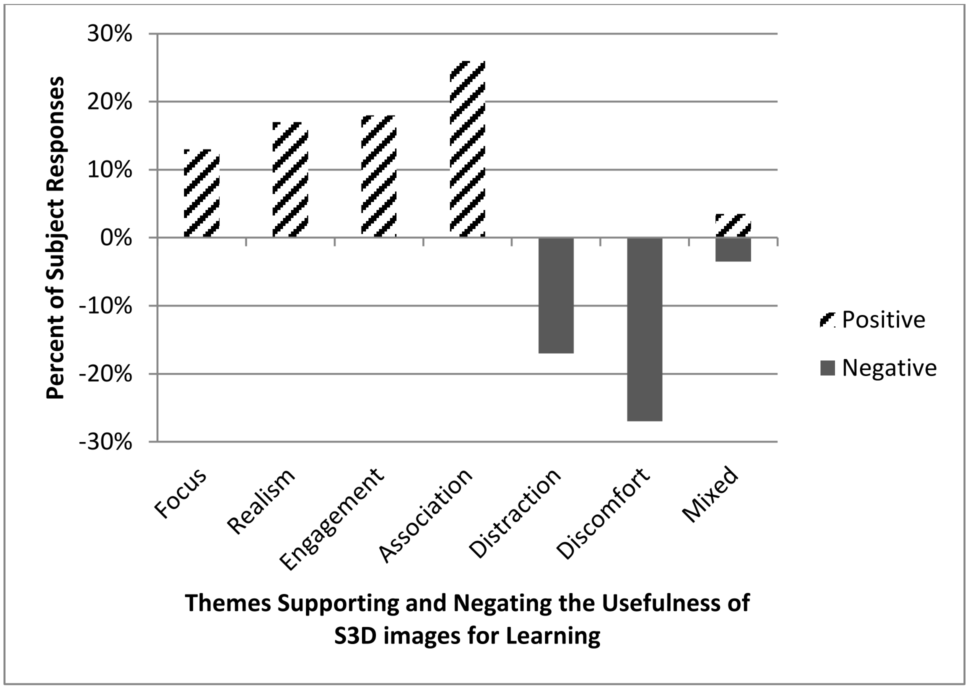

Figure 11. The distribution of the perceived positive and negative themes regarding the usefulness of S3D for learning. The striped bars represent the number of positive comments toward S3D images. The solid bars represent the number of negative comments toward S3D images.

A total of 17 (21%) comments included the notion of "**enhanced realism**." Some participants thought the S3D objects were "more life-like" and they felt they "had the object in front..." [of them]. The participants reported that they "could touch" the objects and that they were "more interactive."

Some examples of specific comments:

- "*It feels as if you can touch it* [the object represented by an S3D image] *...* " [subject# 56, female, 18]
- "*[An S3D image] gives a seemingly tangible view instead of just a picture.*" [subject# 4, female, 18]

- "*... the fact they* [S3D images] *were in [S]3D made it seem more urgent that I learnt them / gave more importance, and a sense of greater interaction with them, even though I know full they are just images!*" [subject# 66, female, 19]

A total of 18 (22%) comments included the notion of "**enhanced engagement**." Some participants found the S3D images "stimulating" and "more interactive."

Some examples of specific comments:

- "*Because it* [an S3D image] *engages the attention more even if it's to solidify the image.*" [subject# 30, female, 20]
- "*For some more tactile, hands-on learners, it* [an S3D image] *could be more engaging.*" [subject# 60, male, 18]

Twenty-six subjects (32%) expressed further beneficial perceptions of S3D images, but which could not be easily grouped into the subcategories given above. Therefore, they are classified simply as "enhanced association." These comments included descriptions of S3D images as "more memorable", "could lead to improved memory and word association", "connect the word to the object better", "activate more imagination", "helpful for learning", "could associate better."

Some examples of specific comments:

- "*The [S]3D image put a more memorable image in my head.*" [subject# 52, male, 19]
- *"... I felt like I could associate the Polish word with the object better.*" [subject# 56, female, 18].

Furthermore, some subjects described S3D images as "cool", "fun", "wow" and "more interesting." These type of comments prompt one to consider that S3D images could have had a novelty effect on some learners.

Comments negating the usefulness of S3D images for vocabulary learning. The analysis of the participants' comments helped distinguish two clear themes regarding perceived negative effects of S3D images for learning: These negative themes were “distractibility” and “discomfort.”

A total of 17 (21%) comments included the concept of “**distractibility**” or disorientation. Some examples of specific comments:

- “*I found myself distracted by the* [S3D] *image and couldn't focus on the relation between the word and the picture*.” [subject #82, female, 21]
- “*I personally found the [S]3D more distracting than helpful*.” [subject #62, female, 19]
- “*I was too focused on the [S3D] image, not the word*.” [subject #29, female, 21]

A total of 33 participants (40%) reported feeling “**discomfort**” while viewing the S3D images. Specific participants reported feeling “dizzy”, “sick”, and “tired” when viewing S3D images. Further, some expressed getting “a headache” and that they found S3D images to be “too much for the eyes” or “fuzzy.”

Some examples of specific comments:

- “*It* [an S3D image] *may be somewhat useful but the glasses would get irritating after a while*.” [subject #11, female, 21]
- “*It* [an S3D image] *gave me a headache, though in the future with technology it might be beneficial*.” [subject #12, female, 28]
- “*It* [an S3D image] *hurts my eyes and can make me dizzy after extended periods*.” [subject #13, female, 32]

Mixed comments. As shown in the previous paragraphs, there were both positive and negative comments regarding the S3D images. However, six participants (7%) provided mixed comments. Those mixed comments mostly pointed out something positive, such as engagement but then complained how uncomfortable it could be to view the S3D images or how distracting they could be.

Some examples of specific comments:

- "*The* [S3D] *images were more engaging but the [S]3D effects give me a headache after a while*." [subject #67, female, 20]
- "*For me it* [an S3D image] *was very engaging but almost distracting, [S]3D kind of makes me feel dizzy/sick*." [subject #32, male, 24]
- "*I think it* [teaching with S3D images] *can be* [useful] *once the student is no longer distracted by the wow factor of the [S]3D images. For some images I personally got distracted at how "cool" I thought the [S]3D [images] were*." [subject #35, female, 19]
- "*It* [an S3D image] *is more engaging but I think it may take away focus on the learning aspect*." [subject #36, male, 23]

Post hoc analyses

The post hoc analyses of the data included additional tests pertaining to the following four issues: the impact of discomfort on the effectiveness of S3D images, the impact of experience with S3D technology, the self-perceived retention of vocabulary represented through NS3D and S3D images, and the self-perceived usefulness of using S3D images for learning vocabulary. The following sections describe the results of the post hoc analyses.

The impact of discomfort on the effectiveness of S3D images. The subjects gave feedback on discomfort on two separate occasions. First, in the follow-up questionnaire, there was a question that specifically asked whether the participants experienced discomfort while viewing S3D images. In answering this question, a total of 33 subjects (40%) reported experiencing discomfort when viewing S3D images. Furthermore, as mentioned in the previous section, when prompted to provide open-ended comments on the usefulness of S3D viewing, 26% of the subjects mentioned discomfort as a drawback of the S3D technology. Because these percentages represent a large proportion of the sample, additional tests were conducted to establish how discomfort, or the lack of it, influenced the test scores.

The full sample of subjects ($N = 82$) was divided into two subgroups based on whether or not they reported (on the questionnaire) experiencing discomfort when viewing S3D images. Thirty-three participants (40%) reported discomfort and 49 (60%) reported no discomfort. In order to evaluate the difference in performance test scores between NS3D and S3D images, four additional paired *t*-tests were conducted, for the discomfort and no-discomfort subgroups on both the productive and receptive tests.

Table 8 summarizes the results of paired *t*-tests for the subgroup that reported discomfort while viewing S3D images. For productive tests, the mean NS3D score was 5.58 and the mean S3D score was 4.52. The difference between these means amounted to 1.06. Because it was assumed that discomfort would impede subjects from learning the words represented with S3D images, a one-tailed *p*-value was taken under consideration. The difference of mean scores between NS3D and S3D words was significant ($t_{(33)} = 1.96$, $p = 0.03$) with Cohen's *d* effect size amounting to 0.69.

For receptive tests, the mean NS3D score was 10.48 and the mean S3D score was 9.76. The difference between those means amounted to 0.72 with the mean NS3D score being significantly higher than the mean S3D score ($t_{(33)} = 2.10$, $p = 0.02$). The effect size calculated using Cohen's *d* amounted to 0.74.

Table 8

The Results of the Paired T-Tests for Discomfort and No-discomfort Subgroups

Subgroup	Measure	Mean Scores		*df*	*p* (one-tailed)	*t*	Cohen's *d*
		NS3D	S3D				
Discomfort	Productive	5.58	4.52	32	0.03	1.96	0.69
	Receptive	10.48	9.76	32	0.02	2.10	0.74
No-discomfort	Productive	4.39	4.67	48	0.20	0.84	0.24
	Receptive	9.20	9.20	48	1.00	0.00	0.00

As Table 8 summarizes, in the productive recall tests for the learners who reported no discomfort while looking through 3D glasses, the mean NS3D score was 4.39 and the mean S3D score was 4.67. Even though the mean S3D score was higher (by 0.28), the difference in means was not significant ($t_{(33)} = 0.84$, $p = 0.20$) and with Cohen's *d* amounting to 0.24.

Similarly, no significant difference ($t_{(33)} = 0.00$, $p = 1.00$) was detected in the receptive tests for the learners who reported no discomfort while viewing S3D images. The mean NS3D score and the mean S3D score were identical (9.20) in this case. Consequently, Cohen's *d* was 0.00.

The impact of experience with S3D technology. One of the questions in the background information survey asked *"Have you ever played a video game in [S]3D?"* Based on the answers to that question, the full sample of subjects (N = 82) was divided into two subgroups: the subjects who reported having played a video game in S3D (n_1 = 23; 28%) and the subjects who reported not having played a video game in S3D (n_2 = 59; 72%). In order to evaluate the difference in performance test scores between NS3D and S3D images, four additional paired t-tests were conducted, for the subgroup of the subjects who reported having played a video game in S3D and the subgroup without such an experience.

Table 9 summarizes the results of paired t-tests for the subgroup that reported having played a video game in S3D. For the productive test, the mean NS3D score was 5.52 and the mean S3D score was 5.13. The difference between these means amounted to 0.39. Because it was assumed that the experience playing a video game in S3D would help the subjects recall the words in the S3D format, a one-tailed p-value was taken under consideration. The difference of mean scores between NS3D and S3D words was not significant ($t_{(23)}$ = 0.58, p = 0.28). The effect size calculated using Cohen's d amounted to 0.25.

For the receptive test, the mean NS3D score was 9.61 and the mean S3D score was 9.83. The difference between those means amounted to 0.22 points, which was not a significant difference ($t_{(23)}$ = 0.49, p = 0.31) on a one-tailed test. The effect size calculated using Cohen's d was 0.21.

Table 9

Results of T-test Scores of Subjects with S3D Experience and without S3D Experience

Subgroup	Measure	Mean Scores		*df*	*p* (one-tailed)	*t*	Cohen's *d*
		NS3D	S3D				
S3D experience	Productive	5.52	5.13	22	0.28	0.58	0.25
	Receptive	9.61	9.83	22	0.31	0.49	0.21
No-S3D experience	Productive	4.61	4.41	58	0.27	0.60	0.16
	Receptive	9.76	9.27	58	0.05	1.71	0.45

As Table 9 summarizes, in the productive recall tests for the learners who reported not having played a video game in S3D, the mean NS3D score was 4.61 and the mean S3D score was 4.41. Because it was assumed that the learners without the experience of playing a video game in S3D would do worse on S3D images, a one-tailed test was used for this subgroup. Even though the mean S3D score was higher (by the difference of 0.20 points), the difference in means was not significant ($t_{(23)} = 0.60$, $p = 0.27$). The effect size calculated using Cohen's *d* was 0.16.

A significant difference ($t_{(23)} = 1.71$, $p = 0.05$) was detected in the receptive test for the learners who reported not having played a video S3D game. The mean NS3D score was 9.76 and the mean S3D score was 9.27, which made the difference amount to 0.49 points. The effect size calculated using Cohen's *d* was 0.45. These results suggest that the overall lack of benefits from using S3D technology is driven by the subgroup of learners who are inexperienced with S3D technology.

The self-perceived retention of vocabulary represented through NS3D and S3D images. The subjects were asked the following question on the follow-up questionnaire: "*Which names of objects do you think you remembered better: the ones represented in 2D or 3D?"*

(Again, the subjects were asked about *2D* and *3D* images because they were not expected to be familiar with technical terms *NS3D* and *S3D*.)

All the 82 participants responded to the question, with the minority (n_1 = 37, 45%) reporting that they thought they better remembered words represented with S3D images and the majority (n_2 = 45, 55%) saying that they thought they better remembered the words represented through NS3D images. In order to evaluate the difference in performance between NS3D and S3D images, four additional paired *t*-tests were conducted, for the subgroup of the subjects who reported that they thought they better remembered the words represented with S3D images and those who reported that they thought they better remembered the words represented with NS3D images.

Table 10 summarizes the results of paired *t*-tests for the subgroups based on which words they thought they remembered better. Because it was assumed that the learners would accurately perceive their own performance, a one-tailed test was used for these subgroups. For the subgroup that perceived better performance on S3D words, the mean NS3D score was 5.14 on the productive test, while the mean S3D score was 5.41. The difference between these means amounted to 0.27 points, which was not significant ($t_{(37)} = 0.62$, $p = 0.27$).

For the receptive test, the mean NS3D score was 10.22 and the mean S3D score was 10.24. The difference between those means amounted to only 0.02, which was also not a significant difference ($t_{(37)} = 0.08$, $p = 0.47$) on a one-tailed test. The effect size calculated using Cohen's *d* was 0.21 in the productive measure and 0.03 in the receptive measure.

Table 10

Results of T-test of Subgroups that Reported Remembering S3D Words Better than NS3D Words

Subgroups	Measure	Mean Scores		*df*	*p* *(one-tailed)*	*t*	Cohen's *d*
		NS3D	S3D				
S3D better	Productive	5.14	5.41	36	0.27	0.62	0.21
	Receptive	10.22	10.24	36	0.47	0.08	0.03
NS3D better	Productive	4.64	3.96	44	0.05	1.65	0.50
	Receptive	9.31	8.76	44	0.06	1.59	0.48

As Table 10 summarizes, in the productive recall tests for the learners who reported that they thought they remembered NS3D images better, the mean NS3D score was 4.64 and the mean S3D score was 3.96. The difference between the two means was 0.68, which is a significant difference ($t_{(45)} = 1.65$, $p = 0.05$).

In the receptive recall test (see Table 10), the mean NS3D score was 9.31 and the mean S3D score was 8.76, which made the difference amount to 0.55, which is a marginally significant difference ($t_{(45)} = 1.59$, $p = 0.06$). The effect size calculated using Cohen's *d* was 0.50 for the productive measure and 0.48 for the receptive measure.

The self-perceived usefulness of using 3D images for learning vocabulary. The subjects were asked the following Yes-No question on the follow-up questionnaire: "*Do you think it would be useful for you to learn vocabulary using [S]3D images*?"

All the 82 participants responded to the question, with the majority ($n_1 = 48$, 59%) confirming that they perceive S3D images as useful for vocabulary learning and the minority ($n_2 = 34$; 61%) admitting they perceived S3D images as not useful for vocabulary learning. In order to evaluate the difference in performance test scores between NS3D and S3D images, four additional paired *t*-tests were conducted, for the subgroup of the subjects who reported S3D images useful for learning vocabulary and those who reported S3D images as not useful for learning vocabulary.

Table 11 summarizes the results of the paired *t*-tests for the subgroup that reported S3D images as useful for learning vocabulary. Because it was assumed that the learners would accurately perceive their own performance, one-tailed tests were used for both subgroups. For the productive test, the mean NS3D score and the mean S3D score amounted to the same value 4.94, which made the difference insignificant ($t_{(48)} = 0.00$, $p = 0.50$), with zero effect size, (Cohen's $d = 0.00$).

For the receptive test, the mean NS3D score was 10.10 and the mean S3D score was 9.65. The difference between those means amounted to 0.45, which was not a significant difference ($t_{(48)} = 1.47$, $p = 0.07$) on a one-tailed test. The effect size calculated using Cohen's d was 0.43.

Table 11

Results of T-tests of Subgroups that Reported S3D as Useful and as not Useful for Learning Vocabulary

Subgroup	Measure	Mean Scores		*df*	*p* *(one-tailed)*	*t*	Cohen's *d*
		NS3D	S3D				
Useful	Productive	4.94	4.94	47	0.50	0.00	0.00
	Receptive	10.10	9.65	47	0.07	1.47	0.43
Not Useful	Productive	4.76	4.15	33	0.11	1.25	0.44
	Receptive	9.18	9.12	33	0.44	0.15	0.05

As Table 11 summarizes, in the productive recall test for the learners who reported S3D images as not useful for learning vocabulary, the mean NS3D score was 4.76 and the mean S3D score was 4.15. Even though the mean NS3D score was higher (by the difference of 0.61), the difference in means was not significant ($t_{(34)} = 1.25$, $p = 0.22$). The effect size calculated using Cohen's *d* was 0.44.

In the receptive recall test, the learners who reported S3D images as not useful for learning vocabulary, the mean NS3D score was 9.18 and the mean S3D score was 9.12, which made the difference amount to 0.06, being insignificant ($t_{(34)} = 0.15$, $p = 0.88$). The effect size calculated using Cohen's *d* amounted to 0.05.

Summary of the Results

The primary purpose of the study was to examine the effect of S3D images on productive and receptive recall of second language vocabulary. The findings from paired *t*-tests revealed no statistically significant overall difference between the effect of NS3D and S3D images. However, post hoc analyses, in which the full sample was divided into relevant subgroups, revealed several interesting additional results:

- the subgroup who reported discomfort with S3D technology performed significantly worse on words represented with S3D images;
- the subgroup who reported no discomfort performed at the same level of accuracy on words represented with NS3D images as on words represented with S3D images;
- the subgroup of subjects with prior experience of S3D technology performed at the same level of accuracy on words represented with NS3D images as on words represented with S3D images;
- the subgroup without prior experience with S3D technology performed significantly worse on words presented with S3D images on the receptive test;

- the subgroup who self-perceived their learning to be superior with S3D images performed equally well on the words represented with S3D images as with NS3D images;
- the subgroup who self-perceived their learning to be superior with NS3D images did indeed perform better on NS3D words;
- subgroups based on the self-perceived usefulness of S3D images showed no significant differences on test performance across formats of the images.

Posttest follow-up feedback from participants helped to identify the following further findings:

- the participants reported statistically significantly higher levels of engagement toward S3D images (Cohen's *d* = 0.58);
- the majority (59%) of the participants reported that they perceived 3SD images to be useful for vocabulary learning. This finding was further supported by a large number of positive comments;
- the comments helped identify several additional perceived benefits of S3D images, including enhanced focus, enhanced realism, enhanced engagement, and enhanced association;
- the participants reported that the distraction and the discomfort caused by viewing S3D images were the two main drawbacks of learning with S3D images.

The next chapter will follow with further discussion of the results and conclusions.

CHAPTER V

DISCUSSION AND CONCLUSIONS

This closing chapter of the dissertation restates the research problem, briefly reviews the research methodology and summarizes the findings of the study. The main segments of the chapter provide discussion involving the interpretation of the results, the contribution of the study and its practical implications. The chapter closes with an examination of limitations and suggestions for further research, as well as with concluding remarks.

Re-statement of the Research Problem

Proficient command of vocabulary is a crucial element of language learning (Schmitt, 2000, 2008, 2010; Zimmerman, 1997). Nevertheless, few methods put enough emphasis on effective vocabulary instruction. As a consequence, language learners often resort to disconnected learning, relying on vocabulary "cramming." Such a method, however, does not guarantee long-term retention (Nation, 2001).

In an explicit learning setting, in order for longer-term vocabulary retention to take place, more meaningful and effective learning conditions are needed. The use of visual aids, through the incorporation of images and physical objects, has been used to provide those "deeper" learning conditions (Bush, 2007; Ollila & Olson, 1972).

Physical objects (i.e. realia), which portray depth most accurately, are beneficial for learning (Rule & Barrera, 1999; Rule, Barrera, & Steward, 2004; Webb, Rule, Cavanaugh, & Munson, 2014) but are sometimes impractical in classrooms. The digital representations of realia are often more feasible substitutes. Digital visual representations of objects can vary in degrees of realism, ranging from the simplest 2D images with no portrayal of depth, through 2.5D (in this study referred to as NS3D images) with *pseudo* depth, to stereoscopic 3D (S3D) images, which provide a more convincing impression of depth. The effect of these highly realistic-looking S3D images on vocabulary learning is the focus of the current study.

Advances in technology, coupled with decreasing cost, are now making it relatively easy to implement S3D images in the classroom. If S3D images provide one of the closest digital representations of real objects, using S3D images to substitute for physical realia could potentially be beneficial for learning. On the other hand, the more advanced visual stimuli of S3D images could also impede learning by causing distraction (Pass, Renkl, & Sweller, 2003; Sweller, 1994) and/or discomfort (Bando, Iijima, & Yano, 2012; Kim, Yoo, & Seo, 2013; McIntire & Liggett, 2014; Mikšícek, 2006). The feasibility of using S3D images motivates the need for research into the effectiveness of this technology. Nevertheless, existing research on S3D technology for learning is limited to disciplines where spatial perception plays an important role (Price, Lee, & Malatesta, 2014). Such disciplines include display design (Miller & Beaton, 1991), aviation (Parrish, Williams, & Nold, 1994), and teleoperation (Drascic, 1991). In the field of foreign language learning, such research is non-existent. The intention of this current study is to fill this missing gap.

Review of the Methodology

As elaborated in Chapter 3, the current study is an experimental exploration designed to test the effect of S3D images on vocabulary recall. This research primarily used a within-subjects design where subjects viewed a series of carefully designed images in either NS3D or S3D formats that were randomly distributed.

Eighty-two (82) participants took part in the experiment by completing immediate productive and receptive vocabulary tests, and by filling out background surveys and follow-up questionnaires. The data were primarily analyzed using quantitative methods but the findings were further enriched with elements of qualitative methods. The quantitative component tested the null hypothesis that S3D images have no effect on productive and receptive recall of foreign language vocabulary. In addition, post hoc analyses tested aspects of discomfort, prior experience with S3D technology, self-perception of S3D superiority, and self-perception of S3D usefulness. All tests in the study were evaluated using paired *t*-tests.

Summary of the Results

The findings of the study revealed that there is no statistically significant difference between the effect of NS3D and S3D images in the overall study population. At the very least, one can safely conclude that S3D images are just as good as NS3D images for language learning. Post hoc analyses, where the full sample of subjects was divided into relevant subgroups, provided the following additional results:

- learners who reported discomfort or/and had no prior experience with S3D technology performed significantly better on words represented with NS3D images;
- learners who reported no discomfort or/and had some prior experience with S3D technology remembered words represented with NS3D and S3D images equally well;
- self-perceived superiority of S3D images was not reflected on the performance tests;
- learners who self-perceived superior performance with NS3D images did actually perform better on NS3D images;
- self-perceived usefulness of S3D or NS3D images was not reflected on the performance tests;

Finally, the analysis of the data gathered through the surveys and posttest follow-up questionnaires, provided evidence for the following:

- reported levels of engagement toward S3D images were significantly higher than toward NS3D images;
- the majority of the participants found S3D images to be useful for learning vocabulary;
- several recurring themes in participants' comments pertained to the benefits of learning with S3D images, such as enhanced focus, enhanced realism, enhanced engagement, and enhanced association;
- distractibility and discomfort associated with viewing S3D images were the main negative recurring themes in comments reported by the participants in the follow-up questionnaire.

Discussion of the Results

Interpretation of the Findings in Relation to Prior Research. When analyzing the outcomes of the subjects' performance and feedback from the follow-up questionnaires, this dissertation framed the findings through the lens of Merrill (2002). According to Merrill, sound instruction is built on three aspects: **e**ffectiveness, **e**ngagement, and **e**fficiency, i.e. the **E3**.

Effectiveness. The tests in this study showed no statistically significant difference in the effectiveness between S3D and NS3D images as measured by either productive or receptive tests. Previously published studies, reviewed by McIntire, Havig, & Geiselman (2014), showed that in 60% of the reviewed experiments, S3D viewing was more effective than alternative formats for learning, while 15% of the studies showed mixed results. The remaining 25% of the experiments revealed S3D and NS3D viewing to be similarly effective for learning (McIntire, Havig, & Geiselman, 2014). The current study is consistent with there being no overall difference in the effectiveness of the two viewing formats. The present study also supports the previous finding that there is no significant benefit of using S3D representations when learning tasks are not explicitly depth-related (McIntire, Havig, & Geiselman, 2014). Because NS3D images were as beneficial as S3D images, it is necessary to analyze further factors beyond learners' overall performance in order to gain a better understanding of when and how these two formats differ in their effectiveness.

Efficiency. The current study has not formally tested the efficiency of S3D images, but is motivated by the fact that technological progress is rapidly decreasing the cost of acquiring and using S3D technology and therefore increasing the efficiency of S3D technologies relative to NS3D technologies. It is commonly accepted that the more investment in equipment and time that is needed, the less efficient an instructional unit is. As mentioned in Chapter 1, producing and viewing NS3D images was routine and did not require anything beyond basic technology skills and minimal resources. However, in order to produce S3D images, it was necessary to have more advanced photographic editing skills. In addition, more complex equipment (S3D camera and viewing equipment - glasses or monitors) was needed. Therefore, we can conclude that it was more efficient to create NS3D images because they were less expensive and less difficult to create than S3D images. However, the rapidly decreasing cost of digital photographic technology is steadily eroding the efficiency benefits of NS3D technology. It is expected that the advancement of technology is going to decrease the cost and consequently improve the level of efficiency of S3D images.

The 3D technology industry has been actively promoting S3D-related content and technologies to the educational sectors. Examples of S3D content development companies include Discovery Education, Promethean World, and RM Educational Software (Stroud, 2010). Some hardware companies even forego the premium for S3D projectors and began offering them at the same price as regular (NS3D) projectors. The desire for businesses to provide innovative technologies, such as S3D projectors, for education also allows for a temporary increase in the efficiency of this technology.

Engagement. The concept of engagement emerged on several occasions in the follow-up questionnaire feedback from the participants. Increased engagement is one of the potential characteristics of S3D technology that may, in turn, drive greater effectiveness. As a consequence, further analysis was performed to examine the interaction between engagement and S3D technology on learning.

Engagement has long been identified as an important component of successful learning. Learners who are engaged attain their learning goals faster and with more depth. Moreover, they tend to stay more focused and motivated throughout their learning process (Hannafin & Hooper, 1993). The current study employed supplemental statistical analysis testing the difference between the perceived levels of engagement toward NS3D and S3D images. The mean engagement score for NS3D images amounted to 3.22 (out of 5), while for S3D images it was 3.66. The difference between those two scores showed that the perceived engagement toward S3D images was significantly greater than to NS3D images ($p = 0.01$) with the effect size amounting to 0.58.

In addition to formal statistical tests, multiple comments ($n = 18$, representing 22% of the sample) in the follow-up questionnaire fortified the idea that the S3D images are "more engaging", "more stimulating" and "more interactive." In sum, both the quantitative and the qualitative analyses suggest that learning with S3D images promotes enhanced engagement. Consequently, learning with S3D images could lead to more successful learning.

Besides the Merrill's *E3* of effectiveness, efficiency, and engagement, there are further themes that emerged in the follow-up questionnaire, which are worth elaborating on. These themes include the perceived usefulness of S3D images as well as other positive and negative comments.

Perceived usefulness and effectiveness of S3D images for learning vocabulary. The majority (58.54%) of learners reported finding S3D images to be useful for learning vocabulary. Subjects (n = 26, 32%) described S3D images as "more memorable", "fun", "more interesting" and claimed that the S3D images "activated imagination" and "put a more memorable image in [their] head." These positive attitudes contrast the outcomes of some previous studies (Vandeland & Regenbrecht, 2013) where the researchers found NS3D images to be preferred for learning. At the same time, the current findings are consistent with a report by Brown, Hamilton and Denison (2012) who found S3D images to be preferable to NS3D images. The self-perceived usefulness of S3D images was not reflected in actual test scores. There was no significant difference between performance on S3D and NS3D words in the post hoc analysis when subjects were divided into subgroups based on their perception of the usefulness of S3D images.

When prompted to elaborate on the reasons for the usefulness of S3D images for vocabulary learning, the participants provided feedback which revealed both a favorable trend and an unfavorable one with regards to reported impressions of using S3D images for learning. Within each trend there emerged several sub-themes recurring in the participants' comments. Within the favorable trend the themes were categorized as: "enhanced focus", "enhanced realism", "enhanced engagement", and "enhanced association". Within the unfavorable trend the themes were classified as "distraction" and "discomfort." There were also several mixed comments.

In addition to questions about the usefulness of S3D images, subjects were also asked directly if they thought they performed better on S3D images. In the post hoc analysis, only those subjects who perceived themselves to have done worse on S3D words actually did significantly worse on S3D words. Therefore, it appears that the lack of benefits of S3D methods are being driven by a distinct subgroup of students and this subgroup accurately recognizes that they perform worse with S3D technology. The possibility of learners self-identifying if they would benefit from S3D technology could provide a useful and relatively easy method to identify and target (or restrict) technologies such as S3D images to those students who would gain the greatest benefits from those technologies.

Enhanced Realism. The analysis of the participants' comments revealed that some participants (21%) found the S3D images to be more “life-like”, “tangible”, and “interactive.” The reported realism of the S3D images suggested that participants experienced a form of (tele)presence while viewing the S3D images.

Presence can be defined as *“…the subjective experience of being in one place or environment, even when one is physically situated in another”* (Witmer & Singer, 1998, p. 225). This term is usually used to refer to *“experiencing the computer-generated environment rather than the actual physical locale”* (Witmer & Singer, 1998, p. 225) and is often referred to as *“telepresence”*, *“sense of presence”*, or *“being there.”* Presence is considered to have a potentially positive influence on learning (Barfield & Weghorst, 1993; Draper, Kaber, & Usher, 1998; Tüzün & Özdinç, 2016), possibly by making it more meaningful.

Because S3D images are one of the most realistic-looking forms of digital images, it is not surprising that some participants would have an impression that the actual objects were in front of them and that they would think S3D images were more interactive and tangible.

Characteristics such as interactivity and tangibility, together with being “life-like” are often associated with realia. Realia have been shown to be beneficial for learning (Rule & Barrera, 1999; Rule, Barrera, & Steward, 2004; Webb, Rule, Cavanaugh, & Munson, 2014). Therefore, it is possible that their digital visual representations (i.e. S3D images) could also have the potential to be effective. It is necessary, however, to account for the differences between realia and their virtual representations: realia can be physically manipulated, while the S3D images can only give an *impression* that they can be physically manipulated.

In the context of foreign language instruction, interactivity and presence (whether real or simulated) can have a positive effect on learning (Wang, Petrina, & Feng, 2016). It is accepted knowledge that learning a language in an immersive environment (optimally, in the country where the language is spoken) is beneficial. When possible, such an immersive learning environment should be provided to the learners, whether in classroom instruction, or through autodidactic materials. Learners feeling a connection with the content of instruction are more likely to learn better and in a more meaningful way.

While there appear to be positive aspects of learning with S3D images, it is useful to also consider their negative side. In the posttest questionnaire comments, there were two main negative themes that emerged: “distractibility” and “discomfort.” Both of these notions were expected to a certain extent, considering the findings of previous studies on learning with (non-) stereoscopic 3D visual representations (Kim, Yoo, & Seo, 2013; McIntire, Havig, & Geiselman, 2012; McIntire & Liggett, 2014; Mikšícek, 2006; Smith, 2009; Vandeland & Regenbrecht, 2013).

Distraction. Published research shows that there can exist negative issues with learning units that contain rich sensory stimuli (Pass, Renkl, & Sweller, 2003; Sweller, 1994). Because

S3D images have an extra dimension compared with NS3D images, that additional stimuli may distract learners from the actual learning content. Additional stimuli provoke extraneous cognitive load and, thus, may impede learning (Pass, Renkl, & Sweller, 2003; Sweller, 1994).

The feedback from the participants confirmed the initial expectations about S3D technology being associated with distraction. Comments, such as *"I personally found the 3D more distracting than helpful"* prompt one to conclude that, at least for certain learners, the additional dimensionality triggered cognitive overload. Further, responses suggesting that certain learners were *"too focused on the* [3D] *image, not the word"* suggest that subjects had insufficient time to memorize the word because their focus was concentrated on the image. It is possible that some subjects may have spent too much time focusing on the images -- instead of focusing on memorizing the vocabulary -- due to the novelty effect of the medium.

While S3D images seemed distracting for some learners, the analysis of the participants' comments also revealed that there were other learners whose opinion on S3D images was exactly the opposite. Some participants reported that the S3D images helped them focus on the object without being distracted by the background. A similar view was shared by another participant saying: *"The image felt more real, so it was harder to get distracted."* More analyses and research are needed to draw clear conclusions on when and why certain subjects would find S3D images distracting, while others would find that they help to avoid distraction.

Discomfort. Comfort is an important component of learning (Bando, Iijima, & Yano, 2012; Kim, Yoo, & Seo, 2013; McIntire & Liggett, 2014; Mikšícek, 2006). Therefore, where possible, any concern about discomfort during learning should be addressed. In the current study, 40% of participants reported discomfort when using S3D technology. Some participants reportedly felt "dizzy", "sick", and "tired." Subjects reported headaches and discomfort in their eyes, such as irritation or lack of vision in one or both of their eyes. Prior investigations into learning with S3D images included reports of similar issues (Kim, Yoo, & Seo, 2013; McIntire, Havig, & Geiselman, 2012; McIntire & Liggett, 2014; Mikšícek, 2006; Smith, 2009; Vandeland & Regenbrecht, 2013).

A possible reason for the discomfort in the current study could be the choice of stereoscopic technology used in the experiment, which was the anaglyph technology. This particular technology was chosen with efficiency in mind, being the most affordable and the easiest for teachers to use in actual classroom settings (for a brief review of the various stereoscopic technologies, refer to Table 1, p. 26). At the same time, the visual quality of anaglyph technology is lower than some alternative stereoscopic technologies.

In order to probe how discomfort interacts with the effectiveness of S3D technology, additional analysis involved partitioning the sample into two subgroups: those who reported discomfort and those who did not. Then a comparison of mean scores for words represented with NS3D and S3D images for each subgroup was used to test how discomfort was associated with the effectiveness of S3D technology.

The supplementary results showed that the subjects who reported discomfort performed statistically significantly worse on words represented by S3D images than by NS3D images. The impact of discomfort on acquisition of words represented with NS3D and S3D images was visible on both the productive (i.e., difficult) test and on the receptive (i.e., easy) test. Complaints and reviews of viewing discomfort have been reported in works by Bando, Iijima, & Yano (2012); Kim, Yoo, & Seo (2013); Mikšícek (2006).

Prior experience with S3D technology. It is possible that students experienced discomfort with S3D technology because it was new for them. This possibility was considered in the post hoc analysis, with the sample being divided into subgroups based on whether or not they reported prior experience with S3D video games. These tests showed that the poor performance of S3D images was driven only by the subgroup with no prior experience of S3D technology. The results for subgroups based on prior experience complement the other tests in the post hoc analyses and together suggest that any drawbacks of S3D technology apply only for distinct subgroups of students who can be clearly identified *ex ante* through questions about their prior experience, or *ex post* with questions about their self-perceived performance or discomfort. However, questions about the self-perceived usefulness of S3D images were insufficient to identify which subjects would benefit from S3D technology.

Contribution and Practical Implications

An extensive body of existing research documents the benefits of learning with visual representations (Anglin, Towers, & Levie, 1996; Mayer, 1997; Mayer, 2009; Mayer & Anderson,1991; Mayer & Moreno, 2003; Moreno & Durán, 2004; Paivio, 1969; Winn, 1989). There also exist multiple studies testing the impact of various degrees of realism of visual representations on learning (Dwyer, 1967, 1968a, 1968b, 1969; Dwyer & Berry, 1982; Dwyer & Joseph, 1984; Schwartz, 1995; Scheiter et al., 2009). Published studies have included focused analyses of simple-line drawings (Dwyer, 1970), photographs (Mayer & Sims, 1994), and animated images (Lowe, 1999; Mayer & Anderson, 1991). The current study extends this line of work by testing the effect of S3D images on learning. In addition, this study provides several new insights relevant to understanding what we know about learning with digital realia, which eventually can be extended to learning with even more complex virtual reality (e.g. *Oculus Rift*).

The pre-existing empirical investigations on the effect of NS3D and S3D images in education are limited to studies encompassing spatial learning (McIntire, Havig, & Geiselman,

2014) and do not focus on vocabulary learning. The current study is the first about S3D technology to take an explicit focus on foreign-language vocabulary learning and the first to incorporate content that does not have an inherent spatial component. These characteristics of the research design allow for findings that can better be generalized across educational settings and are not restricted to the previously-studied spatial topics, such as geometry, navigation, or architecture.

An additional area of long-standing concern for instructional designers is the extent to which discomfort (Bando, Iijima, & Yano, 2012; Kim, Yoo, & Seo, 2013; McIntire & Liggett, 2014; Mikšícek, 2006) or cognitive overload (Pass, Renkl, & Sweller, 2003; Sweller, 1994; Sweller, van Merrienboer, & Paas, 1998) can mitigate the otherwise beneficial aspects of a new technology. This study includes post hoc analyses of how discomfort and / or lack of experience with S3D technology interact with the use of S3D images. These analyses revealed that when discomfort or lack of experience is present, the effectiveness of learning with richer-stimuli content (S3D images) is diminished. This is the first time that the analyses of discomfort and lack of experience with S3D technology have been included in an instructional unit which tests the impact of S3D images on vocabulary learning.

Historically, academics in the field of instructional design and technology have presented their work through the perspective of Merrill (2002) by evaluating the extent to which instruction is effective, efficient, and engaging. Therefore, the current study places its findings within the framework of Merrill's *E3*. One of the findings of this study was that S3D images can be as effective for learning as NS3D images. Therefore, instructional designers should be advised to implement those visual representations which are more efficient (i.e. faster and cheaper to develop) or/and more engaging. As of 2016, it is generally assumed that NS3D images are more efficient. However, with S3D technology becoming more affordable, the differences in efficiency are diminishing. Together, these interpretations represent an application of Merrill's perspectives to a new application of instructional design.

The findings of this study lead to several practical implications for instructional designers, instructional technologists, and foreign language instructors. This study allows for better understanding on how to facilitate explicit vocabulary learning by taking effectiveness, efficiency, and engagement into account. While there is no evidence that the unconditional use of S3D images is always superior for vocabulary learning, this study does provide some insights into the circumstances when S3D images could be more effective than NS3D images, as well as the concerns that should be addressed in order to design effective lessons by incorporating S3D images. Table 12 provides a summary of measures, methods and results of the current study.

Table 12

Summary of Measures, Methods, and Results

Measures	Subgroups	Methods	Results
1) effectiveness	full sample	quantitative	NS3D = S3D
2a) effectiveness	discomfort reported	quantitative	NS3D > S3D
2b) effectiveness	no discomfort reported	quantitative	NS3D = S3D
3a) effectiveness	experience with S3D	quantitative	NS3D = S3D
3b) effectiveness	no experience with S3D	quantitative	NS3D ≥ S3D
4a) effectiveness	self-perception of superior S3D	quantitative	NS3D = S3D
4b) effectiveness	self-perception of superior NS3D	quantitative	NS3D ≥ S3D
5a) effectiveness	self-perception of S3D usefulness	quantitative	NS3D = S3D
5b) effectiveness	no self-perception of S3D usefulness	quantitative	NS3D = S3D
6) engagement	full sample	quantitative and qualitative	NS3D < S3D
7) perceived usefulness	full sample	quantitative and qualitative	NS3D < S3D
8) efficiency	full sample	subjective observation	NS3D ≥ S3D

Based on the summary of the current study given in Table 8, the following advice could be given to educators:

1) Because S3D images were shown to be as effective as NS3D images for learning vocabulary, either format may be used effectively. The choice of the technology should depend on further factors, such as efficiency, the content of learning, and/or affective factors.

2a) S3D images may be less effective compared to NS3D images when learners experience discomfort. It is advisable to consider the comfort / discomfort levels carefully before exposing learners to S3D images. A screening test may be needed before exposing learners to S3D images.

2b) When no discomfort is present, either NS3D and S3D images may be equally effective. It may be more advisable to use NS3D images to represent objects which by nature are rather flat (e.g. paintings, newspapers). However, S3D images may be more useful to represent objects which have more pronounced dimensions (e.g. a box, a ball).

3a) Learners with prior experience with S3D technology benefit equally from S3D and NS3D images. If such an opportunity exists, those learners could be given options of which images they want to use for their learning.

3b) Lack of experience with S3D technology can have a detrimental effect on learning through S3D images. Therefore, it is advisable not to use S3D images by learners with no prior experience with S3D technology. Alternatively, training sessions of viewing S3D images may be necessary to acquaint learners with this technology prior to having them learn with it.

4a) Learners who self-perceive superior performance with S3D images actually perform equally well with S3D and NS3D formats. Therefore, instructors should consider factors other than self-perceived performance when evaluating these learners.

4b) Learners who self-perceive NS3D images to be superior for learning, do, in fact, learn as well, or better, with them. It may be advisable to use NS3D images with these types of learners.

5a and 5b) The self-perception of the usefulness of S3D images is not reflected in performance scores. Learners show no prior ability to recognize whether S3D images will be useful for learning. Therefore, instructors should consider factors other than self-perceived usefulness when assigning S3D images.

6) S3D images may be superior to NS3D images when increased engagement is the priority. For younger learners, who may need more engaging instruction, the implementation of S3D images may be more beneficial. The same may apply for learners with a shorter attention span (e.g. learners with ADHD), who may have difficulty paying attention during standard classroom-led instruction. S3D images may also function well as attention-getters.

7) S3D images may be superior to NS3D images when the perceived usefulness of an instructional unit is the priority. Although learners do not forecast their performance accurately when using S3D images, it may still be the case that S3D images increase self-motivational factors of learning. This may be useful with self-didactic tools (e.g. digital flashcards) where motivation may not be constant and so more immersive tools may be needed.

8) In the past, NS3D technology was more efficient due to its lower cost and simplicity of use. Therefore, when funds were an issue, NS3D images may have had clear advantages. In contemporary settings, many educational facilities now have funding or facilities that allow for the use of S3D images. Therefore, past concerns about the efficiency of using S3D technology may not be as serious of an issue as in the past.

Limitations

As is the case with any research project, the current study has several limitations that should be considered. The first major limitation is that the study examined only the simple recognition of objects. The tests chosen for assessment may not reflect deeper levels of vocabulary acquisition. Nation (2001) points out that in the broadest sense, knowing a word involves form (e.g. what a word looks like), meaning (e.g. what a word makes us think of), and use (e.g. how a word is employed correctly in a phrase). He further distinguishes between the receptive (i.e. what we can understand) and the productive (i.e. what we can say or write) knowledge of words, with receptive being easier.

The instruments in this study tested only how well the participants recall vocabulary as measured by translation tests. The participants were not tested on whether they know how to pronounce the words, how to spell them in L2, how to use them in the correct context, or how to incorporate them in a sentence. Because the increased sensory input of S3D images may stimulate deeper learning, it may be the case that more complex memory tests are required to detect the different types of learning that occur with S3D images.

One more issue to keep in mind is that images (regardless of their level of realism or format) are usually not helpful in depicting abstract concepts, words, or phrases. Therefore, images have this limitation of being mostly limited to portraying concrete ideas.

Novelty. As with many studies investigating technology, this examination also has a common limitation: the novelty effect. As new educational technologies are introduced in instruction, the novelty effect may cause several outcomes that are unlikely to persist over time. Learners excited about the first "impression" of the new tool are likely to express their excitement as "cool" and "fun." While this study made an attempt to diminish the novelty effect by introducing the S3D images in the "warm up", prior to the experiment, it is likely that this short exposure was not sufficient to fully eliminate the novelty effect. Therefore, it is important to bear this limitation in mind while interpreting the findings of the study. For example, novelty may have been one of the causes of distraction during the viewing of S3D images, which may have diminished the effectiveness of S3D images on learning – i.e., the learners may not have spent equal time, compared to NS3D, on memorizing/learning the vocabulary represented with S3D images.

Suggestions for Future Research

It is difficult to determine the exact aspects driving the effectiveness of S3D images on learning vocabulary on the basis of this study alone. Taking under consideration the limitations of the present study, as well as drawing experience from the feedback in follow-up questionnaires provided by the participants, there are several extensions that could be conducted. Some suggestions include:

- *extending the population to other samples*. In the current study, the subjects had to be university students who were native speakers of English without knowledge of a language that was a cognate to Polish. It would be useful to replicate the study with another population. For example, with native speakers of other languages than English; with learners of other ages than university students (i.e. studying the effect of S3D images on various generations of learners).
- *correcting for the novelty effect*. It would be useful to test how differing levels of familiarity with S3D technology drive differences in the effectiveness of using S3D images for learning. Such tests would allow an examination of how much the novelty

effect is important in determining how students perform when using a new technology, such as S3D images.

- *exploring alternative linguistic matters*. This study focused on testing concrete nouns. It would be useful to also study other language components, such as abstract nouns, adjectives, adverbs, verbs, and idiomatic expressions. It would be especially useful to provide more detailed evidence as to if S3D technology is useful for learning in general or only for tasks with an explicit spatial component.
- *improving assessment with delayed testing*. For practical reasons and the risk of mortality, the current study did not include delayed testing. However, "delayed posttests should be included in all acquisition research designs" (Nation, 2001, p. 157). Linguists point out limitations to results of studies where only immediate post-testing is applied. These limitations comprise the reasoning that sole immediate post-testing does not take under consideration durable, long-term learning and it "cannot inform about the dynamic and incremental nature of the learning process" (Nation, 2001, p. 155).
- *improving the quality of the S3D images*. A total of 40% of the participants reported feeling discomfort while viewing the S3D images. It is likely that the discomfort could be mitigated by improving the quality of the S3D images. This could be done by incorporating more advanced methods of displaying S3D images, such as polarization or interference filter technology.
- *extension with detailed interviews of learners who excelled at vocabulary recall*. Some participants' performance on tests was exceptional and impressive. It would be useful to interview those learners, asking them to elaborate on their learning strategies. The

questions could focus on notions such as what they paid attention to (the images or the words) and how much the images versus the text helped them remember the items.

- *incorporating discomfort tolerance training.* It is possible that discomfort will dissipate after repeated use of S3D technology and therefore this problem will be alleviated once students become more experienced with the technology. It is also possible that some learners reporting discomfort could be trained to cope with it. The brain could adjust and filter out the disturbance causing the discomfort to the extent where the learners could eventually benefit from S3D visuals without feeling side-effects. Because it is usually younger people who have higher levels of adaptability than older people, if the training were to occur, it would be advisable to start it with the younger population of learners. A related challenge regards the risk that few volunteers could be willing to go through discomfort tolerance training, which makes it difficult to implement such training in public educational settings. Lastly, if the discomfort tolerance training were to take place, it would be also very interesting to test whether discomfort is temporary or permanent. However, due to ethical reasons, there may be difficulties in getting approval for such a study.

Conclusions

The mastery of vocabulary is essential for foreign language learners. One of the reasons for the lack of success in finding “the perfect method” of teaching vocabulary is that vocabulary teaching has traditionally been disconnected from the content being learned (e.g. memorizing word lists). More meaningful and “deeper” methods of learning are necessary in order to achieve successful explicit vocabulary learning and retention.

Some of the attempts to provide more meaningful ways to teach vocabulary have included teaching with realia. Historically, the implementation of realia has been effective, but for practical reasons realia have been (partially) replaced with images of various formats. The formats range from minimally-realistic (2D), through moderately-realistic (NS3D, “pseudo 3D”), to the most realistic (S3D).

In this study S3D and NS3D images were shown to be equally effective for learning vocabulary, and therefore either format can be recommended for use. Under certain conditions, however, the implementation of S3D images may be superior. These conditions are when: 1) there is no viewing discomfort; 2) increased engagement is the priority; 3) the perceived usefulness is the priority. Under other circumstances, using S3D images may be detrimental for learning. These circumstances are when: 1) learners face discomfort; 2) learners lack prior experience with S3D technology; 3) learners perceive S3D images to be inferior to NS3D images. Taking under consideration the fact that S3D technology is constantly advancing and is becoming increasingly affordable, the potential of S3D technology in education is promising. However, currently, S3D technology should still be used with caution. Meanwhile, further studies are necessary to shape a more comprehensive understanding of the effectiveness, the efficiency and the engagement of S3D on learning vocabulary.

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APPENDICES

Appendix A

Productive Recall Test

This test will measure how well you recall the Polish names of objects you saw during the activity. Read the Polish word in Column #1. Write its English translation in Column #2. You will have five minutes to complete the 30 items.

Column #1	Column #2
Polish word	Translation in English
ananas	
but	
czajnik	
doniczka	
drzewo	
garner	
kalosz	
kamień	
kapelusz	
kask	
koło	
krzak	
krzesło	
książka	
ławka	
łopata	
miś	
miska	
patyk	
piłka	
pudło	
roślina	
szczotka	
taczki	
torba	
walizka	
wiadro	
wiatrak	
wózek	
znak	

Appendix B

Receptive Recall Test

This test will measure how well you recall the names of objects you saw during the slideshow. Circle the letter of the English translation that corresponds to the Polish word. You will have five minutes to complete the 30 items.

1.
znak means
a) road sign
b) hat
c) suitcase
d) plant

2.
wózek means
a) kettle
b) stroller
c) helmet
d) shovel

3.
wiatrak means
a) box
b) stick
c) fan
d) wheelbarrow

4.
wiadro means
a) bowl
b) helmet
c) stroller
d) bucket

5.
walizka means
a) suitcase
b) flower pot
c) tree
d) bench

6.
torba means
a) book
b) bag
c) stick
d) teddy bear

7.
taczki means
a) wheelbarrow
b) chair
c) shoe
d) book

8.
szczotka means
a) pineapple
b) brush
c) wheel
d) tree

9.
roślina means
a) garnek
b) road sign
c) plant
d) helmet

10.
pudło means
a) bench
b) wheel
c) flower pot
d) box

11.
piłka means
a) rain boot
b) bowl
c) ball
d) shovel

12.
patyk means
a) pot
b) rock
c) bush
d) stick

13.
miska means
a) bowl
b) pineapple
c) shoe
d) book

14.
miś means
a) teddy bear
b) bag
c) stroller
d) fan

15.
łopata means
a) kettle
b) chair
c) rain boot
d) shovel

16.
ławka means
a) road sign
b) pot
c) hat
d) bench

17.
książka means
a) ball
b) book
c) teddy bear
d) plant

18.
krzesło means
a) shovel
b) bush
c) tree
d) chair

19.
krzak means
a) bush
b) pineapple
c) wheelbarrow
d) hat

20.
koło means
a) suitcase
b) book
c) wheel
d) shoe

21.
kask means
a) brush
b) tree
c) bowl
d) helmet

22.
garnek means
a) pineapple
b) rock
c) pot
d) book

23.
drzewo means
a) tree
b) ball
c) bush
d) kettle

24.
doniczka means
a) flower pot
b) teddy bear
c) chair
d) shoe

25.
kapelusz means
a) chair
b) hat
c) wheelbarrow
d) helmet

26.
kamień means
a) rock
b) bench
c) shoe
d) bag

27.
kalosz means
a) rain boot
b) book
c) tree
d) wheel

28.
czajnik means
a) box
b) stroller
c) suitcase
d) kettle

29.
but means
a) bucket
b) shoe
c) bench
d) brush

30.
ananas means
a) stick
b) bag
c) pineapple
d) bowl

Appendix C

Background Information Survey

1. What is your gender? *(mark the appropriate answer)*

____ Female ____ Male

2. What is your age? _________

3. What is your school rank? *(mark the appropriate answer)*

___ Freshman ___ Sophomore ___ Junior ___ Senior ___ Graduate

4. What is your native language? _______________

5. What foreign languages do you know or have studied (if any)?

Language 1: _______________ Number of years: ________

Level of fluency: _____ Fluent _____ Advanced _____ Communicative _____Beginner

Language 2: _______________ Number of years: ________

Level of fluency: _____ Fluent _____ Advanced _____ Communicative _____Beginner

Language 3: _______________ Number of years: ________

Level of fluency: _____ Fluent _____ Advanced _____ Communicative _____Beginner

6. Are you familiar with any Polish words? _____ *no* ______*yes*

If you are familiar with some Polish words, please list them below.

______________________, ______________________, ______________________,

______________________, ______________________, ______________________,

7. On average, how many hours a day do you spend using electronics? ________

8. Have you ever watched a movie in 3D? _____ *no* ______*yes*

9. Have you ever played a video game in 3D? _____ *no* ______*yes*

10. Please write down your email address ____________________________________
(Your email will be confidential and will be used ONLY by the researcher for the following reasons:

1) so that you could be notified about the date, the time, and the location of the data collection;
2) so that you could be notified if you are the lucky winner of a gift card;
3) so that you could be informed if you qualify to participate in the study;
4) so that you could be informed if you do not qualify to participate in the study ---

In order to qualify to participate in the study, you:
- need to be 18 years old or older;
- need to be a native a speaker of English;
- cannot know any language that is a cognate to Polish (Czech, Russian, Ukrainian, Slovak, Bulgarian, Slovene, Macedonian, Belarusian, Lithuanian, Latvian, or Serbo-Croatian).

Appendix D

Follow-up Questions

1. *On a scale from 1 to 5 (1 being low, 5 being high), how engaging did you find the 2D images?*

   Low (1)——(2)——(3)——(4)——(5) High

2. *On a scale from 1 to 5 (1 being low, 5 being high), how engaging did you find the 3D images?*

   Low (1)——(2)——(3)——(4)——(5) High

3. *Do you own a system which allows for 3D viewing (for example, 3D TV, Nintendo 3Ds, or others)?*

   ☐ *No* ☐ *Yes* Which one? (Brand/Name) ______________________________

   How often do you use it? ______________________________

4. *Which names of objects do you think you remembered better: the ones represented in 2D or 3D?*

   ☐ *2D objects* ☐ *3D objects*

5. *Do you think it would be useful for you to learn vocabulary using 3D images?*

   ☐ *No* ☐ *Yes*

   *Why/Why not?*____

   ____

6. *Did you experience any discomfort while looking through the 3D glasses?*

   ☐ *No* ☐ *Yes*

7. *Did you already know any of the Polish words prior to this task?*

   ☐ *No* ☐ *Yes*

8. *Additional comments.* ____

   ____

   ____

Appendix E

List of Polish Words with their English Translations

Column #1	Column #2
Polish word	Translation in English
ananas	*pineapple*
but	*shoe*
czajnik	*kettle*
doniczka	*flower pot*
drzewo	*tree*
garnek	*pot*
kalosz	*rain shoe*
kamień	*rock*
kapelusz	*hat*
kask	*helmet*
koło	*wheel*
krzak	*bush*
krzesło	*chair*
książka	*book*
ławka	*bench*
łopata	*shovel*
miś	*teddy bear*
miska	*bowl*
patyk	*stick*
piłka	*ball*
pudło	*box*
roślina	*plant*
szczotka	*brush*
taczki	*wheelbarrow*
torba	*bag*
walizka	*suitcase*
wiadro	*bucket*
wiatrak	*fan*
wózek	*stroller*
znak	*road sign*

Appendix F

Summary of the Participation Timing

PARTICIPATION SESSION #1 (in-class with the instructor and the researcher in classroom):

- Recruitment, consent form completion, background information survey, experiment scheduling: **5'**,

Overall participation session #1 time: **5** minutes.

PARTICIPATION SESSION #2 (with the researcher in the conference room):

- Assignment of participants to their computers and instructions: ~**2'**,
- "Warm-up": **1'**,
- Experiment: (15" × 15 words represented by S3D images = 225"): ~**4'**, and (15" × 15 words represented by NS3D images = 225"): ~**4'**,
- Productive recall test: (10" x 15 words represented by S3D images = 150"): ~**2.5'**, and (10" x 15 words represented by NS3D images = 150"): ~**2.5'**,
- Receptive recall test: (10" x 15 words represented by S3D images = 150"): ~**2.5'**, and (10" x 15 words represented by NS3D images = 150"): ~**2.5'**,
- Follow-up questionnaire: ~**5'**.

Overall participation session #2 time: up to **30** minutes.

Appendix G

Copyright Image Permission

04-27-2016

Dr. Thom Thibeault
800 Lakeshore Drive, Birmingham, AL 35229

Dear Dr. Thibeault:

I am a doctoral candidate at Southern Illinois University, Carbondale. I am in the process of preparing my dissertation as a partial requirement for obtaining a Doctoral Degree. I am seeking permission to include in my dissertation an image taken from your website http://redhotwords.com. Here is the image:

This image will be used to exemplify the concept of glossing.

Please indicate your approval of this request by signing the letter and returning it to me. Your signing of this letter will also confirm that you own the copyright to the above-described material.

Very truly yours,

Regina Kaplan-Rakowski

Thomas F. Thibeault

For copyright owner use:

PERMISSION GRANTED FOR THE USE REQUESTED ABOVE:

By: Thomas F. Thibeault

Date: 28 April 2016

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Kaplan-Rakowski, R., & Rakowski, D. (2011). Educational technologies for the neomillenial generation. In E. Dunkels, G-M Franberg, C. Hallgren (Eds.), Interactive media use and youth: Learning, knowledge exchange and behavior. Hershey, PA: Information Science Reference.

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